Traumatized Broca's Area

A Linguistic Analysis of Speech in Posttraumatic Stress Disorder

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Abstract

This research explores the possible effects of Posttraumatic Stress Disorder (PTSD) on the speech capacity of individuals diagnosed with PTSD. Past research (Peres et al., 2005) concluded that there are difficulties in synthesizing, categorizing and integrating the trauma memory into a narrative. Furthermore it has been shown that participants diagnosed with PTSD exhibit decreased rCBF (regional Cerebral Blood Flow) to the Broca's area when they are either verbally (Rauch et al., 1996; Shin et al., 1997) or visually (Shin & McNally et al., 1997) exposed to their trauma. Since Broca's aphasics also exhibit rCBF to the Broca's area, the effect of reduced blood flow in these two very different patient groups was compared in order to find out if the speech of individuals with PTSD shows characteristics and similarities to the speech of Broca's aphasics. Two speech samples, a neutral speech sample and a 'traumatic' speech sample, were collected from five PTSD participants and five Trauma Exposed Control (TEC) participants. Additionally five speech samples of Broca's Aphasics were obtained from the AphasiaBank (MacWhinney et al., 2011). These samples were investigated linguistically by calculating a percentage of omissions of functional categories and omissions of inflections, as well as the calculation of the Zipfian Distribution. Although the results show no significant differences in the slope of the Zipfian Distribution for PTSD participant's 'neutral' and 'traumatic' speech, there is a trend that can be observed in the expected direction. This opens up questions about the successful elicitation of traumatic memories; effects of the importance of sample size and token count in a Zipfian analysis; and our assumptions about the nature of the blood flow to the Broca's area as well as the location of the functions within that area.

Key Words: Broca's Aphasia, Posttraumatic Stress Disorder, Psychological Trauma, Zipf's Law

"It is a strange thing that all the memories have those two qualities. They are full of quietness, that is the most striking thing about them; and even when things weren't like that in reality; they still seemed to have that quality. They were soundless apparitions, which speak to me in looks and gestures, wordless and silent – and their silence is precisely what disturbs me."

- Erich Maria Remarque (1996 reprint)

1.0 Introduction

Although the effects of trauma and Posttraumatic Stress Disorder (PTSD) have already been extensively documented in the psychology and psychiatry literature, there is still room for exploration in this field of study. Past research (Peres et al., 2005) has reported that there are difficulties in synthesizing, categorizing and integrating the trauma memory into a narrative. The so-far available literature presents functional and structural findings of neuroimaging that give indication that these difficulties could be related to the decreased volume of the hippocampus, the relative decreased activation of the left hemisphere and a decrease in the activity of the prefrontal cortex of the anterior cingulum as well as the Broca's area (Hull, 2002; Bremner, 2002; Rauch et al., 1996; Shin et al., 1997). Some of these neuroimaging studies have shown that participants diagnosed with PTSD exhibit decreased regional Cerebral Blood Flow (rCBF) to the Broca's area when they are either verbally (Rauch et al., 1996; Shin et al., 1997) or visually (Shin & McNally et al., 1997) exposed to their trauma. This means that the Broca's area, one of the crucial linguistic areas in the brain, is being 'blocked' when a PTSD patient is reminded of their trauma. Combining this line of research with the research done on people that have suffered damage to the Broca's area, so-called Broca's aphasics, linguistic and psychiatric research meet in the here presented study. More precisely hypothesizing that a decrease in rCBF to the Broca's area could have significant consequences for the speech production of the individual, the here presented research aims at investigating the effects of PTSD on speech capacity. Therefore a linguistic analysis was conducted on 'neutral' and 'traumatic' speech samples of PTSD patients and Trauma-Exposed Control (TEC) patients, as well as on the speech of Broca's aphasics. The analysis consisted of a calculation of error percentages in the speech of these patient groups and the calculation of Zipf's law to see the word frequency distribution.

In section 2 the theoretical framework of this research will be presented by looking at the different fields of study that this research combines. These fields are Posttraumatic Stress Disorder (PTSD), neuroimaging of PTSD as well as the Broca's area and Broca's aphasics. This leads to the presentation of the research questions and the significance of this research in section 3. In section 4 the methodology will be presented by first giving a comprehensive review of Zipf's law, its application to linguistics and previous research. Further participant groups, procedures and the research design will also be described. Then a detailed explanation of the testing of both hypotheses is given in section 5. This is followed by a presentation of the results and discussion of the findings and a conclusion.

2.0 Theoretical Framework

2.1 *Posttraumatic Stress Disorder*

A situation in which 'the person has experienced, witnessed, or been confronted with an event that involved actual or threatened death or serious injury […] to oneself or others" and "the person's response involved intense fear, helplessness, or horror' (American Psychiatric Association, 2000) is defined by the DSM-IV as a situation that can cause posttraumatic stress disorder (henceforth PTSD). Though not everyone that lives through something traumatic consequently develops PTSD. In order to be clinically diagnosed with PTSD, patients have to exhibit symptoms from three distinct clusters, namely re-experiencing symptoms, avoidance/numbing symptoms and hyperarousal symptoms. These symptoms have to be present at least one month after the trauma has been experienced. The category of re-experiencing symptoms includes intrusive thoughts and images of the event, nightmares, increased mental and/or physiological distress on being reminded of the event. The category of avoidance symptoms includes avoidance of situations, thoughts, or images associated with the trauma, as well as psychogenic amnesia for the event. The hyperarousal symptoms include sleep disturbance, poor concentration, attentional hpervigilance to signals of dangers, increased irritability and exaggerated startle response. In addition to these diagnostic symptoms of PTSD, psychophysiological research in the field of PTSD has been able to identify further physical reactions of patients diagnosed with PTSD. These psychophysiological symptoms generally cover heightened startle responses and peripheral physiological hyperactivity as well as increases in blood pressure, heart rate, skin conductivity, and muscle tension (Pitman et al. 1987; Blanchard et al., 1991). While earlier research of PTSD often focused on the phsychophysiological aspects of the disorder, a different aspect of PTSD is of greater importance to the research presented here: the neuroimaging of posttraumatic stress disorder. Since the 1990s neuroimaging of PTSD has not only grown as a field but has also been able to identify different mechanisms and changes in the brain that seem to be linked to the disorder. The following section will highlight the most important findings of this neuroimaging research that are related and relevant to the language faculty.

2.2 *Neuroimaging of PTSD*

General common knowledge, as well as the trauma literature, often point out that traumatic experiences are difficult to talk about and integrate into a narrative. Individuals who have suffered psychological or emotional trauma are often hesitant to talk about the experience or simply cannot because it is too difficult. Past research (Peres et al., 2005) has come to describe this as difficulties in synthesizing, categorizing and integrating the trauma memory into a narrative. Although the above-mentioned difficulties have extensively been documented within the narrative and psychiatric literature, possible neurological causes have often not been taken into consideration. Neuroimaging studies conducted in the 1990's however shed some light on what might be the underlying causes for these difficulties. With the purpose of 'elucidating the mediating functional neuro-anatomy of posttraumatic stress disorder (PTSD) symptoms' (Shin et al., 1997: 521) Rauch et al. (1996) as well as Shin et al. (1997) conducted Positron Emission Tomographic (PET) studies. In the study conducted by Rauch et al. (1996) regional cerebral blood flow (rCBF) was measured in individuals with PTSD by using script-driven imagery and PET-scans. The subjects diagnosed with PTSD were asked to imagine traumatic and neutral events in two separate scans. The results showed significantly differing rCBF-levels for the traumatic condition and the neutral condition. The scans further revealed that the rCBF-levels in the traumatic condition were increased in several right-sided limbic, paralimbic and visual areas. These areas included amygdala, orbitofrontal cortex, insular cortex, anterior temporal pole, anterior cingulated cortex and the secondary visual cortex. In addition to these rCBF-increased areas, the Broca's area was found to show a significant decrease in rCBF.

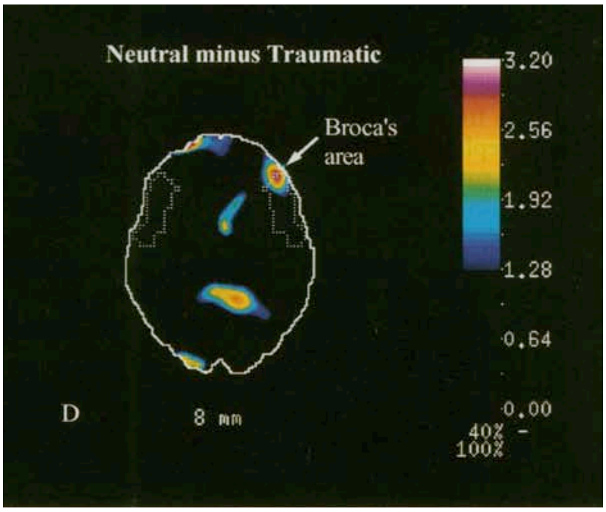

Figure 1 - Positron emission tomography statistical parametric map of Neutral minus Traumatic condition. Activation is located within left Broca's area (representing a decrease in relative blood flow associated with the Traumatic condition. (Rauch et al., 1996)

Shin and colleagues (1997) replicated the study of Rauch et al. (1996) using individuals that had been exposed to trauma but had not been diagnosed with PTSD as a control group to individuals that had been diagnosed with PTSD. The results of the PTSD group showed increased rCBF in the orbitofrontal cortex and the anterior temporal poles. Further, in accordance with the results by Rauch et al. (1996), decreased rCBF was found in the Broca's area, middle frontal gyri, inferior and middle temporal gyri, inferior parietal lobule and fusiform gyrus. The trauma-exposed individuals without a diagnosis of PTSD on the other hand showed increased rCBF in the orbitofrontal cortex, anterior cingulte cortex, anterior temporal poles, insular cortex, superior temporal gyrus, as well as inferior, medial and superior frontal gyri. Decreased rCBF were found in primary and secondary visual cortex, visual association cortex and inferior parietal lobule, but not in the Broca's area. These two studies conducted by Rauch et al. (1996) and Shin et al. (1997) provide evidence that imagery of traumatic events in individuals diagnosed with PTSD indeed trigger an emotional response that is being mediate by the paralimbic regions. It should be realized however that there are few regions that show increased rCBF in the individuals with PTSD as well as in the trauma-exposed individuals without PTSD. It seems then that these paralimbic regions with increased rCBF in both groups exhibit a normal reaction to traumatic materials rather than being part of a diagnosis of PTSD. Further it is interesting to see that while individuals diagnosed with PTSD exhibit a decrease in blood flow to the Broca's area when imagining their trauma, a decrease in blood flow to the Broca's area cannot be observed when trauma-exposed individuals without PTSD do the same. Thus it can be concluded that decreased rCBF to the Broca's area seems to be part of the PTSD diagnosis.

A second study by Shin and Kosslyn et al. (1997) replicated the above-described study by Shin et al. (1997) by using Vietnam combat veterans with and without posttraumatic stress disorder while being exposed to combat-related visual stimuli. Again positron emission tomography was used to measure rCBF in the combat veterans while being presented to neutral, negative and combat-related pictures. The results of the scans of the combat veterans with PTSD show that there is increased rCBF in the central anterior cingulated gyrus and the right amygdala as well as in other paralimbic areas. Similar to the previous neuroimaging studies presented above, again a decrease of rCBF in the Broca's area (especially Brodmann area 45) was found in the individuals with PTSD. Thus the authors themselves suggest that 'given the role of Broca's area in language function, decreased rCBF in this region may be consistent with diminished linguistic processing while subjects with PTSD viewed and evaluated combat pictures' (Shin and Kosslyn et al., 1997: 240).

In the same line of argumentation and making a reference to these neuroimaging studies conducted by Rauch et al. (1996), Shin et al. (1997) and Shin and Kosslyn et al. (1997), many researchers (Hull, 2002; Bremner, 2002; Rauch et al., 1996; Shin et al., 1997; Shin and Kosslyn et al., 1997) have suggested that the difficulties observed in trauma victims to verbalize their trauma and integrate it into a narrative, may generally be the result of a hypoperfused Broca's area (a Broca's area that has reduced blood flow). Crucially it should be kept in mind however that if it were indeed the case that the decrease in rCBF to the Broca's area is causing difficulties to speak, it would only be relevant for individuals diagnosed with PTSD and not to trauma-exposed individual.

Many multirepresentational theories of PTSD have been proposed in the past, in which authors have tried to integrate the findings of PTSD research into a comprehensive model of the disorder. One such cognitive model by Ehlers and Clark (2000) has theorized that 'memories for traumatic events are poorly integrated into the existing autobiographical memory database' (Dalgleish, 2004). Because of this poor integration, the authors argue, PTSD patients have difficulties to intentionally recall traumatic memories, which leads to poor narrative accounts of the traumatic event. This claim is following in the line of neuroimaging results, which have suggested that memories in PTSD do not have the same narrative quality, as they tend to be stored more as somatosensory components (Rauch et al., 1996; van der Kolk & Fisler, 1995; Clark et al., 2003). Building on this suggestion the authors conducted a study in which they 'demonstrated that different cortical networks appear to be involved in PTSD for establishing and/or forming the representation of verbally derived information in working memory' (Clark et al., 2003: 479) and that memories are biased in PTSD toward representations that are less verbal and more spatial in character' (Clark et al., 2003: 479). The authors further argue that there is a shift away from verbal processing due to the reduced dependence on verbal memory, which is neurologically manifested in the hypoperfusion of the Broca's area.

2.3 *Broca's area and Broca's Aphasics*

The Broca's area is one of the main language areas within the human brain. It is usually defined as comprising Brodmann's area 44 and 45 (Davis et al., 2008), although the neuroanatomical boundaries vary across individuals and the definitions of where exactly the Broca's area is located have been controversial. Despite these controversies the functions of the Broca's area have been well documented in past neurological and linguistic research focusing on Broca's aphasia and functional brain imaging.

Broca's aphasia, also known as Agrammatism, is a general linguistic impairment that is most often caused by a head trauma or a stroke in which the Broca's area suffers damage. The speech of so-called Broca's aphasics is often described as being effortful and telegraphic. However linguistic research in aphasiology has been able to show that there are many more characteristics to the speech of Broca's aphasics, of which the most commonly present findings will be discussed here. A very characteristic feature of Broca's aphasics in language production is the frequent omission of functional categories including determiners, tense and complementizers (Avrutin, 2001) as well as the use of non-finite utterances when a tensed verb is required. In addition to Broca's aphasics commonly omitting inflections of verbs (Bastiaanse & van Zonneveld, 1998), their speech is also characterized by omissions of null subjects and determiners (Kolk et al., 1990; among others). Bastiaanse & Jonkers (1998) (as well as Swinney et al., 1989, and Shapiro & Levine, 1990) have further shown that agrammatic speakers have problems with lexical access and word retrieval.

Although the Broca's area was initially thought to be responsible for language production only, progressing linguistic research showed that Broca's aphasics also have deficits in language comprehension. Some of these comprehension difficulties are outlined below. A frequently reproduced finding of comprehension difficulties in Broca's aphasics has been the understanding of passive sentences (Grodzinsky et al., 1999). The sentence comprehension difficulties however are not limited to overt phrasal movements, but also include difficulties in structures without overt movement. Avrutin (1999) shows that Broca's aphasics have difficulties establishing reference for a pronoun when there are two possible antecedents in the sentence. Further difficulties with pronoun interpretation were also observed in studies conducted by Groszinsky et al. (1993) and Pinango (2000).

Two differing theories have developed in the research community in an attempt to explain the origin of these production and comprehension difficulties that Broca's aphasics suffer from. The Trace Deletion Hypothesis formulated by Grodzinsky (1984) for example argued that Broca's aphasics are unable to represent trace and therefore have problems understanding overt movement. Building on the arguments proposed by Grodzinsky, further supportive evidence of the Trace Deletion Hypothesis led researchers to believe that Broca's aphasics have structural deficits and that the difficulties seen are a result of that. Various other researchers (Hartsuiker & Kolk, 1998; de Roo (1999); Avrutin (2000), Lizet van Ewijk & Avrutin (2011), among others) on the other hand found contradicting evidence and formulated a different standpoint on the matter. These researchers argue that the mistakes of

Broca's aphasics are not due to structural deficits but due to processing limitations. This would mean that the patients' knowledge of linguistic rules is intact and only the processing capacity to access these rules is limited.

The study of Broca's aphasics and research in aphasiology has been able to reveal many functions of the Broca's area. Nevertheless it should be kept in mind that there is 'not a one to one correspondence between Broca's aphasia and lesions in Broca's area. Some patients with damage to Broca's area do not have Broca's aphasia, and some patients with Broca's aphasia do not have lesions in Broca's area.' (Davis et al., 2008: 51). In addition to this, Broca's aphasics often have large lesions that involve and effect surrounding areas, which is exactly why it is difficult to map all the characteristics observed in Broca's aphasics specifically (and exclusively) to the Broca's area. Next to the study of Broca's aphasics, functional imaging studies have also revealed the role of Broca's area in various language related tasks as well as non-linguistic or cognitive processes. These studies have shown activation in the Broca's area related to phonological working memory (Fiez et al., 1996), various semantic tasks (Bookheimer, 2002) and responsivity of the semantic memory (Thompson-Schill et al., 1999), verb production (Tranel et al., 2005) and spelling (Beeson et al., 2003). While these functional imaging studies can show that the Broca's area is involved in these activities, they are unable to argue that the Broca's area is necessary for these processes. Combining the results from functional imaging studies of the Broca's area and lesion studies with Broca's aphasics, a great overlap in results becomes visible. This could be seen as evidence for those particular functions to be mapped to the Broca's area. Further evidence to what the functions of the Broca's area are comes from a study conducted by Davis et al. (2008), in which the Broca's area of one patient, who had suffered a stroke, was acutely hypoperfused, meaning that there was low blood flow to the Broca's area. Through the testing of various language related functions during hypoperfusion and repoperfusion of the patient's Broca's area, language functions dependent on the Broca's area in this particular individual could be identified. The functions that were impaired during hypoperfusion were comprehension and production of active and passive semantically reversible sentences, spelling, and motor planning/programming of speech articulation. Immediate recovery of all these functions could be observed when the blood flow to the area was restored. A similar line of research combining aphasiology and functional brain imaging has revealed that ischemic lesions or hypoperfusion of the Broca's area is significantly associated with Broca's aphasia (Newhart, 2011; Ochfeld, 2010). In other words, reduced blood flow (rCBF) to the Broca's area that cannot be restored seems to be the most common cause for Broca's aphasia.

3.0 Research Questions

3.1 *Research Questions*

What becomes evident from the study by Davis et al. (2008) in particular is that reduced regional Cerebral Blood Flow (rCBF) to the Broca's area, as is the case with Broca's aphasics, can compromise the functions (particularly language related functions) that are located in the Broca's area. The patient of the Davis et al.'s study (2008) however did not become a Broca's aphasic thanks to the normal level of rCBF that returned to his Broca's area shortly after the stroke. Could something similar be happening to PTSD patients that are confronted with their trauma? Rauch et al. (1996) and others do report reduced blood flow to the Broca's area after all. PTSD patients could be like the patient presented by Davis et al. (2008), meaning that the Broca's area is hypoperfused when the patient is exposed to or talking about their trauma, and that the blood flow then is restored to normal when the patient is no longer exposed to the trauma. From a linguistic point of view this would mean that during the trauma exposed period the PTSD patients could show linguistic difficulties characteristic of Broca's aphasia, which would then be restored to normal together with the returning blood flow. This leads to the following research question:

Does the 'traumatic' speech of individuals with PTSD show similarities and characteristics of the speech of Broca's aphasics?

This research questions was investigated by doing a linguistic analysis on the speech of PTSD and Trauma-Exposed Control (TEC) participants while their traumatic experiences were triggered. Additionally the results of the linguistic analysis were also compared to the speech of Broca's aphasics. (A more detailed description of the methodology and analysis will be provided in section 4 and 5.)

3.2 *Significance of the Research*

The results of neuroimaging presented in 2.2 provide a possible scientific basis to what has often been described as the incapability of narrating and verbalizing in traumatized individuals. Moreover these results also point to the linguistic inconsistencies that can occur in trauma-victims' speech. I hope to show that these difficulties can be further specified and directly linked to the decrease in rCBF of the Broca's area in trauma exposure of PTSD patients.

Ultimately the results of this study have linguistic as well as psychiatric implications. The psychiatric implications are important for theories and models of posttraumatic stress disorder and the neurological differences that describe this disorder. It had already been suggested by Hull (2002) that 'the ability of psychological treatment, especially 'talking therapies' may be compromised during some phases of the disorder [because of the] hypoperfusion of Broca's area when trauma-related memories are provoked' (Hull, 2002: 108). Linguistic implications of this research could contribute to computational linguistics by giving an indication of how the functioning of language areas in the human brain is dependent on the supply of regional Cerebral Blood Flow. Being in accordance with the computational theory of linguistics the results of this study could show linguistically computational effects that have a neuro-physical cause. Furthermore this study could bear supporting evidence for the theory that the mistakes of Broca's aphasics are not due to structural deficits but due to processing limitations. Despite the PTSD patients having an intact working language faculty, the capacity to access everything within this faculty could be limited during times of low blood supply to the Broca's area.

4.0 Methodology

4.1 *Zipf's Law*

George Kingsley Zipf popularized in the sixties a finding from the beginning of the century, which shows that there is a curious pattern that is followed by word frequencies in their distribution. This pattern has been referred to as Zipf's law or the Zipfian distribution. This power law shows that the frequency of any word is inversely proportional to its rank in any given corpus of natural language (Zipf, 1949). Based on this, a linear dependency can be observed between the rank and the frequency of which a word will occur, as long as the data is plotted on a doubly logarithmic scale. Consequently this means that the most frequent word will occur about twice as often as the second most frequent word, three times as often as the third most frequent word and so forth. Recently two separate formulations for the calculation of the Zipfian distribution (Li, 2002) were compared in a study conducted by van Egmond et al. (2012). These formulations, following van Egmond et al. (2012), are referred to as alpha-formulation and beta-formulation:

alpha-formulation: $f_k \propto k^{-\alpha}$ **beta-formulation:** $p_f \approx f^{-\beta}$

In the first formulation f_k is the frequency of the k'th word if words are ordered by decreasing frequency, and in the second formulation p_f is the proportion of words whose frequency is f in a given text. Previous research has typically found that $\propto \approx 1$ and $\beta \approx 2$. Since van Egmond (2011) showed that the beta-formulation is more sensitive in depicting the distributional effects, only the values of the beta-calculations will be used to calculate significance.

Previous research has brought some evidence that Zipf's law is not only specific to occur in the context of language, but can also be observed in various physical and social systems such as city sizes for example (Corominas-Murtra and Solé, 2010). The reason behind such a frequent occurrence in various different fields was shown by Corominas-Murtra and Solé (2010) who explained Zipf's law to be a 'natural outcome of systems belonging to this class of stochastic systems' (Corominas-Murtra and Solé, 2010: 6). For the purpose of this study however only the language related aspect of Zipf's law is of interest. Baroni (2008) has in fact shown that Zipf's law applies to all natural language texts. Trying to explain why such a distributional pattern can be observed, two opposing views have formed in the research community. One group of researchers believe that what can be observed is rather meaningless and merely a result of random processes (e.g. Miller & Chomsky, 1963; Mandelbrot, 1966; Li, 1972; Suzuki et al., 2005). The other group of researchers believes that Zipf's law is the result of the language faculty, the underlying system to speech in all humans (e.g. Zipf, 1949; Balasubrahmanyan & Naranan, 2002; Ferrer i Cancho & Solé, 2005; Corominas-Murtra & Solé, 2010). Contributing to the on-going debate, the standpoint of seeing Zipf's law as a result of random processes has been put into serious question when Ferrer i Cancho and Elvevåg (2010) showed that random texts, as opposed to natural language texts, do not exhibit the real Zipf's law-like rank distribution.

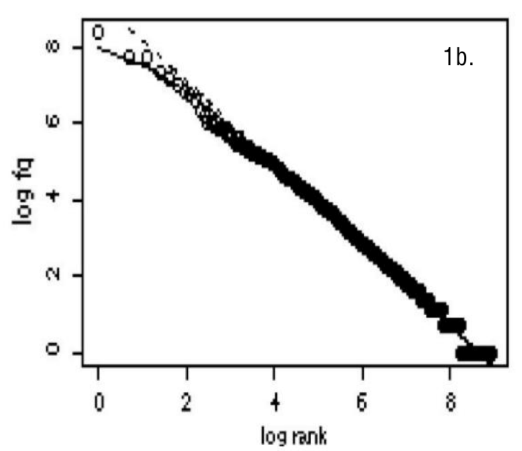

Figure 2. Zipf's law in H.G. Well, *The War of the Worlds* (1989) (Baroni 2008). Rank/Frequency plot on a log-log scale.

So far the research in this field has proven that no matter what the mechanisms behind the Zipfian distribution are, its application can be a useful measure to compare different groups and reveal significant differences. Using this method for example, researchers have investigated the speech of schizophrenic patients (Piotrovskii, Pashkovskii and Piotrovskii, 1994) and children with Down syndrome (Piotrowski and Spivak, 2007). The results showed that the speech of these individuals still conforms to Zipf's law, but has a slightly altered distribution than normal healthy adults. More specifically, what can be observed is that those speech forms have a different slope of the power law. The slope was observed to be more gradual for schizophrenic patients with disconnected speech and to be curved instead of being in a straight line for schizophrenic patients with a topic obsession (Piotrovskii, Pashkovskii and Piotrovskii, 1994). For children with Down syndrome however the slope was found to be steeper (Piotrowski and Spivak, 2007).

Interestingly van Egmond (2011) showed in a study in which frequency distribution of content words was investigated, that the distribution of non-fluent aphasic speakers also conforms to Zipf's law. Similar to the speech of schizophrenic patients and the speech of children with Down syndrome, van Egmond found that the speech of non-fluent aphasic speakers also exhibits a different slope. Thus 'aphasic speakers display a significantly more gradual slope' (van Egmond, 2011: 23) in contrast to healthy adult speakers. Of course the groups of schizophrenic patients, children with Down syndrome and Boca's aphasics are fairly different from each other and do not have much in common. Nevertheless they share a commonality when it comes to the Zipfian distribution, namely the fact that they all exhibit a less varied choice of words, which becomes visible through the calculation of the Zipfian distribution. In addition to the van Egmond (2011) study showing that the distribution of content words in Broca's aphasics' speech follows Zipf's law, a more recent study by van Egmond et al. (2012) compared the Zipfian distribution for all words, content words and function words in Broca's aphasics speech and revealed that Zipf's law does not apply to function words.

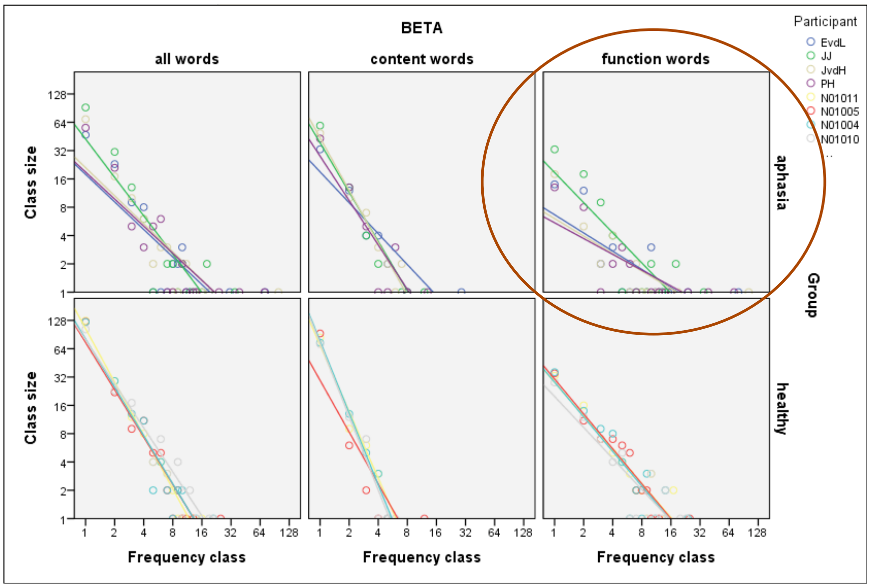

Figure 3 - Results of the Zipf's law calculation with the beta-formulation for all words, content words and function words (van Egmond et al. 2012)

But what does this distortion in the Zipfian Distribution even mean? It has been argued by various researchers (Kittredge et al., 2008; Avrutin, 2006; van Egmond, 2011; etc.) that there is a connection between word frequencies, lexical access and processing costs. It has been put forward that difficulties such as word-finding difficulties can be explained by the time-course approach, which claims that these problems arise due to syntactic processing that is slowed down. Based on this time-course approach, it has been suggested that when processing resources are reduced, information has to be processed with limited resources. This can for example be executed by reducing the complexity of lexical access and therefore only activating the words with the highest level of activation, as they require the least amount of effort to be activated. This would mean that, especially in cases of reduced processing capacities, frequency influences lexical retrieval. The findings that the speech of Broca's aphasics conforms to Zipf's law therefore shows that although Broca's aphasics' speech sounds significantly altered, the word-finding difficulties that they suffer from are not due to defects of the system but rather due to processing difficulties (van Egmond, 2011; van Egmond et al., 2012). These findings further also support the time-course approach.

Since it has been shown that the speech of various patient groups conforms to Zipf's law but exhibits a different slope compared to healthy patients, there is reason to believe that the same might also be true for the 'traumatic' speech of PTSD patients. Even though the 'traumatic' speech of PTSD patients might not sound very different from normal speech and although there might not be a significant percentage of omission of functional categories to be observed, Zipf's law may be able to pick up on more subtle abnormalities visible through the frequency distribution. A possibility for example is that PTSD patients mainly use high frequency words and almost no low frequency words when talking about their trauma. In such a case the percentage of frequency words might not be able to reveal any differences, while the distribution of frequencies calculated with Zipf's law is much more sensitive to smaller distortions. Zipf's law could therefore reveal an effect that is not visible through the calculation of omission percentages. Findings confirming that the Zipfian Distribution of the 'traumatic' speech of PTSD participants is distorted could mean that processing capacities are limited while PTSD participants are exposed to their trauma.

This study examined whether or not the 'traumatic' speech of PTSD patients follows Zipf's law in word frequency distribution of all words. Then, given that the frequency distribution of PTSD patients' 'traumatic' speech conforms to Zipf's law, it was further investigated whether or not the observed slope is different for PTSD patients' 'traumatic' speech as compared to a trauma-exposed control (TEC) group. Additionally it was investigated if the slope of the 'traumatic' speech resembles the slope of Broca's aphasics' speech.

4.2 *Participants*

For the purpose of this research a linguistic analysis was performed on speech data collected during interviews with five PTSD patients and five Trauma-Exposed Control patients (TEC). Additionally speech data of five Broca's aphasics was obtained from the AphasiaBank (MacWhinney et al., 2011). The PTSD and TEC data consisted of two types of speech samples per participant. One of the speech samples was a recording of the paticipants talking about a traumatic experience, labelled as 'traumatic' speech. The second speech sample consisted of the participants talking about a non-traumatic 'neutral' topic. This second speech sample, labelled 'neutral' speech, served as a control to the 'traumatic' speech. Without the 'neutral' speech sample it would not be possible to determine whether the observations made of the error percentages and in the Zipfian distribution of the 'traumatic' speech are possibly related to a decrease in blood flow to the Broca's area or not. The 'neutral' speech thus serves as a control to the 'traumatic' speech for each subject (within-subject control). And additional group of healthy control subjects was not added to the study for two reasons. Firstly it is assumed that the 'neutral' speech of PTSD and TEC participants is comparable to the speech of healthy trauma-exposed controls, as the neuro-imaging studies confirm. Secondly it is already known what the Zipfian distribution of healthy adults looks like.

The evidence that the Broca's area is compromised in individuals with PTSD as they are being confronted with their trauma comes from neuroimaging studies that have used both male (Shin et al., 1997; Bremner et al, 1999; Lindauer et al., 2004) and female (Shin et al., 1997) participants. Therefore gender is not expected to have an influence. Both the PTSD and the TEC group consisted of four female and one male participant, while the Broca's aphasics group consisted of two males and three females. The mean age of participants in the PTSD group was 40.4. For the TEC group the mean age of participants was (31.4) and for the Broca's aphasics group the mean age was (60.75). All participants were native speakers of English. The data collected and presented here was used for research purposes only and in order to the keep the participants' identity confidential each participant received a code identifier.

	Race	Age	Gender	Trauma	CAPS	CTQ
MK	Caucasian	43	Female	Domestic Abuse, Sexual Abuse	56	69
RP	Asian	36	Female	Physical/Sexual Attack by Ex, Physical Abuse	28	63
JS	Caucasian	53	Female	Rape, Neglect, Physical Assault		81
DL	Caucasian	47	Female	Sexual Abuse	38	60
TN	Asian	23	Male	Suicide of Father	94	48

Table 1 - Group Demographics: PTSD

	Race	Age	Gender	Trauma	CAPS	CTQ
KF	African American	42	Female	Car Accident, Unexpected Death	NA	NA
WD	African American	24	Male	Car Accident, Murder of Best Friend	8	64
YO	African American	35	Female	Gang Rape	6	68
TW	African American	38	Female	Rape	17	46
SO	African American	18	Female	Shooting Witness, Domestic Violence Witness	25	62

Table 2 - Group Demographics: TEC

4.2.1 *PTSD Participants and Trauma-Exposed Control (TEC) Participants*

Both t speech data of the PTSD participants and Trauma-Exposed Control (TEC) participants was collected during the documentation of trauma history as part of a series of brain-imaging studies conducted by Prof. Dr. Alexander Neumeister at the Department of Psychiatry at the New York University (NYU). All participants for the brain-imaging studies were recruited from the outpatient clinic of the NYU

Medical Centre and included all races. Participants with a history of drug dependence (including benzodiazepines [BZD] but not including alcohol) were not admitted to the studies. Before the start of the study, the NYU IRB approved the research and all procedures involved.

After the arrival of the participant at the Department of Psychiatry of NYU, the participant was led into a private room and was given time to carefully read through the consent forms (one for the imaging studies and one for the recording of the interviews) and to become familiarized with the research procedure. In addition to reading the consent form, a full explanation of all research procedures, risks, benefits, and rights of the subject was given before proceeding. After signing the consent form, each participant was given self-evaluation forms to be completed in private. Following the completion of the consent form and the self-evaluation forms, two interviews were conducted with each participant. The order in which the interviews were conducted remained the same through out the entire data collection and all neutral interviews were conducted in a single session without breaks. The diagnostic interviews during which the 'traumatic' speech was recorded, was completed in either one or two sessions. In one case the diagnostic interview had to be broken off and completed at a different point in time, because the participant started reliving their trauma. All interviews were recorded with the help of an unobtrusive digital voice recorder (Olympus VN-702 PC). Firstly the 'neutral' speech data was collected in an interview led by the author personally. The interview was a semi-structured conversation, which was initiated and led by the interviewer asking questions about the same topic range: New York City, work/employment and summer plans. (A guideline sheet to the 'neutral' interview can be found in the Appendix.) No intervention was taken if a new topic came up during the interview.

The second interview was recorded while Prof. Dr. Neumeister or Sean Sobin were assessing the presence of PTSD. Diagnostic evaluations using the Structured Clinical Interview for DSM-IV-TR (SCID) was used to confirm the existence of a primarily depressive or PTSD phenotype in the patient group and the absence of any lifetime psychiatric disorder in healthy control subjects. The evaluation of the Clinical Ratings was performed at NYU School of Medicine in NYC and included the Hamilton Rating Scale of Depression, the Montgomery Asberg Depression Rating Scale, the Hamilton Anxiety Rating Scale to rate anxiety, and the Clinician-Administered PTSD Scale (CAPS) to measure PTSD symptoms. Only the recordings taken during the completion of the DSM-IV-TR (SCID) and the Clinician-Administered PTSD Scale (CAPS) was used for the 'traumatic' speech samples.

4.2.2 *Broca's Aphasics' Participants*

The second participant group included in this study were Broca's aphasics' patients. Language data of Broca's aphasics was used from ten subjects. This language data was obtained from the AphasiaBank (MacWhinney et al., 2011); an online shared database of multimedia interactions for the study of communication in aphasia. As the availability of Broca's aphasics' speech data is rather limited, no inclusion or exclusion criteria were given for this group of participants. Solely data of free speech was accepted as data for this study. Since a direct comparison between the speech of PTSD patients and Broca's aphasics is out of the questions, there was no need for these entirely different participant groups to be comparable in terms of participants. The only thing that was compared was the effect of the reduced blood flow to the Broca's area in these two populations. The mean age of participants was 60.75 and all participants were native speakers of English.

4.3 *Research Design*

The design of this study is a 5x2 design with five independent and two quantitative dependent variables. The collected data is constituted of five types of speech samples,

1) the ‘neutral’ speech sample of the PTSD patients,
2) the ‘traumatic’ speech sample of the PTSD patients,
3) the ‘neutral’ speech of the TEC patients,
4) the ‘traumatic’ speech of the TEC patients, and
5) the speech samples of the Broca’s aphasics.

These speech samples were first transcribed and then analysed for linguistic errors and their error percentages in the different speech data. The CHAT transcription format was used to transcribe and mark parts of speech of all collected data. The types of linguistic errors were classified into two different categories: ‘omission of functional categories’ and ‘omission of inflections’. A percentage of error rates were calculated for each one of the above named categories in each one of the types of speech samples, leading to a 5x2 design.

Furthermore the Zipfian Distribution of all speech samples was calculated by using the alpha-formulation and the beta-formulation of Zipf’s law. A more detailed account of the calculation of the Zipfian Distribution can be found in section 5.1.2.

	Omissions of Functional	Omission of Inflections
PTSD: ‘Neutral’ Speech		
PTSD: ‘Traumatic’ Speech		
TEC: ‘Neutral’ Speech		
TEC: ‘Traumatic’ Speech		
Broca’s Aphasics’ Speech		

Table 3 - 5x2 Study Design (Step4)

Disorder-related information was obtained for all the individuals diagnosed with PTSD. This background information includes severity of PTSD, previous and current treatments of PTSD that the participants are or have been undergoing, medication (related to PTSD) that the participant is currently taking and any other disorders or syndromes that the patient had been diagnosed with. The background information served as possible control measurements to explain the results. All of this information was gathered as part of the brain-imaging studies at the New York University and were kept confidential.

5.0 Analysis and Expected Results

5.1 *Error Percentage Calculation*

All types of the five groups' speech samples, the 'neutral' speech and the 'traumatic' speech sample of the PTSD patients and the TEC patients, as well as the speech samples of the Broca's aphasics, were analysed for linguistics errors and their percentages in the speech produced. The types of linguistic errors were split up into two different categories, these being 'omission of functional categories' and 'omission of inflections'. The percentages of error rates were calculated for each one of the above named categories in each one of the types of speech samples, leading to a 5x2 design. First a general error percentage for each type of speech sample was calculated with the expectation that the error percentage in the 'neutral' speech samples will be very low with a percentage of 0 or near to 0. The Broca's aphasics' speech on the other hand was expected to show a relatively high percentage of errors. After having maintained a general error percentage for each type of speech, separate error percentages were calculated for each error type. For both of the categories the error percentage was calculated by contrasting the count of the elements of the category and the count of actual omissions. For a calculation of the percentage of inflection omissions for example, all inflections (including the ones pronounced and the ones that have been omitted) occurring in the 'traumatic' speech data were counted. Then all omitted inflections in the same data were counted so that a percentage can be calculated of how many inflections had been omitted. The same was then done for all other types of speech data in order to be able to compare the error percentages of inflection omissions of each language data individually. Then the exact same procedure was applied to the calculation of omissions of functional categories.

The error rates and percentages of each participant's 'neutral' speech sample were then supposed to be compared to the error rates and percentages of the same participant's 'traumatic' speech sample, which served as a control. Participants with too high error percentages in their 'neutral' speech samples would be excluded from the study, as it will not be able to determine whether the errors are due to reduced blood flow or other linguistics reasons. Based on the prediction that the two different populations of PTSD patients and Broca's aphasics show a similar effect of reduced rCBF to the Broca's area, the effect of this reduced blood flow was compared in the error percentages of the 'traumatic' speech and the percentage of errors made in the Broca's aphasics' speech. This is to determine whether there is a significant comparability between the percentage of errors made in PTSD patients' 'traumatic speech' and Broca's aphasics' speech.

Research Hypothesis 1:

The percentage of errors of the 'traumatic' speech is higher than the percentage of errors of the 'neutral' speech.

Null Hypothesis 1:

The percentage of errors of the 'traumatic' speech is equal to the percentage or less than the percentage of errors of the 'neutral' speech.

The following is a step-by-step procedure of the analysis of the error percentage calculations:

Step1: Transcription of the collected speech data (all three speech types) into CHAT-format with the labelling for part of speech.

Step2: Counting the errors for each participant in the 'neutral' speech. Exclusion of participants with too high error rates in their 'neutral' speech.

Step3: Counting the errors for each error type in the 'neutral' speech, 'traumatic' speech and Broca's aphasics' speech for each participant separately and calculating an error percentage.

	Omissions of	Omission of
Participant 1		
Participant 2		
Participant 3…		

Table 4 - Step3: Separate Percentage Calculation for all types of Data

Step4: Calculating a general error percentage for each error type for the different speech data.

Step 5: Reject or accept the Null Hypotheses.

5.2 *Zipf's Law Calculation*

Next to calculating the error percentages of the omissions, the word frequency distribution was calculated using Zipf's law. The word frequency distribution was calculated for all types of words using the alpha-formulations as well as the beta-formulation in a linear regression. The same number of tokens was used for each participant in the analyses. Choosing the smallest sample size from the pool of participants, the first 346 tokens were selected of each participant's speech data. Then the analyses were run for all words of each participant's speech with the results displayed on a double logarithmic scale with r^2–values as an indication of goodness of fit. The shape of the slope could be read from the alpha-values and the beta-values. Finally a randomization test was applied to compare group differences. Two research hypotheses were made about the Zipfian distribution of the 'traumatic' speech of PTSD patients.

Research Hypothesis 3:

The 'traumatic' speech of PTSD patients conforms to Zipf's law.

Null Hypothesis 3:

The ‘traumatic’ speech of PTSD patients does not conform to Zipf’s law.

Research Hypothesis 4:

The slope of Zipf’s law of the ‘traumatic’ speech of PTSD patients is significantly different from the slope of Zipf’s law of healthy speakers.

Null Hypothesis 4:

The slope of Zipf’s law of the ‘traumatic’ speech of PTSD patients is not significantly different from the slope of Zipf’s law of healthy speakers.

The following is a step-by-step procedure of the analysis of the Zipf’s law calculations:

Step1: Count of words and selection of the same number of tokens for each analysis (alpha-analysis and beta-analysis) per participant.

Step2: Measurement of the alpha-formulation and the beta-formulation through linear regression.

Step3: Run a randomization test to compare group differences.

Step 4: Reject or accept the Null Hypotheses.

6.0 Results

6.1 Omissions

The count of omissions per participant, as presented in Table 5, demonstrates that only a very low count of omissions of functional categories could be observed, while no omissions of inflections could be observed at all. The most surprising thing about these numbers is data of Broca's aphasics did not show any omissions either (neither omissions of functional categories, nor omissions of inflections), although it is known that these types of omissions are very common in Broca's aphasics' speech. This striking difference between what was expected and what was found could be due to various reasons. The first difficulty arose from judging what should be seen as an omission of function words. Natural free speech is evidently not as well structured and complete in its sentence structure (or the sentence itself) as written speech is. These partially incomplete utterances however do not necessarily always sound odd or wrong to the listener or even result in ungrammaticality, as they are often accepted as colloquial speech or simply as part of reformulations. This difficulty of judging omissions has also been confirmed by the CHAT Manual, which points out that 'it may often be the case that

Omissions		**Neutral**		**Traumatic**	
		F.C.	**Infl.**	**F.C.**	**Infl.**
PTSD	DL	0	0	0	0
	JS	1	0	0	0
	MK	4	0	0	0
	RP	0	0	0	0
	TN	1	0	1	0
	Total	**6**	**0**	**1**	**0**
TEC	KF	1	0	0	0
	SO	0	0	2	0
	TW	1	0	0	0
	WD	1	0	0	0
	YO	0	0	0	0
	Total	**3**	**0**	**0**	**0**
Aphasia	adler16a	0	0	0	0
	elman03a	0	0	0	0
	elman06a	0	0	0	0
	tap13a	0	0	0	0
	tap19a	0	0	0	0
	Total	**0**	**0**	**0**	**0**

Table 5 – Occurrence of all Omissions per Participants

the user cannot decide whether an omission is grammatical or not' (MacWhinney, 2012). Given these difficulties, the data was only marked with omissions of functional categories when such an omission was detected by the listener by noticing that there was an element missing. Such an event occurred in the data of all PTSD participants and all TEC participants only 12 times, which is a far too small number to indicate any significance. Strangely enough almost all omissions except for one occurred in the neutral speech samples of the participants. This is very much in contrast to the hypothesis put forward in Research Hypothesis 2. Due to the lack of omissions in the Broca's aphasics' data and the very little occurrences of omissions in the rest of the data, it was decided that there was no need for a calculation of percentage for omission of functional categories. Additionally, since the Broca's aphasics' data did not show any types of omissions at all, it is safe to say that the investigation of the data trough the use of omission percentages did not yield any results and is inconclusive due to all speech types showing little to no omissions. Therefore all hypotheses, Research Hypothesis 1, Null Hypothesis 1, and Research Hypothesis 2 and Null Hypothesis 2 were rejected.

6.2 *Zipfian Distribution*

6.2.1 *Alpha-Analysis*

The alpha-formulation of the Zipfian Distribution is formulated as the frequency of rank *k* that approaches k to the power of minus alpha with alpha traditionally being

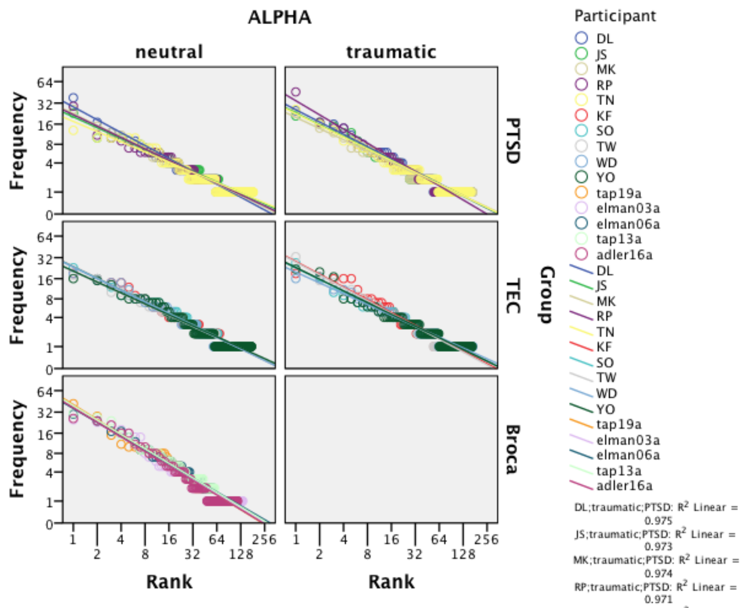

Figure 3 - Zipf's Graphs for the Alpha-Analysis per Group

1. The graphs in Figure 5 show the Zipfian Distributions of the alpha-analysis of the participants divided into groups. All individual graphs of the participants can be found in the Appendix. On the basis of the Zipfian Distribution displayed on double logarithmic scales (see Figure 3) we see that the frequency distribution of all the analyzed speech samples conform to Zipf's Law. This can further be investigated by looking at the specific alpha-values per participant.

Alpha-Analysis		Neutral		Traumatic	
		Coefficient	**r2**	**Coefficient**	**r2**
PTSD	DL	0.731	0.984	0.719	0.972
	JS	0.644	0.968	0.697	0.968
	MK	0.683	0.982	0.665	0.978
	RP	0.666	0.971	0.792	0.991
	TN	0.624	0.941	0.683	0.982
	Average	**0.669**	**0.969**	**0.711**	**0.979**
TEC	KF	0.68	0.941	0.743	0.974
	SO	0.678	0.964	0.679	0.977
	TW	0.654	0.967	0.737	0.991
	WD	0.69	0.962	0.649	0.983
	YO	0.657	0.953	0.683	0.986
	Average	**0.671**	**0.982**	**0.698**	**0.982**
Aphasia	adler16a	0.816	0.969		
	elman03a	0.81	0.969		
	elman06a	0.771	0.964		
	tap13a	0.79	0.966		
	tap19a	0.819	0.958		
	Average	**0.801**	**0.961**		

Table 6 - Results of the Alpha-Analysis

All alpha-values of the given data were calculated by using a linear regression to estimate the curve with frequency and rank as variables. The r^2-values give an indication of how well the given data conforms to Zipf's law with a $r^2 = 0.984$ (as given for participant DL's neutral speech) for example showing that the model can explain 98.4% of the data. Given that $r^2 > 0.940$ for all participants, it is safe to assume that all speech samples conform to Zipf's law. Therefore the Research Hypothesis 1 stating that the 'traumatic' speech of PTSD patients conforms to Zipf's law was accepted. Given this general conformity of the r^2-values, it is valid to look at the scope coefficient for the In(Rank) of the Unstandardized Coefficient B, which is the alpha-value when given a positive value. From the alpha-values in the table it is seen that the values of the Broca's aphasics are significantly higher than all the values of the other groups, which is indicative of a worse performance of the Broca's aphasic. In addition to this very clear observation it can also be seen that the alpha-values for the 'traumatic' speech samples are slightly higher than they are for the 'traumatic' speech samples. This observation holds for both the PTSD and the TEC group. In order to get a more accurate analysis on the performance of the groups, the beta-analysis was run, which has been shown to be a more sensitive measure (van Egmond et al., 2012).

6.2.2 Beta-Analysis

The beta-formulation of the Zipfian Distribution is the proportion of words whose frequency is f in a given text (p_f) is approximately equal to frequency f to the power of minus beta, with beta traditionally being 2. As the number of words was equal for all speech samples, number of words rather than

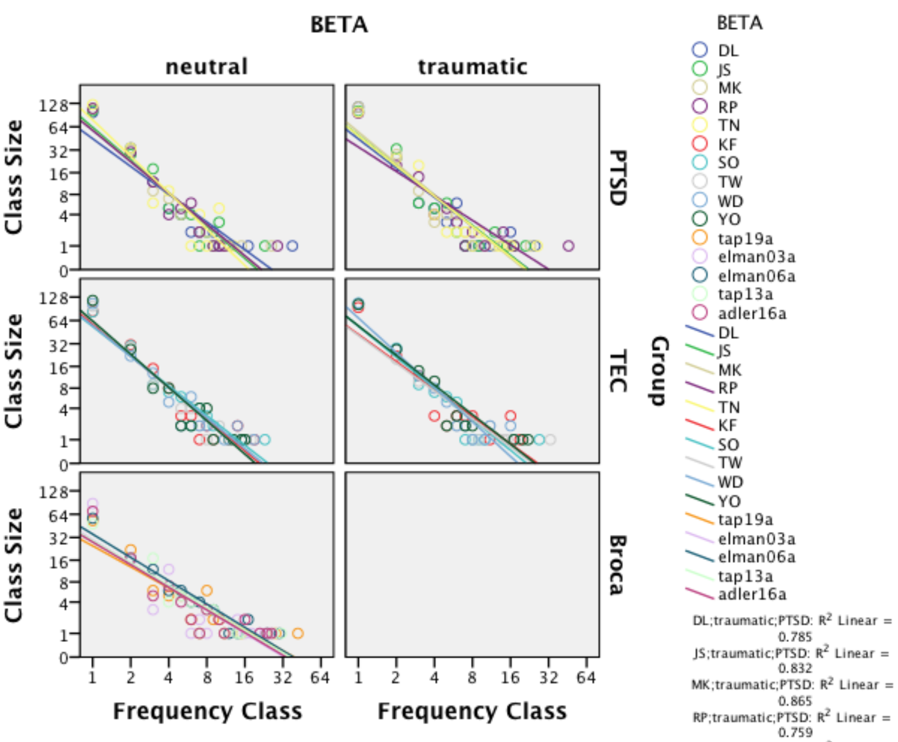

Figure 4 - Zipf's Graphs of the Beta-Analysis per Group

proportion of words could be used in the analysis. Again the Zipfian Distribution was depicted on a double logarithmic scale, but this time for 'frequency class' and 'class size'. The graphs in Figure 4 shows the Zipfian Distributions of the beta-analysis of the participants divided into groups and again it appears as if all groups conform to Zipf's law. This is further confirmed by the r^2-values showing that even in the group with the lowest r^2-values (Broca's Aphasics), at least 81.9% is explained by the model. Again all individual graphs can be found in the Appendix. All beta-values of the given data were calculated by using a linear regression to estimate the curve with class size and frequency class as variables. Again the Adjusted r^2-values give an

Beta-Analysis		**Neutral**		**Traumatic**	
		Coefficient	**r^2**	**Coefficient**	**r^2**
PTSD	DL	1.423	0.833	1.492	0.796
	JS	1.636	0.837	1.538	0.855
	MK	1.623	0.911	1.61	0.903
	RP	1.598	0.864	1.257	0.782
	TN	1.784	0.788	1.545	0.919
	Average	**1.612**	**0.846**	**1.488**	**0.851**
TEC	KF	1.615	0.881	1.379	0.821
	SO	1.514	0.934	1.597	0.841
	TW	1.686	0.921	1.435	0.817
	WD	1.554	0.889	1.7	0.873
	YO	1.688	0.885	1.511	0.903
	Average	**1.611**	**0.902**	**1.524**	**0.851**
Aphasia	adler16a	1.111	0.753		
	elman03a	1.223	0.765		
	elman06a	1.222	0.923		
	tap13a	1.198	0.835		
	tap19a	1.185	0.821		
	Average	**1.188**	**0.819**		

Table 7 - Results of the Beta-Analysis

indication of how well the given data conforms to Zipf's law and the positive Unstandardized Coefficient B gives the beta-value. The beta-values conform the results obtained from the alpha-analysis, which show that the Broca's aphasics perform poorer than all the other groups. Furthermore it can again be seen that the values for the 'traumatic' speech data is lower than for the 'neutral' speech data in both cases of the PTSD participants and the TEC participants.

6.2.3 Group Differences

A randomization test with one quantitative variable and one binary categorical variable was applied to calculate the statistical difference between the groups. During this test 1000 samples were generated and each group was reallocated. This test, as opposed to a traditionally used t-test, was chosen because of the small sample size of the data and the absence of evidence for a normal distribution. Exactly because of this small group size however, it should be kept in mind that all results of the statistical analysis should be seen tentatively and can only be seen as an indication.

The tables below present the results of the beta-analysis, the mean values of each group and the p-value of the randomization test for the coefficients (the beta-values) and the r^2-values. By conducting the randomization test for the r^2-values we were looking at how equally the speech of two groups conforms to Zipf's law. When using the beta-values however we are looking at whether the slope of Zipf's law is the same or different for two given groups. Looking at the tables below, it can be read that the neutral speech of PTSD patients and the neutral speech of TEC patients' does not conform to Zipf's law in the same way and that the slope of Zipf's law is the same for both groups. This means that although the slope of the two groups is almost identical (1.612 = 1.611), the PTSD participants' neutral speech conforms to Zipf's law worse than the speech of TEC participants. The 'traumatic' speech of PTSD participants and the 'traumatic' speech of TEC participants however conform to Zipf's law in the same way with and identical r^2 mean = 0.851. Comparing the PTSD participants' neutral and 'traumatic' speech, we can see that both types of speech conform to Zipf's law in the same way and their slopes are not significantly different from each other either. This means that the Research Hypothesis 4 needs to be rejected and that the Null Hypothesis 4 has to be accepted. Although the difference between the beta-slopes is not significant, it can be seen from the numbers that the beta-slope for the 'traumatic' speech of PTSD participants is nevertheless lower. This could suggest that a bigger sample could potentially influence the beta-slope of the 'traumatic' speech and result in being significantly lower than the 'neutral' speech. Since the results of the randomization test for the comparison of beta-values between all groups are not significant, it means that the beta-slope for all groups is more or less the same. The only other group, in which a significant difference was found in the way that the groups conform to Zipf's law, is the 'neutral' and the 'traumatic' speech of the TEC group.

Beta-Analysis		Neutral		Traumatic		
		Coefficient	r^2	Coefficient	r^2	
PTSD	DL	1.423	0.833	1.492	0.796	NS ; NS
	JS	1.636	0.837	1.538	0.855	
	MK	1.623	0.911	1.610	0.903	
	RP	1.598	0.864	1.257	0.782	
	TN	1.784	0.788	1.545	0.919	
	Average	**1.612**	**0.846**	**1.488**	**0.851**	
TEC	KF	1.615	0.881	1.379	0.821	NS ; p = 0.04
	SO	1.514	0.934	1.597	0.841	
	TW	1.686	0.921	1.435	0.817	
	WD	1.554	0.889	1.700	0.873	
	YO	1.688	0.885	1.511	0.903	
	Average	**1.611**	**0.902**	**1.524**	**0.851**	
		NS	P = 0.02	NS	NS	

Table 8 - Group Difference Results PTSD & TEC

As Table 8 presents, the neutral as well as the 'traumatic' speech of PTSD participants and the speech of Broca's aphasics are significantly the same in the way they conform to Zipf's law. The beta-slope of the Broca's aphasics' speech however is significantly lower compared to the PTSD participants' 'neutral' and 'traumatic' speech, which means that the Broca's aphasics use fewer words and that these words are used more often in their speech.

Beta-Analysis		**Neutral**		**Traumatic**	
		Coefficient	**r^2**	**Coefficient**	**r^2**
PTSD	DL	1.423	0.833	1.492	0.796
	JS	1.636	0.837	1.538	0.855
	MK	1.623	0.911	1.61	0.903
	RP	1.598	0.864	1.257	0.782
	TN	1.784	0.788	1.545	0.919
	Average	**1.612**	**0.846**	**1.488**	**0.851**
Aphasia	adler16a	1.111	0.753	1.111	0.753
	elman03a	1.223	0.765	1.223	0.765
	elman06a	1.222	0.923	1.222	0.923
	tap13a	1.198	0.835	1.198	0.835
	tap19a	1.185	0.821	1.185	0.821
	Average	**1.188**	**0.819**	**1.188**	**0.819**
		P = 0.006	NS	p < 0.001	NS

Table 9 - Group Different Results PTSD & Aphasia

In the comparison of the TEC participants' speech to Broca's aphasics' speech shows that while their slopes do not significantly differ from each other, the neutral speech of TEC participants conforms better to Zipf's law than the speech of Broca's aphasics and that there is no difference in the way the 'traumatic' speech of TEC participants and the speech of Broca's aphasics conforms to Zipf's law.

Beta-Analysis		**Neutral**		**'**	
		Coefficient	**r^2**	**Coefficient**	**r^2**
TEC	KF	1.615	0.881	1.379	0.821
	SO	1.514	0.934	1.597	0.841
	TW	1.686	0.921	1.435	0.817
	WD	1.554	0.889	1.7	0.873
	YO	1.688	0.885	1.511	0.903
	Average	**1.611**	**0.902**	**1.524**	**0.851**
Aphasia	adler16a	1.111	0.753	1.111	0.753
	elman03a	1.223	0.765	1.223	0.765
	elman06a	1.222	0.923	1.222	0.923
	tap13a	1.198	0.835	1.198	0.835
	tap19a	1.185	0.821	1.185	0.821
	Average	**1.188**	**0.819**	**1.188**	**0.819**
		P = 0.006	P = 0.04	P = 0.00	NS

Table 10 - Group Difference Results TEC & Aphasia

In sum it can be said that the speech of all groups conforms to Zipf's law and while there is no significant difference between the beta-slopes of the PTSD participants' and the TEC participants' speech, the beta-slope of the Broca's aphasics' speech is significantly lower from all the other groups. These findings are in accordance with the findings of the study conducted by van Egmond (2011) and van Egmond et al. (2011).

7.0 Discussion

The here presented study investigated the effects of PTSD on speech capacity, based on the assumption that the blood flow to the Broca's area would be reduced in PTSD participants that are exposed to their trauma, while having normal blood flow (or restored to normal) when the PTSD participants talk about something neutral. TEC participants were added to the study as a control group, with the assumption that their 'neutral' as well as 'traumatic' speech should be equivalent to the speech of healthy adults. This is assumed because of the normal blood flow levels to the Broca's area that were found when TEC participants were exposed to their trauma. The speech of both of these groups was also compared to the speech of Broca's aphasics; a patient group that is known to have damage and thus reduced blood flow to the Broca's area and as a consequence shows impaired speech.

Two different measures were applied to investigate the speech data collected from a linguistic point of view. The first measure was a percentage calculation of omissions of functional categories and of omissions of inflections. Both of these types of errors are well known to be common amongst Broca's aphasic patients. The results of the first measure indicate that this measure itself, or its execution, might not have been a good fit for the here presented research.

The second measure applied was the calculation of the Zipfian distribution. The results of this calculation show that the speech of all groups conforms to Zipf's law and that there are no significant differences between the PTSD participants and the TEC participant's speech. As expected significant differences were found for the beta-slopes of the Broca's aphasics and the PTSD and TEC participants. These findings indicate that processing capacities might be limited in Broca's aphasics, which confirms and replicates the findings of van Egmond (2011) and van Egmond et al. (2012).

7.1 Explaining the Results

Interpreting these results against the presented theoretical background and the assumptions that the hypotheses were formulated upon, throws open various unanswered questions. The assumption upon which the research question and hypotheses had been formulated was that there are neuro-imaging studies that show that PTSD patients have reduced rCBF to the Broca's area when they are exposed to their trauma. Therefore the effect that PTSD would have on their speech was compared to the impaired speech of Broca's aphasics, who commonly have reduced blood flow to the Broca's area that can no longer be restored. Following this theoretical background it was assumed that the blood flow to the Broca's area would be reduced when the PTSD participants talk about their trauma and that thus there might be a more gradual slope observable in their Zipfian Distribution. However no such effects could be observed in the data.

Three different explanations can be offered further interpretation of the findings. Looking at the values obtained from the alpha-, as well as beta-analysis, it can be seen that the direction of the values is into the expected direction, namely the PTSD participants perform poorer in the 'traumatic' speech than in the 'neutral' speech. Nevertheless this trend did not render to be significant in the group difference analysis. Of course it could be that the difference between the 'neutral' and the 'traumatic' speech is just not significant. It could however also be, that there is a significant difference, but that this difference is not as strongly pronounced as for example the difference to the Broca's aphasics' speech. In that case the number of tokens selected for each participants and the group size could significantly effect the visibility of the difference. In other words the direction of what can be observed in the numbers could very well be a significant difference confirming the Research Hypothesis 2, and it might merely show up only as a trend in this research because of the limited sample and token size.

Secondly these results raise questions about our assumptions regarding the nature of blood flow to the Broca's area behaves in a certain way during the collection of the speech samples. It might be the case that the participants were not successfully exposed to their trauma. Thus there was no hypoperfusion of the Broca's area. This could be an explanation for why no effect could be seen.

A third possible explanation could be that the rCBF to the Broca's area does not have an effect on speech and that the Research Hypothesis put forward is simply incorrect. The implications of this explanation would mean that either the level of reduction of the blood flow that can be observed in PTSD patients when they are exposed to their trauma was simply not high enough to influence and affect the functions of the Broca's area. Or, alternatively it could mean that the very specific location in which the Broca's area is hypoperfused during the trauma exposure, is not related to any of the task that this study tested for and that suffer from processing limitations in Broca's aphasics.

7.2 Further Observations

It has often been argued that in a text with less than a thousand words, no conclusions can be drawn from the Zipfian Distribution. However, because of the within-subject design of the neutral and 'traumatic' speech of the study, I believe it is safe to say that all effects observed in the Zipfian Distribution of the data are significant. Nevertheless I agree that the results of this study should be seen tentatively and with caution and that we could highly benefit from future research which will replicate the here presented research of the Zipfian Distribution of PTSD and TEC participants' speech with a significantly larger sample size and higher token number.

Although hardly any omissions could be observed in the collected speech samples, there were two other observations made by simply listening to or reading the data. The 'traumatic' speech of PTSD and TEC participants seemed to be significantly slower in comparison to both of the groups' 'neutral' speech, and contained a higher count of pauses as well as pauses of significantly longer duration. Furthermore the 'traumatic' speech of almost all participants (PTSD and TEC) included a higher number of repetitions and reformulations. While the Zipfian Distribution is not necessarily something that a listener can simply pick up on, the tempo, pauses, repetitions and the reformulations are definitely elements that can be noted without statistical testing.

Furthermore, looking at the format of the diagnostic interviews (the SCIT and the CAPS interviews) during which the 'traumatic' speech data was collected, I would like to suggest that there might be more suited formats in which the 'traumatic' speech could be elicited. As both the SCIT and the CAPS are mainly interested in measuring certain effects that the traumatic event has on the patient's behavior and attitude, many of the questions included in the interview can simply be answered with a 'yes' or a 'no' answer and do not necessarily require explanation and deeper reflection. Combined with the individual personalities of participants, this resulted in a wide range of word counts for all individuals. This difference in word counts might also be related to some participants use of avoidance mechanisms as a way of dealing with their trauma. In such cases the participants refrain from talking and thinking about the traumatic event as much as possible. In order to avoid such issues in the data collection, I would suggest that collecting the 'traumatic' speech data during a therapy session for example might be more effective. This way the participant would not only be encouraged to talk and think about their traumatic events under the supervision of a therapist that they have built a trusting relationship with, but the participant would also not be exposed to their traumatic events without it potentially contributing to their recovery. Thus a data collection completed in such a setting would also have the advantage of reducing ethical issues in its design.

Word Count		**Neutral**		**Traumatic**	
		Item Types	**Tokens**	**Item Types**	**Tokens**
PTSD	DL	265	760	185	458
	JS	396	1153	446	1430
	MK	408	1413	606	2575
	RP	242	662	212	629
	TN	299	797	256	736
	Minimum	**242**	**662**	**212**	**458**
TEC	KF	217	658	202	632
	SO	231	688	274	887
	TW	501	2012	295	922
	WD	235	620	205	510
	YO	174	410	156	346
	Minimum	**217**	**410**	**156**	**346**
Aphasia	adler16a	129	514		
	elman03a	205	661		
	elman06a	149	668		
	tap13a	120	517		
	tap19a	180	901		
	Total	**120**	**514**		

Table 11 - Word Count of Interview Transcriptions

8.0 Conclusion

The here presented study had asked whether there 'traumatic' speech of PTSD patients shows characteristics of Broca's aphasics patients' speech. The results show that there seems to be no significant difference in the way that the slope of the 'neutral' speech of PTSD patients differs from the slope of TEC participants. The only group that exhibits a significantly more gradual beta-slope are the Broca's aphasics.

Since no statistically significant effect could be observed for the speech of PTSD participants, but there nevertheless was a trend into he expected direction, this study should be replicated with a larger sample size as well as token count to determine whether or not these things are responsible for the observations being restricted to a trend. Furthermore the questions arise of whether or not the trauma was successfully elicited in the first place and whether or not the reduced blood flow to the Broca's area even has an effect on those functions located in the Broca's area that are under investigation. In order to answer these questions, future research should replicate the here presented study with the addition of brain-imaging machineries indicating the levels of blood flow to the Broca's area while the speech samples are collected. Only then will it be able to determine whether or not the blood flow to the Broca's area was indeed present in the PTSD participants' exposure to their trauma.

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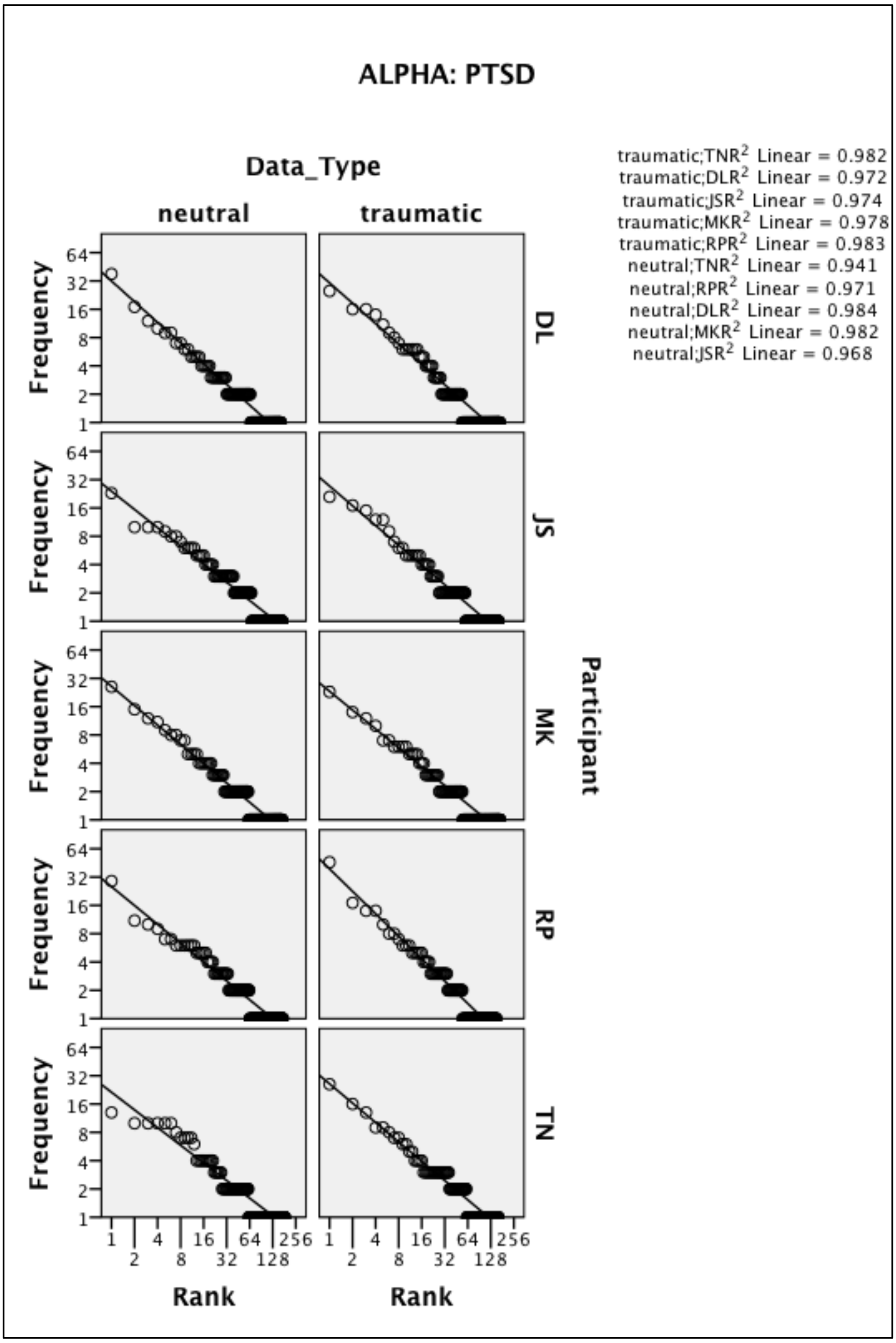
Appendix



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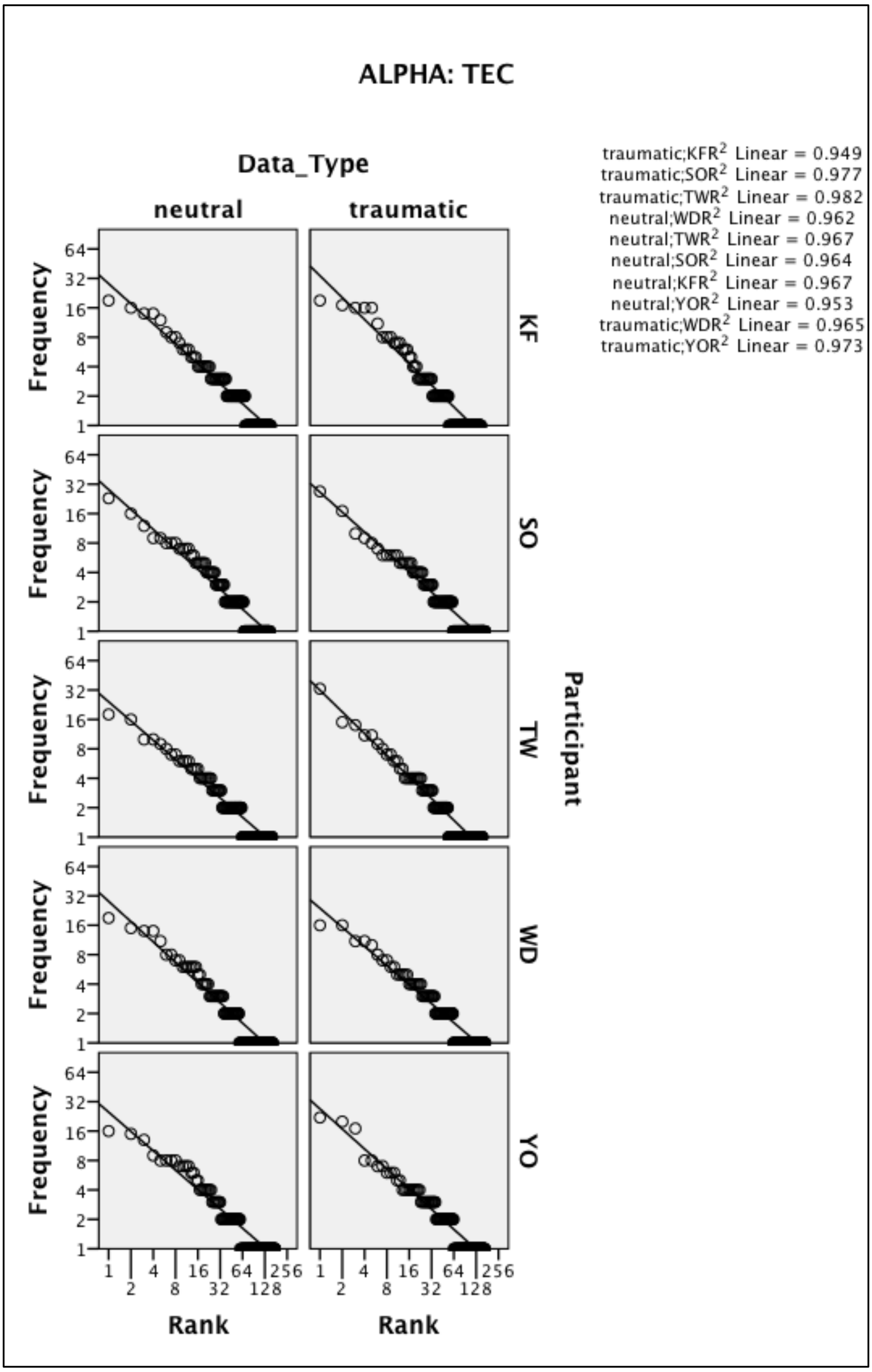

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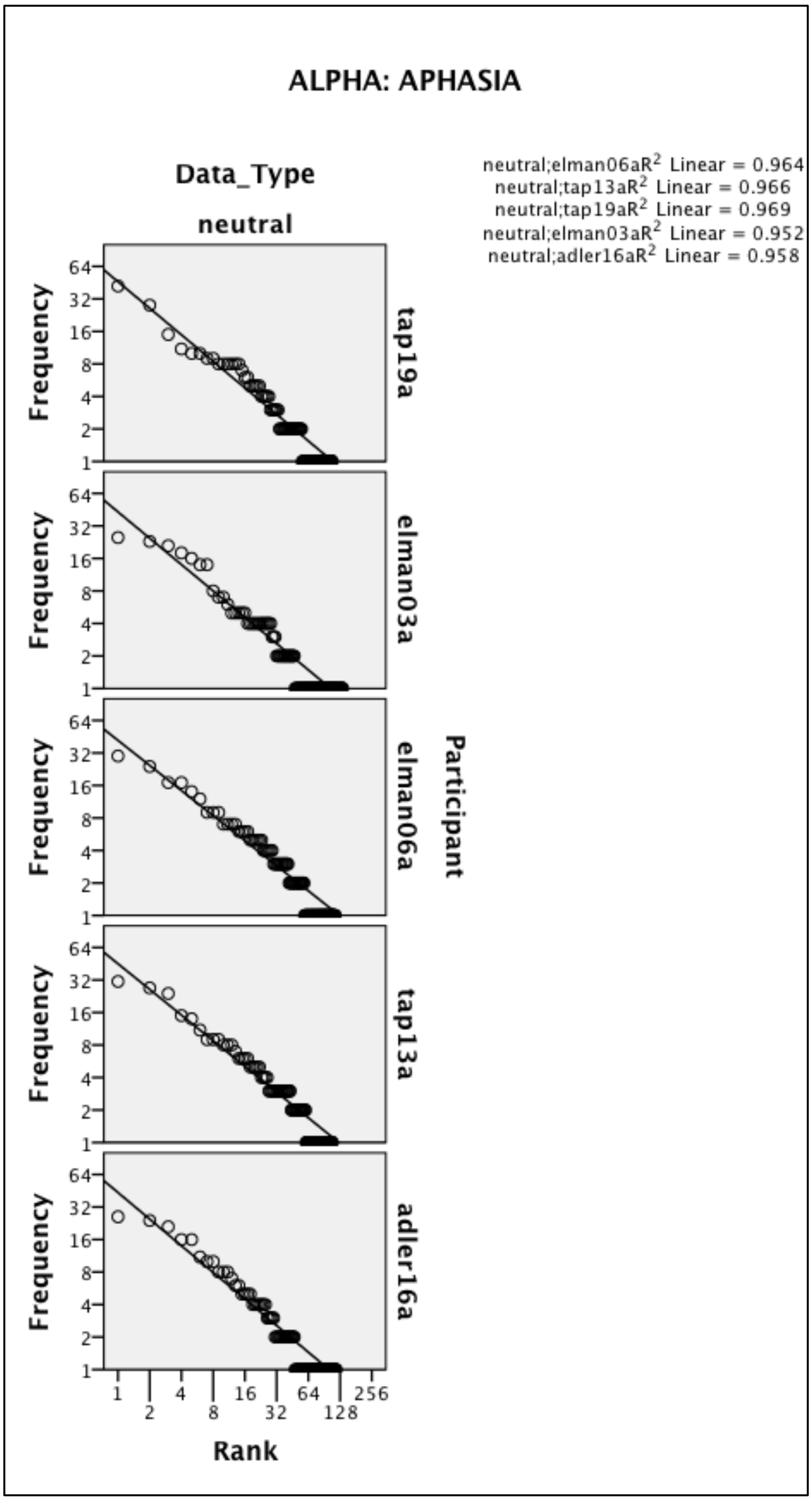
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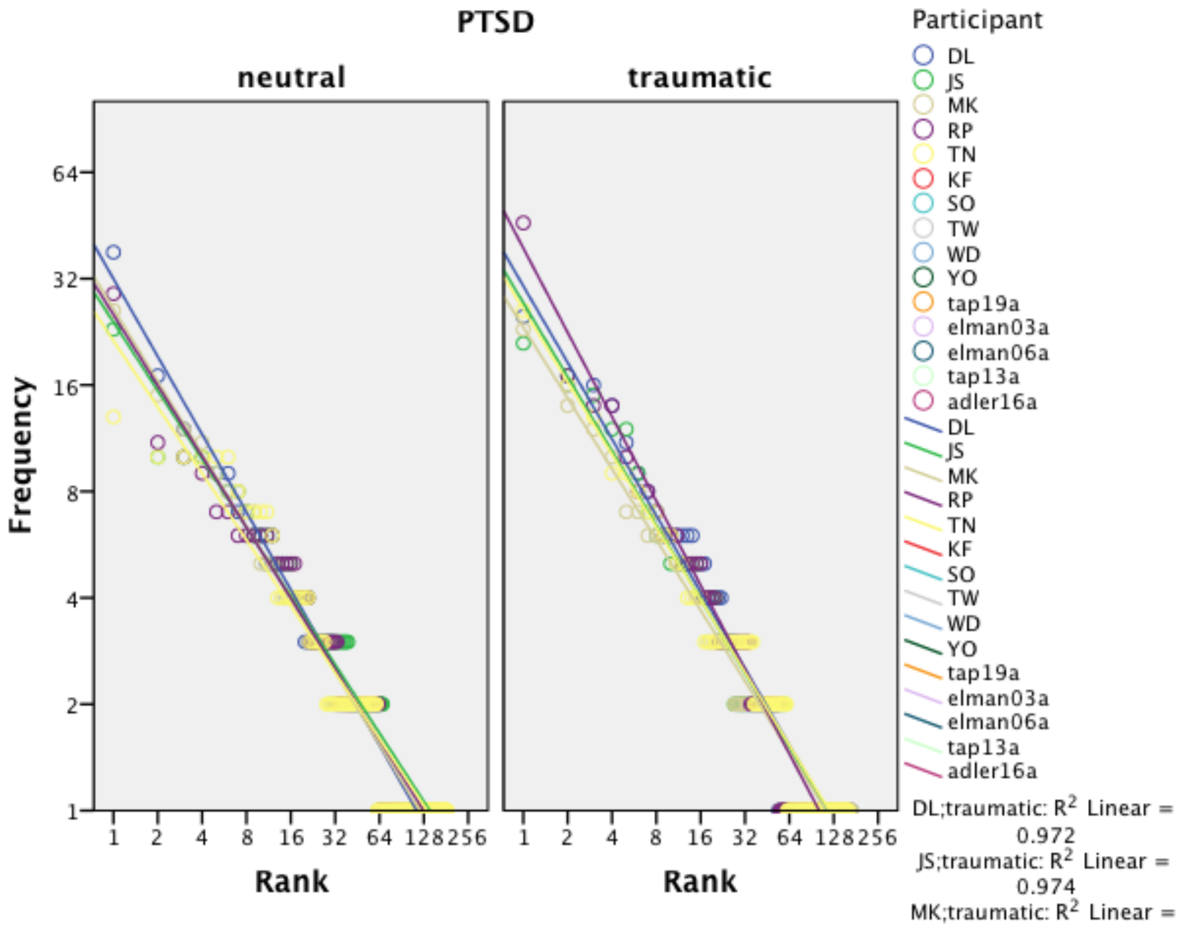
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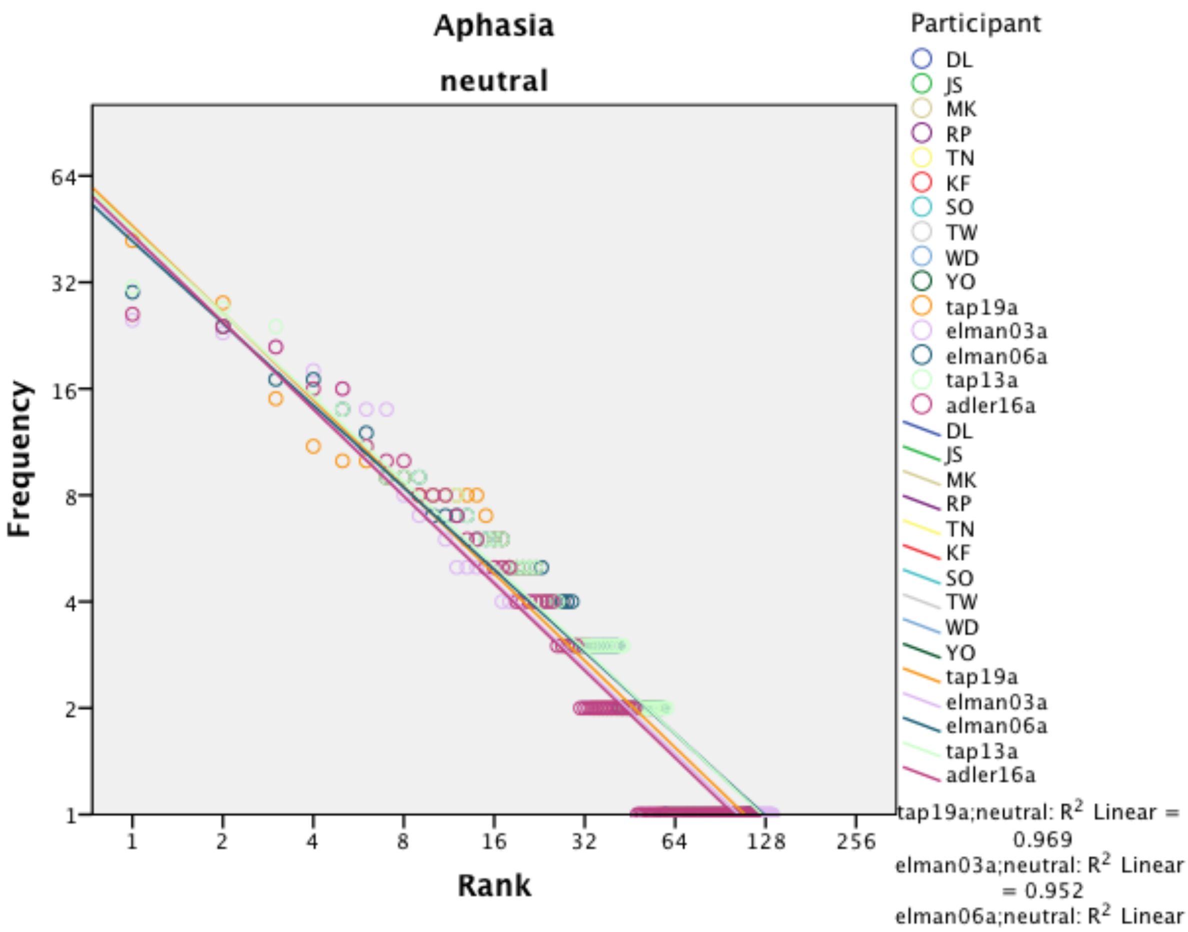
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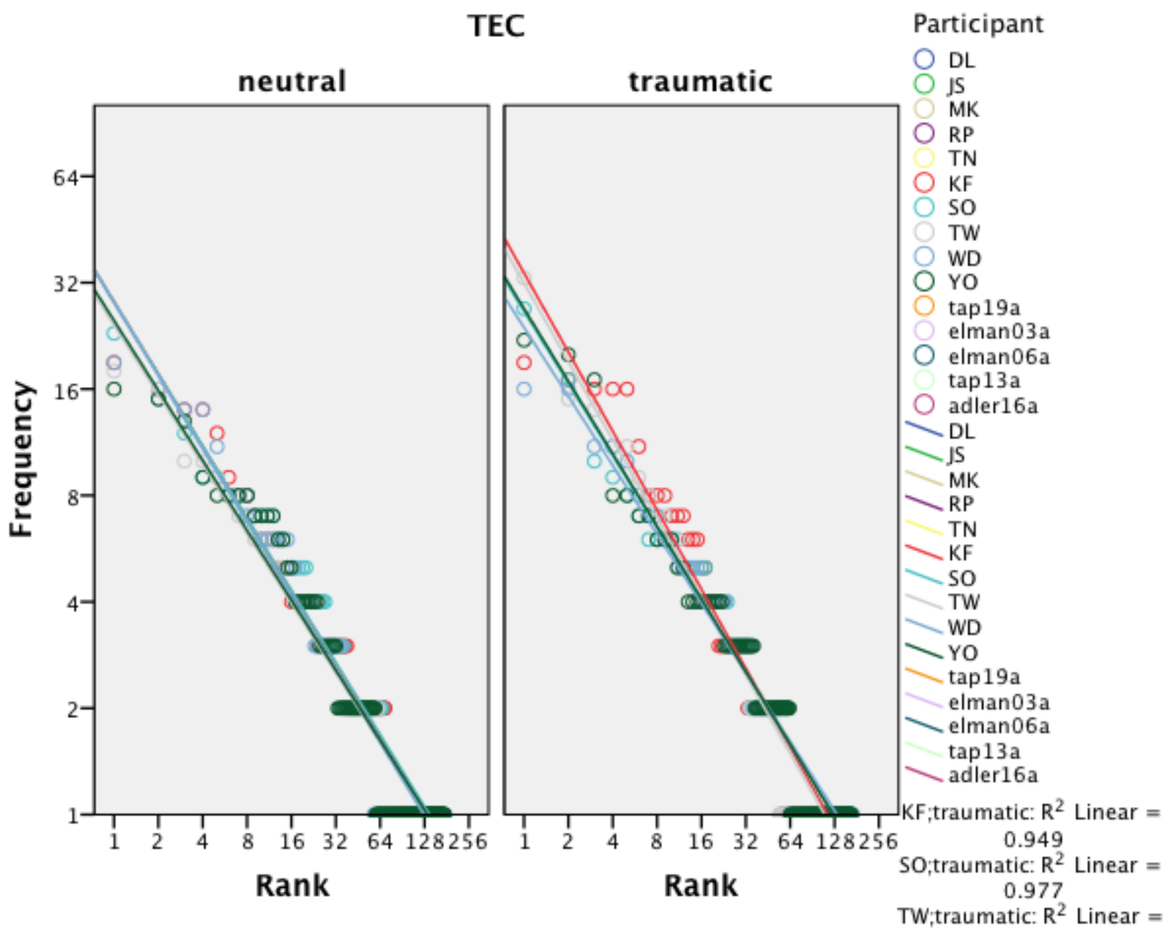
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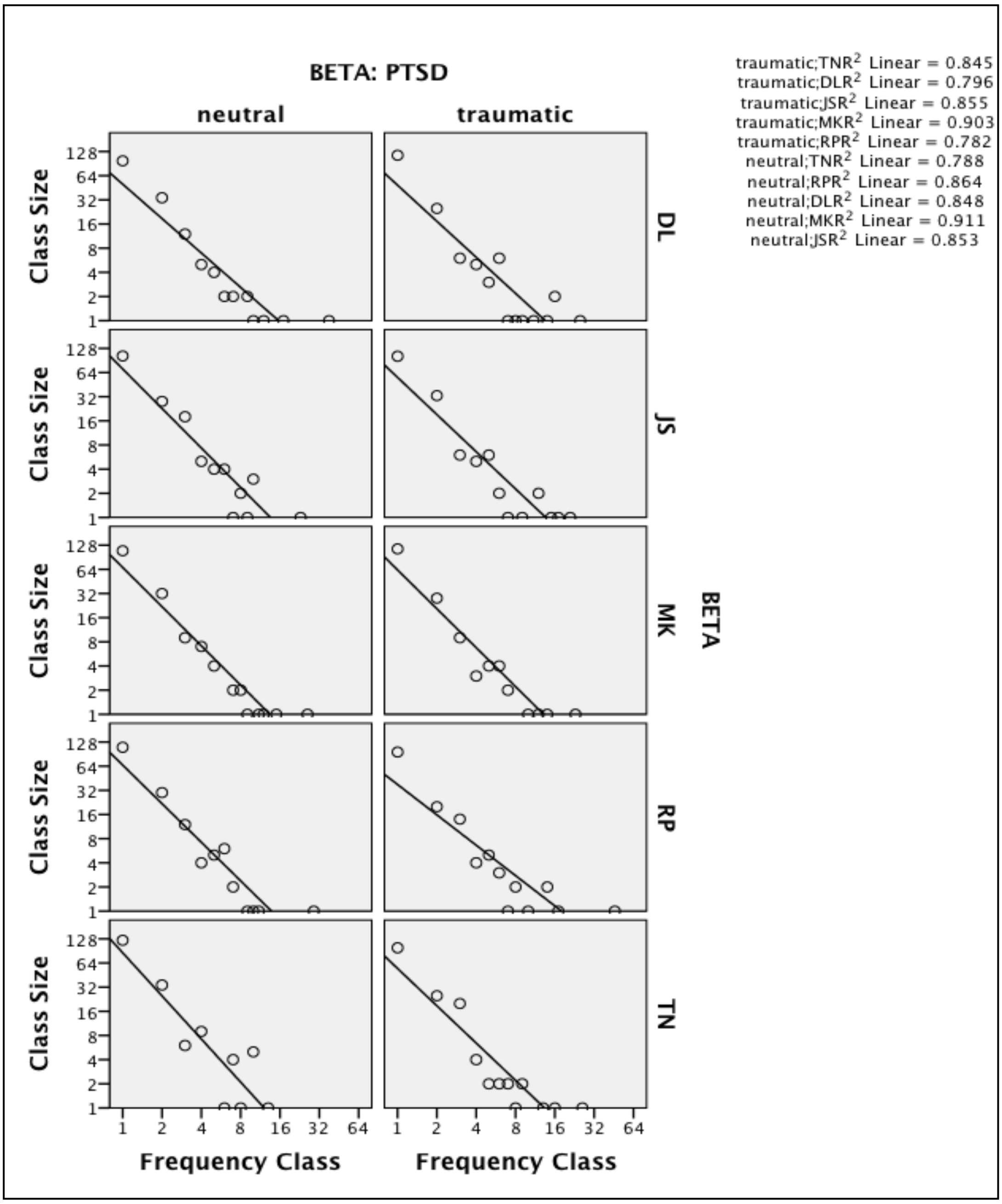
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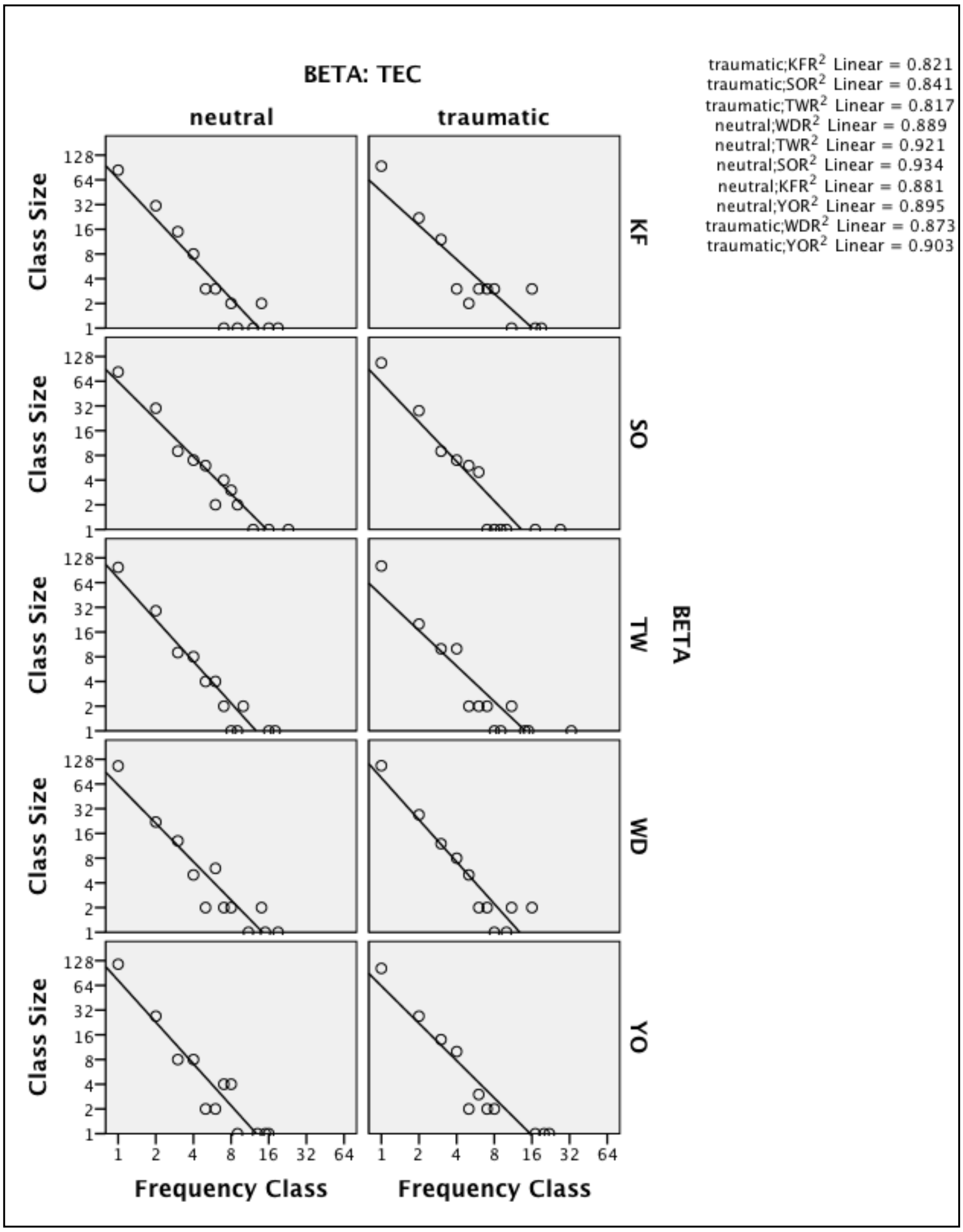
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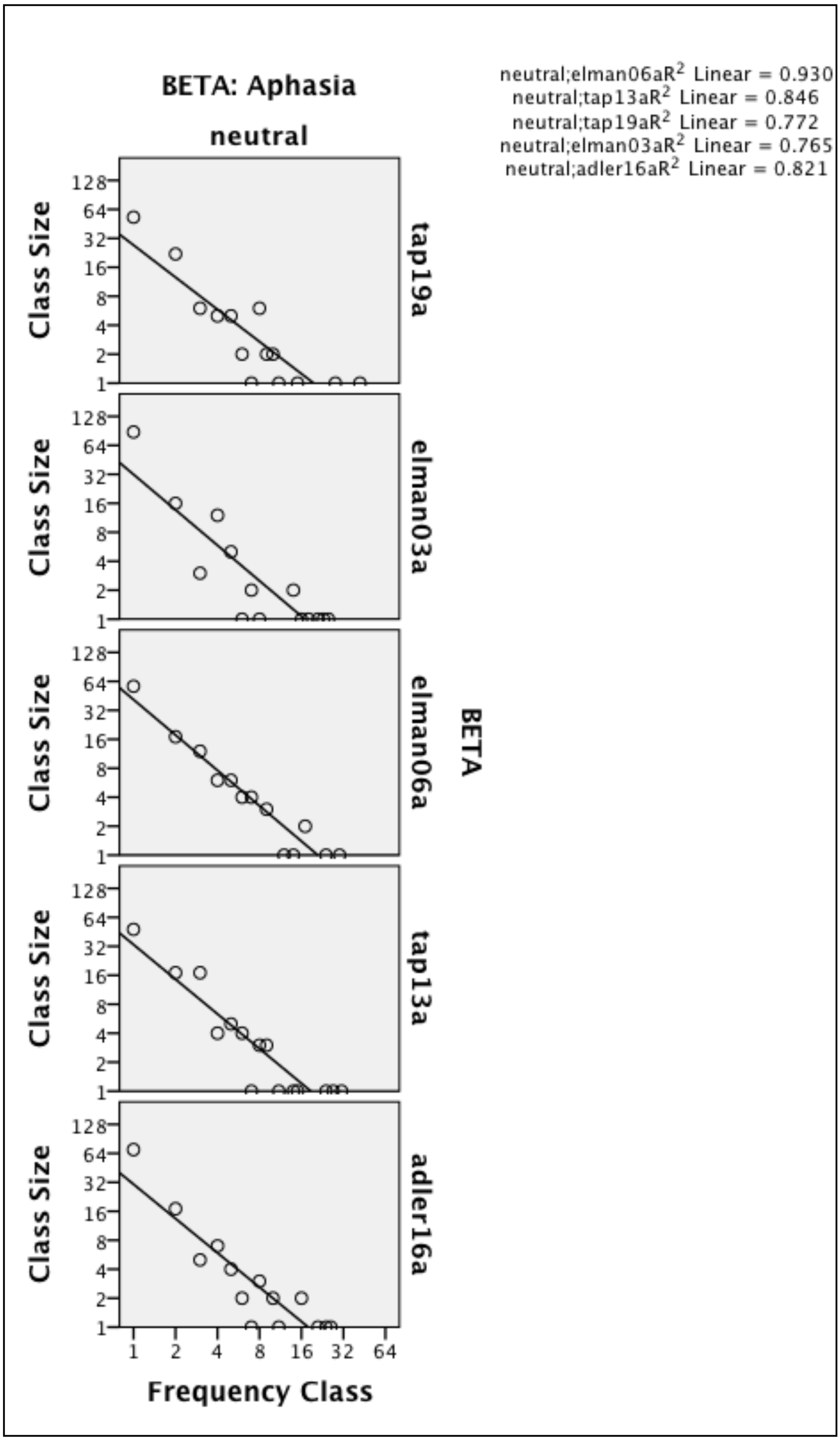
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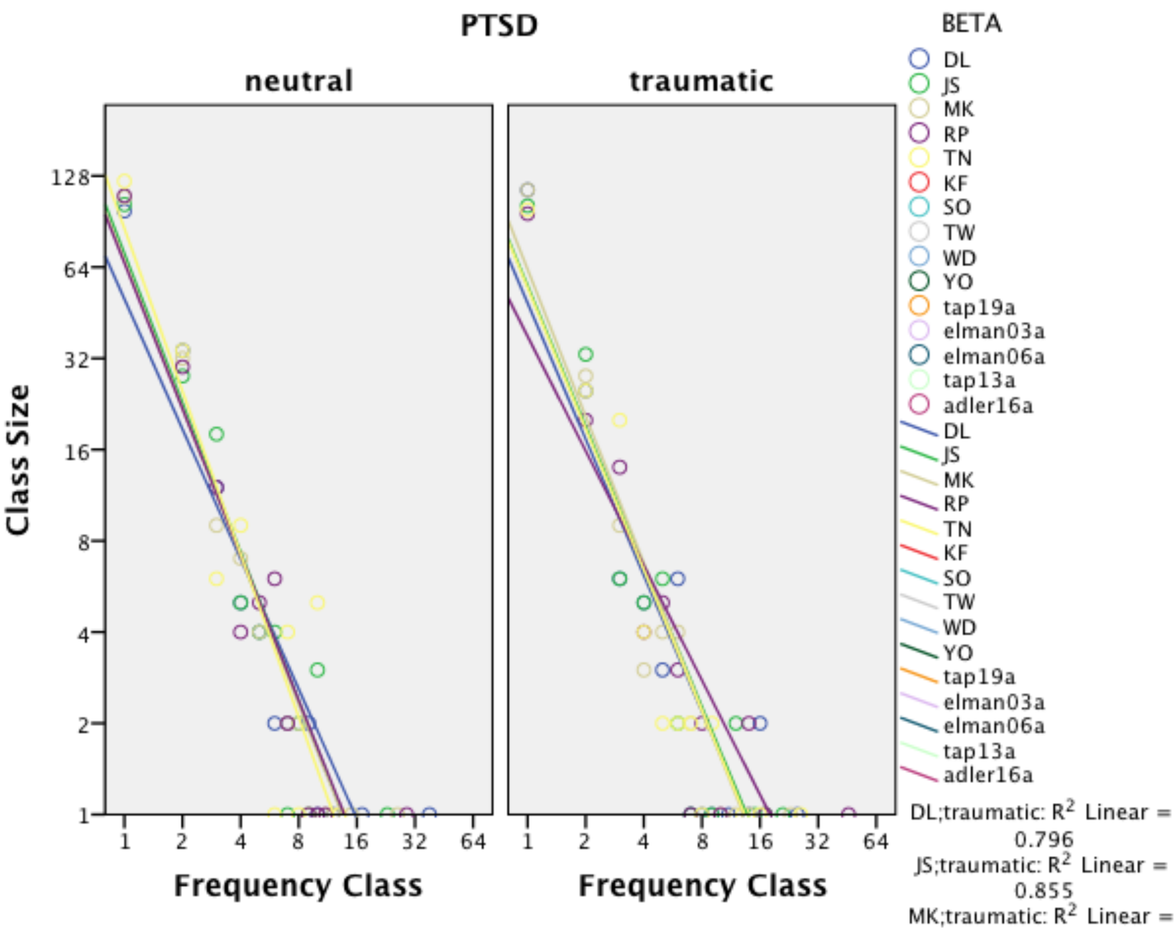

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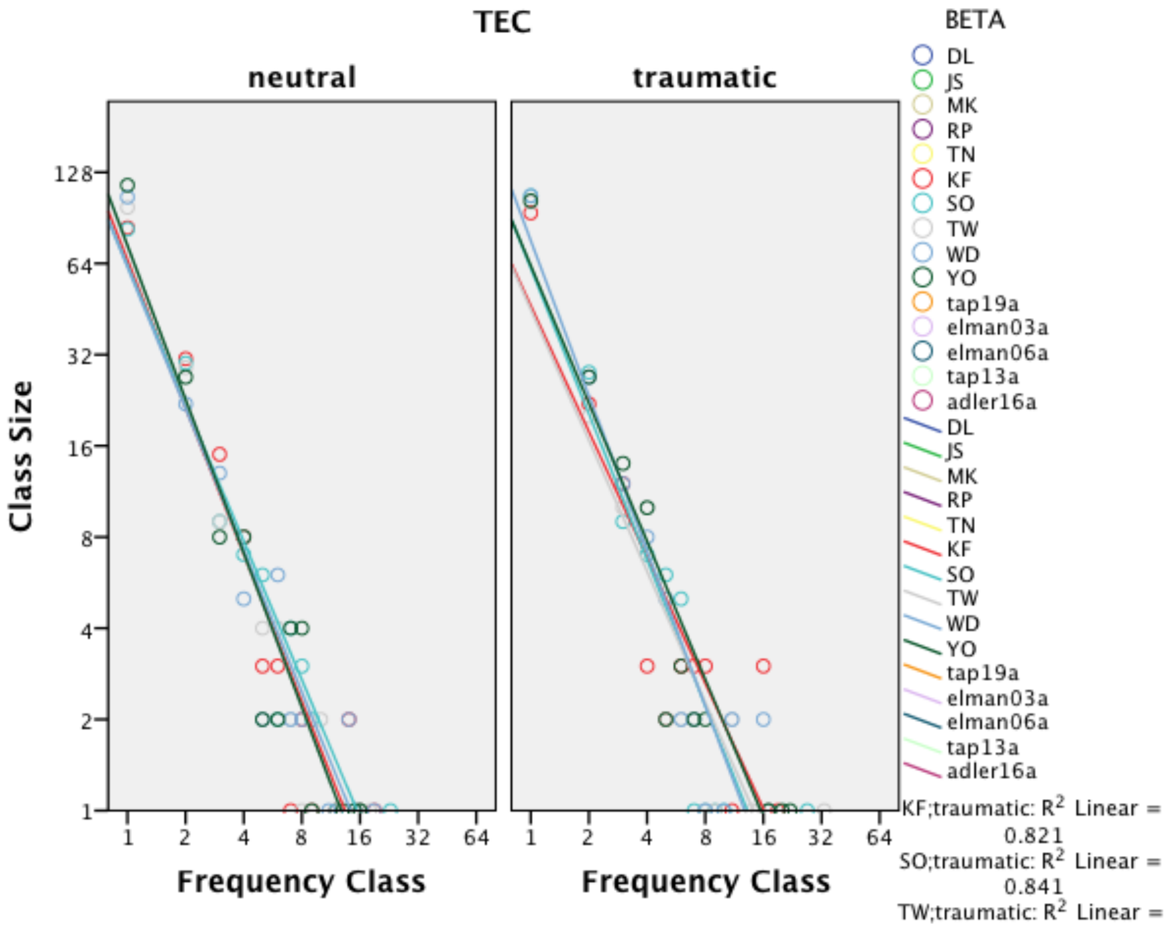
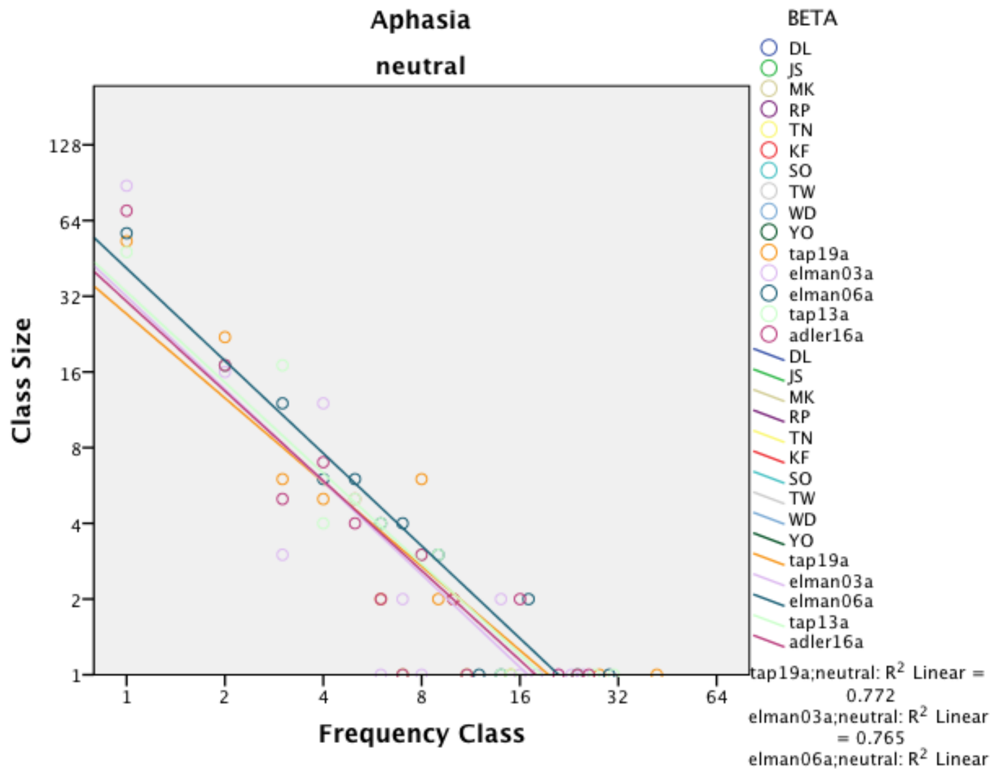
JS;traumatic: R2 Linear = 0.855
MK;traumatic: R2 Linear =



TEC
neutral
traumatic
BETA
DL
JS
MK
RP
TN
KF
SO
TW
WD
YO
tap19a
elman03a
elman06a
tap13a
adler16a
Class Size
Frequency Class
KF;traumatic: R^2 Linear = 0.821
SO;traumatic: R^2 Linear = 0.841
TW;traumatic: R^2 Linear =



Aphasia
neutral
BETA
DL
JS
MK
RP
TN
KF
SO
TW
WD
YO
tap19a
elman03a
elman06a
tap13a
adler16a
Class Size
Frequency Class
tap19a;neutral: R^2 Linear = 0.772
elman03a;neutral: R^2 Linear = 0.765
elman06a;neutral: R^2 Linear

Question Sheet

Hello my name is _______. How are you today? I'd like to have a little chat with you if you don't mind.

Topic: New York

Q: Are you a New Yorker?

If no, Q: Where are you from? For how long have you been living in New York?

Q: I have arrived in New York only a week ago. What are the sights that I should definitely see while I am here? Do you have any tips for me?

Q: Is there something you particularly like/dislike about New York?

Topic: Work

Q: What do you do for a living? Where do you work?

Topic: Summer Plans

Q: Do you have any summer plans yet?

Thank you so much for your time and I will make sure to check out all the things you have advised me. Have a good day.