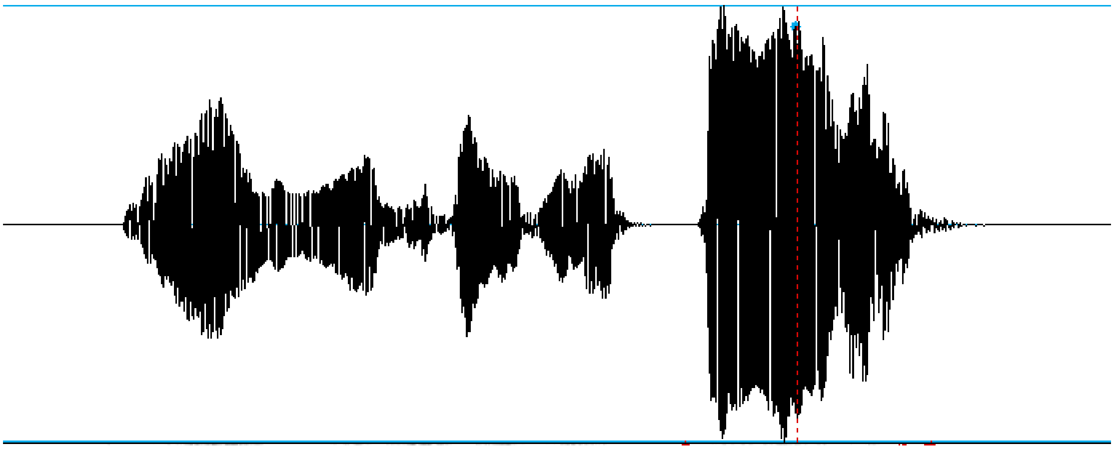
Analysis of VOT in Greek patients with non-fluent aphasia



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Abstract

The aim of the present study is to measure the Voice Onset Time (VOT) productions of Greek non-fluent aphasic patients, so as to determine whether they maintain discrete VOT categories as French non-fluent patients do (Ryalls et al. 1995), or if they exhibit deficits (overlapping or substitution of VOT categories) similar to those of English aphasic patients (Blumstein et al., 1977; the English study's results were also verified by the following languages: Thai (Gandour & Dardanranda, 1984), Taiwanese (Su et al.), and Turkish (Kopkallı-Yavuz et al., 2011).

VOT productions were measured, transcribed and compared for 10 Greek non-fluent aphasic patients and 10 Greek healthy speakers matched for age, sex, handedness and years of education. The statistical analysis revealed that our Greek non-fluent aphasic patients did not perform significantly different than our Greek healthy speakers. The non-fluent aphasic patients produced phonetic errors for the labial place of articulation in comparison to coronals and dorsals; however, the voicing effect results for the labial place of articulation were marginally significant (p=0.06) and therefore no generalizations are possible. Although previous studies have found that non-fluent aphasic patients produce significantly more phonetic errors for all places of articulation, the present study did not. Both Greek non-fluent patients and Greek healthy controls maintained distinct VOT categories similar to their French counterparts. However, we speculate that these results are the outcome of a methodological limitation and that our participants would have exhibited more phonetic errors if there had been more occurrences of voiced plosives in our data.

Keywords: *voice onset time, VOT, acoustic, non-fluent aphasia, Greek, spontaneous speech analysis*

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σὺν μυρίοισι τὰ καλὰ γίγνεται πόνοις

Euripides

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1. Introduction

Aphasia is an acquired language impairment which affects the production and/or comprehension of language at any (or every) of the following modalities: speaking, reading and writing, depending on its type (Broca, Wernicke, Conduction, Global etc.) and severity. The severity of aphasia can vary from moderate to mild to severe, and its cause is due to brain damage, induced either by a stroke accident, brain tumor or trauma. One of the prominent characteristics of the expressive language of aphasic patients is the production of speech errors. Predominately, two types of errors emerge as speech patterns in the aphasic production: (i) phonological errors, namely phonemic substitutions, additions, omissions or transpositions and (ii) phonetic errors, namely articulatory distortions of a target phoneme (Goodglass & Kaplan, 1972).

On the other hand, voicing, the articulatory process where vocal fold vibration is present (e.g. in voiced consonants) or completely absent (e.g. in voiceless consonants), accounts for minimal contrastive pairs that share the same place of articulation such as bilabial plosives [p – b], alveolar [t – d] and velar [k – g]. A feature of the production of plosive[1] consonants is that they have distinguishable ranges of Voice Onset Time in the healthy speakers' productions cross-linguistically. Voice Onset Time (henceforth VOT), is defined as *"the temporal relation between the onset of glottal pulsing and the release of the initial stop consonant"* (Lisker & Abramson, 1964; 1967, p. 2). The fact that distinct and different ranges of VOT productions, namely voiced and voiceless plosive consonants, emerge from healthy speakers' productions can be used to examine the phonemic and phonetic bases of aphasic speech errors. How can VOT be linked to aphasic speech production errors?

Blumstein and her colleagues (1980) were the first to investigate and link production errors of aphasic patients to VOT. Using VOT measures of English brain damaged patients, she demonstrated a large number of phonetic errors, that is overlapping of VOT values between the voiced and voiceless categories for the non-fluent (Broca's) aphasic patients and phonological errors, namely substitutions of VOT categories e.g. production of a target voiced with a voiceless VOT or vice versa, predominantly for the fluent (Wernicke's) aphasic patients. Her results were also verified by following studies in Thai (Gandour &

[1] The words plosive and stop are used interchangeably in the present study.

Dardanranda, 1984), Taiwanese (Su et al.), and Turkish (Kopkallı-Yavuz et al., 2011). However, when Ryalls, Provost and Arsenault (1995) replicated Blumstein's study for the French language, their results were far from convergent. French Broca's patients did not produce more phonetic errors; as a matter of fact they performed similarly to French healthy speakers. Given these divergent results between French and English we suggest that further research should be conducted on the topic and we chose to investigate the Greek language for this purpose.

Thus, the aim of the current study is to assess/analyze the Voice Onset Time (VOT) production of Greek non-fluent aphasic patients so as to determine whether they maintain discrete VOT categories as French non-fluent patients do (Ryalls et al. 1995), or if they exhibit deficits (overlapping of VOT categories) similar to those of English non-fluent aphasic patients (Blumstein et al., 1977; and Thai (Gandour & Dardanranda, 1984), Taiwanese (Su et al.), and Turkish (Kopkallı-Yavuz et al., 2011). Section 2 addresses the theoretical background of VOT productions of healthy speakers which serves as an integral part of making comparisons against the aphasic performance. Section 2 continues with a detailed analysis of the findings of VOT productions by aphasic patients. Sections 3 and 4 lays out the research questions, predictions and hypotheses of the present study. Section 5 pinpoints the experimental findings of VOT productions of Greek healthy speakers. Furthermore, sections 7 and 8 provide the methodology and results and lastly sections 9 and 10 present the discussion and conclusions of the current study.

2. Background

2.1. Voice Onset Time (VOT) in healthy speakers

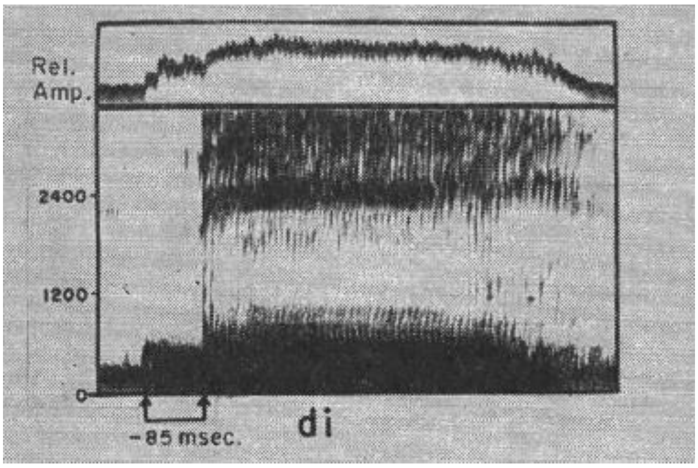
A number of studies have investigated the production of Voice Onset Time (VOT) in the productions of predominant the healthy and secondarily the impaired population. The latter is going to be the focus of the current paper. However, to get a full grasp on the linguistic performance of the aphasic population we first need to understand the underlying mechanisms of VOT in the healthy population.

VOT is the most prominent acoustic cue that distinguishes voiced from voiceless consonants across languages and this temporal characteristic of stop consonants reflects the complex timing of supralaryngeal coordination (Lisker & Abramson, 1964; 1967). Stop consonants have two voicing categories, namely voiced and voiceless, and they are classified into three groups according to their place of articulation. Thus the distinction of [p] and [b] which are bilabial stops, [t] and [d] which are dental stops and [k] and [g] which are velar stops. Taken to wide-band spectrographic analysis, VOT can point out a number of characteristics of the plosive consonants. Namely, three main categories of stops emerge from the VOT continuum (Lisker & Abramson, 1964; 1967):

(1) **Voicing lead**: voicing begins before the release[2] of the burst while the VOT values are negative, ranging from about -125 to -75msec, having a mean value of -100msec. Voiced and unaspirated consonants have voicing lead. For example, French and Greek voiced stops belong in this category (Bortolini et al., 1995; Ryalls, Antoniou, 2010).

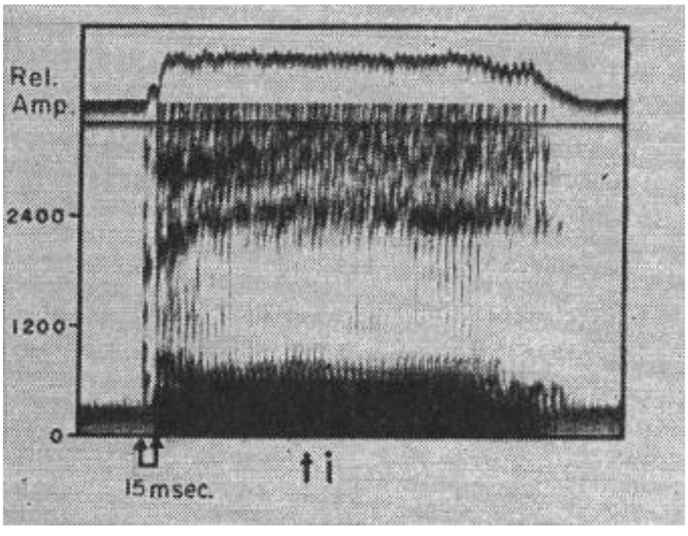
[2] Release: during articulation, the released airflow produces a sudden impulse causing and audible sound or burst.

Figure 1. Wide-band spectrogram illustrating the interval between the release of the stop and the onset of glottal vibration (viz the VOT) of [d] from Thai language. Picture extracted from Lisker & Abramson (1964).



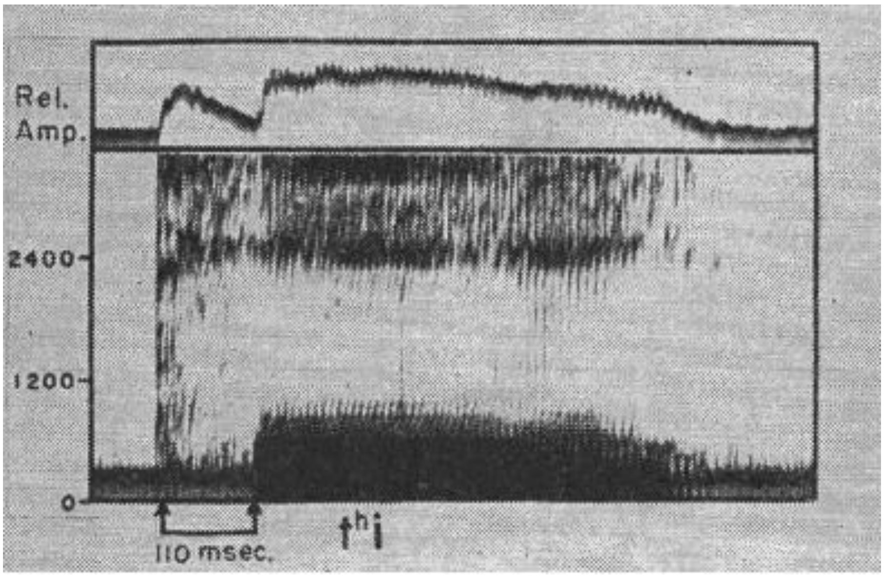
(2) **Short voicing lag**: voicing onset begins after the release of the burst while the VOT values are positive, ranging from 0 to +25msec, with a mean value of +10 msec. Voiceless and unaspirated consonants have short voicing lag. For example, English voiced stops and Italian voiceless stops belong in this category (Lisker & Abramson, 1964; 1967).

Figure 2. Wide-band spectrogram illustrating the interval between the release of the stop and the onset of glottal vibration (viz the VOT) of [t] from Thai language. Picture extracted from Lisker & Abramson (1964).



(3) **Long voicing lag**: voicing onset lags greatly after the release of the burst while the VOT values are positive, ranging from +60 to +100 msec, having a mean value of +75 msec. For example, English voiceless stops are of this type. Voiceless and aspirated consonants belong in this category (Lisker & Abramson, 1964; 1967).

Figure 3. Wide-band spectrogram illustrating the interval between the release of the stop and the onset of glottal vibration (viz the VOT) of [t^h] from Thai language. Picture extracted from Lisker & Abramson (1964).



VOT values have been measured and investigated within the normal population in several languages. Lisker and Abramson (1964) were the first to investigate the mean VOT values of 11 different languages' stop consonants in initial position followed by the vowel [a]. The different languages as reported in Lisker and Abramson (1964) were: American English, Dutch, Puerto Rican Spanish, Iberian Spanish, Hungarian, Tamil, Cantonese, Eastern Armenian, Thai, Korean, Hindi, Marathi. Those eleven languages fell into two groups depending on how many voicing contrasts they had for the distinction of voiced and voiceless dimensions. The languages which had a two voicing category contrast were: American English, Dutch, Iberian Spanish, Puerto Rican Spanish, Hungarian, Cantonese and Tamil (e.g. Spanish has a two way voicing category contrast [b –p], [t –d], [k –g]). The languages exhibiting a three voicing category contrast were: Korean, Eastern Armenian, Hindi, Marathi and Thai (e.g. Thai has a three way category contrast [b – p – p^h], [d – t – t^h], [g – k – k^h]). The fact that two distinct and different ranges of VOT responses, namely voiced and voiceless stop consonants, emerge by healthy speakers' productions can be used to examine the phonemic and phonetic bases of aphasic speech errors. Why and how VOT can be linked to aphasia follows in the next section.

2.2. VOT in aphasia

Blumstein and her colleagues (1980) were the first to investigate Voice Onset Time and its relation to aphasia. One of the prominent characteristics of aphasia is that the language productions of aphasic patients contain speech errors. It has been observed that those production errors are primarily of two types, namely phonological and phonetic. And most importantly, research in aphasia holds that these error types are linked to specific and distinct groups of aphasic patients (Luria, 1966; Goodglass & Kaplan, 1972; Blumstein 1973).

To be more specific, <u>phonological errors</u> involve substitution of phonemes or distinct speech sounds of a particular error (Luria, 1966). For example, a target phoneme [g] has a VOT range of -25msec to +25msec for a native English healthy speaker. Its voiceless homorganic counterpart [k] has a VOT range of +45msec to +65msec (Lisker & Abramson, 1964; 1967). If a target [g] produced by an aphasic patient has a VOT value of +60msec then this is considered a *substitution error* because the value of the target sound falls into the range of the opposite category. Meaning that the VOT value was expected to be between -25msec to +25msec in order to be considered a [g], instead the VOT value of +60msec falls within the range of [k], which is +45msec to +65msec and that is why such an error is considered phonological. According to previous literature, phonological errors are typical of the *posterior fluent aphasics* or else Wernicke's aphasics (Luria, 1966; Goodglass & Kaplan, 1972).

On the other hand, <u>phonetic errors</u> "*represent articulatory distortions of a particular phonemic target"* (p. 154, Blumstein, 1973; Luria, 1966). For instance, a [g] target produced with a VOT of +30msec is considered a phonetic error because its value falls between the two categories [g]: -25msec to +25msec and [k]: +45msec to +65msec (Lisker& Abramson, 1964; 1967). A +30msec VOT value for a [g] target does not occur in the phonetic system of the English language and that is why such an error is considered phonetic. These types of errors are characteristic of *anterior non-fluent aphasics* or else Broca's aphasic patients (Luria, 1966). According to Blumstein (1980) the underlying reason of phonetic errors is a deficit in the articulatory programming that causes an overlapping of VOT categories in the productions of non-fluent aphasic patients.

However, despite the linguistic profile often given to each aphasic group, Blumstein (1973) pinpoints that in actuality Broca's and Wernicke's patients produce both phonemic and phonetic speech errors. She proposed that there is no clear and no exclusive phonetic error tendency over the non-fluent patients' productions. Blumstein claimed that *an error in voicing for example [g] as [k] could either reflect the substitution of one phonemic category for the other and thus be phonological in nature, or in contrast, could reflect a low-level timing error which would be articulatory or phonetic in nature* (p.154, 1980). Nevertheless, with regard to non-fluent aphasic patients, it could be the case that their phonological errors are an extreme version of phonetic errors being the aftermath of articulatory phonetic distortion since their speech is in general slow and laborious. To investigate the type of error produced by aphasic patients, Blumstein (1980) chose to measure the acoustic dimension Voice Onset Time which signals the distinction between voiceless and voiced consonants.

Participants' selection included 4 Broca's aphasics, 4 conduction aphasics, 5 Wernicke's aphasics, one patient with dysarthria yet not aphasic and 4 healthy individuals who served as the control group. The dysarthric patient was included in the study because Blumstein (1980) wanted to establish that phonetic errors at least for the non-fluent patients are indeed affected by the patient's lesion in the brain and not by the motor problems often accompanying anterior aphasia. Subjects were English native speakers. Participants were asked to read a list of words containing initial stops followed by the vowel [a] (see p. 157, Blumstein 1980 for the full list of words). The consonant contrasts investigated were bilabial plosives [b] and [p], alveolar [d] and [t], and velar [g] and [k]. Participants were tested in two sessions. Each trial consisted of a full set of the words containing each consonant in initial position preceded by the word "this". In other words, the testing material consisted of a stimulus card which had the word "this" followed by the test item. Participants were asked to read the phrase two times per session, thus four times in total. For each participant a minimum of 240 VOT tokens was analyzed.

First of all, the analysis verified that English healthy controls produced neither phonetic nor phonemic errors. In general, both controls and Wernicke's patients revealed no overlapping distributions of VOT between the two categories (voiced and voiceless). The range of the category boundaries found for each place of articulation were the following.

The voiced labial consonants had a VOT range of -105 to +15msec and the voiceless category +35 to +150 msec. The alveolar consonants had a VOT range of -105 to +20msec while the voiceless category had a range of +40 to +150 msec. As for the velar consonants the VOT values ranged from -105 to +25msec for the voiced category and from +45 to +150msec for the voiceless category.

As far as the Wernicke's patients are concerned, they were mildly impaired with errors distributed equally between the phonemic (4%) and phonetic errors (4%). According to Blumstein, Wernicke's patients appear to make few production errors and furthermore they do not make substantial phonemic paraphasias in their productions. On the contrary, Broca's aphasics made primarily phonetic errors (26% versus 14% of phonemic errors).

The authors investigated the distribution of the correct target productions as well. The distribution for each of the voiceless consonants produced was significantly different for the Broca's group. The voiceless consonants were distributed over a wider VOT range in comparison to Wernicke's patients and controls. As far as the distribution of voiced consonants is concerned, Broca's aphasics produced fewer pre-voiced consonants in comparison to Wernicke's aphasics. This result could be attributed to an overall articulatory difficulty of initiating vocal fold vibration and this could be also linked to the longer VOTs observed in the distribution of voiceless consonants. The authors concluded that (pg. 164) *the Broca's aphasics have a pervasive phonetic disorder which is not only manifested directly in the large number of phonetic errors, but is evident also in the productions falling within the "correct" target range.*

Last but not least, the authors provided further insight on whether the phonetic deficit of the Broca's patients reflects a speech deficit or a motor control problem. To do this, they compared the results of their Broca's group to those of a non-aphasic dysarthric patient. The pattern of productions was qualitatively different between the two groups. The dysarthric patient produced longer VOT values in general. The VOT range of both voiced and voiceless categories, as provided above, ranges from -105 to +150 for a healthy English speaker. The dysarthric patient produced VOT values beyond the -150 to +150msec interval and exhibited no overlap of voicing categories, in contrast to English Broca's patients.

Following Blumstein's study (1980), further research investigated the VOT productions of aphasic patients in different languages, Thai (Gandour & Dardarananda, 1984), Taiwanese (Su et al., 1992), and Turkish (Kopkallı-Yavuz et al., 2011) in order to expand and provide further insight on the phenomenon cross-linguistically (see Table 1). The majority of these studies verified Blumstein's results in that (a) Wernicke's patients maintain discrete VOT categories and (b) Broca's patients' VOT productions overlap. However, there is an exception among these convergent studies.

Ryalls, Provost and Arsenault (1995), investigated VOT productions by aphasic patients for the French language and had different results. Their French aphasic patients exhibited no overlapping and VOT categories were kept intact. The authors tested 5 Broca's, 5 Wernicke's and 5 healthy native French controls matched for age and sex. Test items were 18 monosyllabic words where the consonants [p], [t], [k] and [b], [d], [g] in initial position were followed by the vowels [i], [a], and [u] (see p. 207 for the full list of test items). The mean VOT values (and not ranges) of the French stops were provided by the study. The mean of the voiceless bilabial consonant [p] was +45msec and its voiced counterpart [b] was -140msec. The voiceless alveolar [t] had an average VOT value of +51msec and its counterpart voiced [d] a VOT value of -142msec. Lastly, the velar pair, voiceless [k] had an average of +72msec and the voiced [g] and average VOT of -146msec.

Table 1. Accumulations of studies that have investigated VOT productions of aphasic patients.

Study	**Language**	**Voicing Category Contrasts**	**Type of Aphasia**	**Overlapping of VOT categories**
Blumstein et al. (1980)	English	Two-way: Voicing lead, voicing lag	Broca, Wernicke, Conduction	**B: Yes** W: No C:Yes
Gandour & Dardarananda (1984)	Thai	Three-way: Voiced unaspirated, Voiceless unaspirated, Voiceless aspirated	Broca, Wernicke, Conduction, Global, Transcortical motor	**B: Yes** W: No
Su et al. (1992)	Taiwanese	Three-way	Broca, Wernicke, Conduction	**B: Yes** W: No C:No
Ryalls, Provost & Arsenault (1995)	French	Two-way: Voicing lead & voicing lag	Broca & Wernicke	**B: No** W: No
Kopkallı-Yavuz et al. (2011)	Turkish	Two-way: Voicing lead & Voicing lag	Broca	Yes

All in all, the French study did not find any differences between their groups. VOT productions were fairly similar to those of healthy controls for both Broca's and Wernicke's aphasics in that there was no overlapping of VOT values. French aphasic patients kept their VOT categories distinct. For Broca's an average of 91% of the productions was correct and an average of 92% for the Wernicke's patients. To add to this result, French Broca's aphasics produced fewer phonetic errors (4%) compared to the Broca's of the English study (24%). The French study's results contradict the general expectation of non-fluent aphasic patients exhibiting a phonetic impairment.

Phonetically, both French and English have two distinct voicing categories, voiced and voiceless stops. French is a language with voiced consonants typically produced with a voicing lead. This means that voicing begins before the release of the stop and this translates to negative VOT values (Lisker & Abramson, 1964). On the contrary, in English voiced consonants are typically produced with a voicing lag. This means that voicing begins after (lags) the release of the stop which translates to positive VOT values (Lisker & Abramson, 1964). As already mentioned, the English studies' results showed overlapping of VOT categories for the non-fluent aphasics and justified this outcome as a speech error (phonetic deficit) than a low-level motor control problem. On the other hand, the French study's results (Ryalls et al., 1995) found no overlapping, instead the patients had kept intact their VOT categories.

One of the arguments proposed by the French study was that perhaps the reason why French Broca's patients did not display an overlap between the two VOT categories, may be linked to the negative VOT values of French voiced consonants. To be more specific, French voiced consonants have negative VOT values and thus have a bigger difference in the range between voiced and voiceless plosives. Conversely, English voiced stops have positive VOT values and thus a smaller difference between the two categories is evident. Consequently, English Broca's speakers have to cover a smaller range of values when articulating stop voiceless and voiced pairs and that might trigger their overlapping phonetic deficit. Instead, French Broca's patients who have to cover a much larger difference, maintain distinct VOT categories.

It was also implied that the divergent results between the French and English Broca's populations' results might be due to the difference in the classification of the severity of the type of Broca's aphasia. Blumstein et al. (1980) did not provide information on the severity of her Broca's aphasics while Ryalls et al. (1995) classified their Broca's patients as mildly impaired. Given that information, severity might play a role in the linguistic profile and VOT results of non-fluent aphasic patients.

It was also suggested that more languages with negative VOTs should be tested in order to gain further insight into whether bigger VOT values between minimal phonetic pairs affect the type of the speech error for Broca's patients. In other words, whether a difference in VOT ranges among languages could be the reason behind the discrepancy in the findings. Kopkallı-Yavuz and colleagues (2011) investigated the VOT productions of Turkish non-fluent aphasic speakers. Turkish voiced stops are also produced with a voicing lead (negative VOT) similarly to French. If Turkish Broca's patients were to keep distinct VOT values for the voiced and voiceless categories, then the French study's suggestion that a difference in the VOT range between voiced and voiceless consonants is the underlying reason which triggers or not the phonetic deficit, could be verified. However, that was not the case. Turkish non-fluent aphasics did not maintain distinct VOT categories. On the contrary, an overlapping of VOT categories was evident.

Thus, Ryalls' suggestion that differences in VOT ranges among languages being the underlying reason was not verified. What could be the reason behind such an outcome? Both Turkish and French have similar phonetic profiles given that voiced consonants are produced with a voicing lead (negative VOT values). Nevertheless, looking closer to each study's results we can see that the VOT ranges between the two languages differ. In French, the average VOT differences reported between the voiced and voiceless categories is remarkably larger than in Turkish. To be specific, for French the average difference for bilabials is 185msec, for alveolars 193msec and for velars 218msec. Instead for Turkish, the average difference is much shorter; for bilabials is 107msec, for alveolars is 103msec and for velars is 79msec. Perhaps a larger VOT difference between voiced and voiceless consonants could be a factor in the discrepancy of the findings regardless of the fact that both languages have negative VOT values for the voiced consonants.

Nonetheless, the Turkish study had a number of limitations. The authors did not recruit healthy participants as controls to compare them to their non-fluent population. Kopkallı-Yavuz used as a control group the results of another study (Öğüt et al. 2006). The data from Öğüt and colleagues involved VOT productions of 33 healthy Turkish individuals who had to read 48 monosyllabic words. Plosives [p], [t], [k], [b], [d], [g] were in initial position followed by vowels [α], [e], [œ], [o], [u], [ɯ], [y], [i]. Kopkallı-Yavuz's test items were also 48 monosyllabic words in total. The test items were different between the two Turkish studies. What is more, the participants were determined as non-fluent based on their linguistic performance from a composite aphasia examination adapted in Turkish (ADD: Maviş & Toğram, 2009) and not through a neurophysiological classification. Based on patients' MRI scans the list of participants included Wernicke's, global and anomic patients even though in the study they were classified as non-fluent based on their linguistic performance.

Together, the findings discussed above call for further investigation on the topic. In the present study, we investigated a language where voiced stops are also produced with a voicing lead – Greek. Both healthy and non-fluent Broca's aphasic speakers participated in the same experimental design (narration of multiple stories, see Section 7 for further details) and their VOT productions were analyzed. Wernicke's patients were excluded from our study because as provided from the above mentioned studies their productions were not divergent and their performance was similar to healthy speakers.

3. Research Questions

Greek has two distinct voicing categories, as do English and French and Turkish, and voiced consonants produced with negative VOT values (Kollia, 1992; Raphael et al., 1995), similar to French and Turkish. Thus, Greek makes an ideal candidate to investigate VOT productions in order to find out firstly, whether Greek non-fluent patients indeed make VOT production errors and secondly, if they produce speech errors, of what kind they are. Do Greek non-fluent aphasic speakers produce phonetic errors, namely overlapping of VOT categories or do they make substitution errors between the voiced and voiceless categories and thus exhibit a phonological deficit? To our knowledge, there is no study that has looked into the analysis of VOT in non-fluent aphasic patients for the Greek language so far. The focus of our study is to give answers to the following research questions, hypotheses and predictions:

1. *Do Greek non-fluent aphasic patients produce longer VOTs than healthy controls?*
2. *Do Greek non-fluent patients maintain discrete VOT categories (as their French counterparts do) or do they exhibit overlapping of VOT categories (as their English counterparts do) in comparison to healthy controls?*

The first research question serves as a “board”, to differentiate whether the aphasic population’s productions differ from the healthy speakers in the first place. Once this difference is established our aim is to zoom in the phonetic profile of the aphasic patients. If they maintain discrete VOT categories, then they behave akin to healthy controls and their French counterparts meaning that articulation or other deficits do not interfere with Greek aphasics’ productions and articulation is kept intact. However, if Greek non fluent aphasic patients exhibit an overlapping of VOT categories at their English counterparts (and Taiwanese, Thai, and Turkish non-fluent aphasics) then the English study’s suggestion that the underlying deficit of Broca’s patients is phonetic in nature is verified by Greek, as well.

4. Hypothesis and Predictions

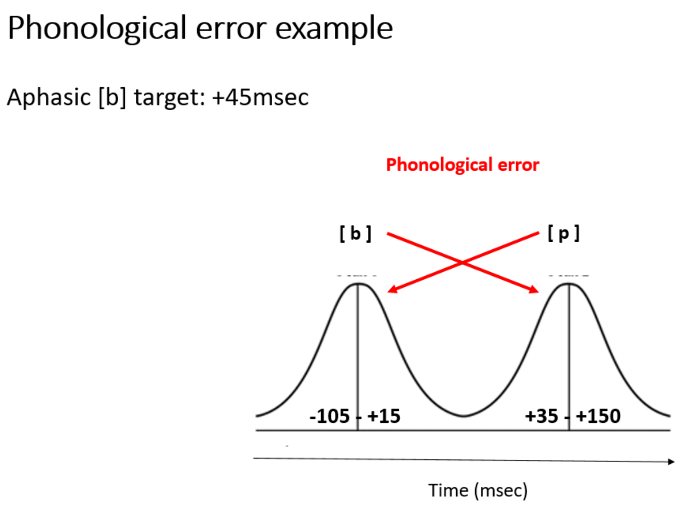
The first research question’s hypotheses and predictions are:

- H_0 : Greek non-fluent aphasic patients produce equally long VOT values compared to healthy controls.
- H_1: Greek non-fluent aphasic patients produce longer VOT values compared to healthy controls.

The second research question’s hypotheses and predictions are:

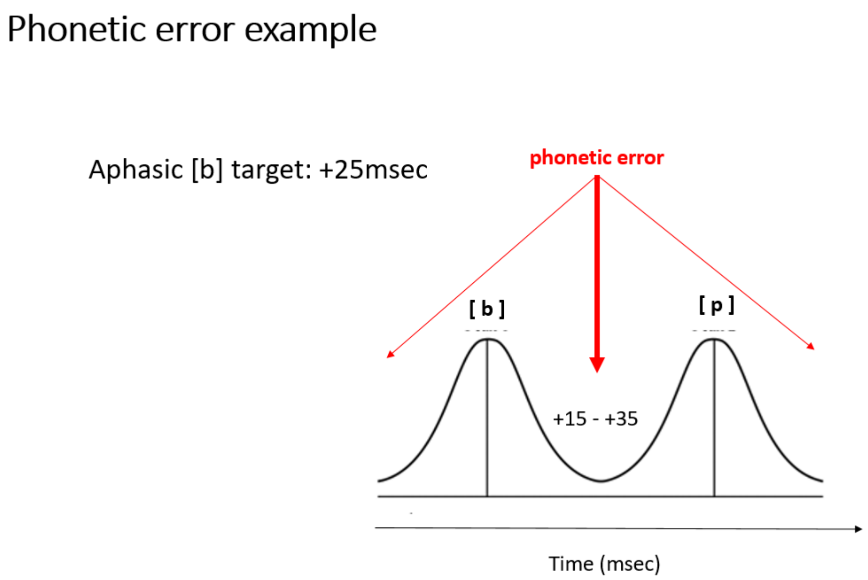
- If the VOT values lie **within the normal range** of the category opposite the target (e.g. production of a target voiced stop with voiceless VOT value, or vice versa; Figure 2), then this is considered a substitution error. Substitution errors are considered to reflect a phonological deficit (Goodglass & Kaplan, 1972; Blumstein et al.1980). If this is verified by our results, then Greek non-fluent aphasic speakers exhibit a phonological/substitution deficit.

Figure 1. Example of a phonological error. Hypothetically, the VOT values of labial voiced [b] place of articulation range from -105msec to +15msec and for its voiceless counterpart [p] from +35msec to +150msec for a Greek healthy speaker. If a non-fluent aphasic patient produces a [b] target with a +45msec VOT, then this number falls in the opposite category ([p]) and this is considered a phonological error. The VOT numbers are arbitrary.



- If the VOT values produced by Greek non-fluent aphasic patients lie **between or outside the two normal ranges** of the voiced and voiceless categories, then this is considered a phonetic error. This overlapping of VOT categories is triggered by a deficit in the articulatory planning and reflects a phonetic deficit (Luria, 1966; Goodglass & Kaplan, 1972, Blumstein et al. 1977l 1980).

Figure 2. Example of a phonetic error. Hypothetically, the VOT values of labial voiced [b] place of articulation range from -105msec to +15msec and for its voiceless counterpart [p] from +35msec to +150msec for a healthy Greek speaker. If a non-fluent aphasic patient produces a [b] target with a +25msec VOT then this number falls between the two normal [p – b] ranges and is considered a phonetic error. The VOT numbers are arbitrary.



- If the mean VOT values of Greek non-fluent aphasic patients are the mean VOT values of Greek healthy controls then this means that Greek aphasic patients maintain distinct VOT categories and perform similar to their French counterparts and akin to Greek healthy speakers.

5. VOT in Modern Greek

Results on VOT in Modern Greek are sparse. This section presents findings collected from studies investigating Greek consonants that include segments of VOT analysis. Yet there is still not a study that has entirely examined VOT in Greek healthy speakers, at least to our knowledge. This section is of great importance in order to establish what VOT values and ranges have been found thus far in productions of Greek healthy speakers so as to compare the findings with our results.

Greek has two distinct voicing categories, voiced and voiceless stops. The voiceless stops of Greek, [p], [t] and [k], are unaspirated plosives produced with a short lag (Fourakis, 1986; Kollia, 1993). In addition, [p] has the longest closure of the three stops and the shortest VOT; reversely [k] has the shortest closure and longest VOT and [t] is intermediate between the two (Fourakis, 1986a, 1986b; Arvaniti, 1987, 2001c; Botinis et al., 2000; Nicolaidis, 2002b). This information falls in line with the universal evidence/tendency of velar consonants having the shortest VOT ranges and bilabial consonants having the longest VOT ranges. According to Arvaniti (2007) closure duration for [t] is longer before [i] than before [a] and VOT for both of [p] and [t] is longer before [i] than [a]. Table 2 presents an accumulation of findings of mean VOT values for Greek voiceless consonants from a series of studies (Antoniou, 2010; Arvaniti 1987; 2001c; Kollia, 1993; Nicolaidis, 2002c; Fourakis, 1986b). According to Botinis, Fourakis and Prinou (2000) measurements, the mean VOT values of Greek voiceless consonants ranged from +22ms to +29ms.

Table 2. Mean VOT values in milliseconds for Greek voiceless consonants in word-initial position followed by a stressed [a]. Accumulated results from several studies. The asterisk (*) represents that the study has not investigated the given stop consonant, thus no results.

	Voice Onset Time (msec)		
Study	[p]	[t]	[k]
Fourakis (1986b)	9	16	23
Arvaniti (1987)	11	15	26
Arvaniti (2001c)	13	16	23
Nicolaidis (2002c)	14	22	*
Kollia (1993)	19	27	49
Antoniou (2010)	14	17	*

The phonetic/phonological status of voiceless plosives is widely accepted within the field of Greek linguistics. However, this is not the case for voiced plosives in Greek. One of the most prominent debates of Greek phonology has been about the phonological status of Greek voiced plosives and specifically whether voiced stops are (a) single phonemes that stand in minimal contrast with voiceless stops, or (b) whether they are sequences of a /nasal+voiceless/ consonant (Arvaniti, 1999, 2007; Arvaniti & Joseph, 2000, 2004; Holton, Mackridge, & Philippaki-Warburton, 1997; Joseph & Philippaki-Warburton, 1987). Worth mentioning is that, as far as orthography is concerned, Greek voiced plosives are represented by digraphs. To be specific, [b] = *μπ*, [d] = *ντ* and [g] = *γκ* or *γγ*.

In general, Greek voiced stops bilabial [b], alveolar [d] and velar [g] appear to be pre-voiced, exhibiting voicing lead values in word-initial position (Botinis, Fourakis & Prinou, 2000). An interesting variation appears in the productions of Greek voiced consonants at intervocalic and/or word medial position in relation to nasalization. It has been claimed by traditional accounts that the voiced consonants are pre-nasalized [^{m}b, ^{n}d, ^{n}g] (Newton, 1972). However, it has also been reported by Arvaniti & Joseph (2000) that the nasal preceding the stop may or may not happen/be produced depending on a vast majority of factors. It has been found that dialect, idiolect, rate of speech, social register and other sociocultural aspects may affect the pronunciation of Greek voiced consonants (Arvaniti & Joseph, 2000.) As a matter of fact this divergence in the pronunciation is something that we have also experienced while transcribing the data of the current thesis since our participants were from several places of Greece and different sociocultural backgrounds. Nonetheless, the phenomenon of nasalization in Modern Greek is beyond the scopes of the present thesis and we measured both realizations of voiced consonants without making any distinctions.

It has also been reported that Modern Greek is undergoing a synchronic sound change, as the nasalization phenomenon is progressively disappearing from the productions of young Athenians (Arvaniti & Joseph, 2000). Nevertheless, Table 3 presents the mean VOT values found by Kollia (1993), Botinis (2001) and Antoniou (2010) for Greek voiced VOT values in word-initial position. According to Botinis, Fourakis and Primou (2000), the mean lead VOT values for Greek voiced consonants ranged from -78ms to -82ms.

Table 3. Mean VOT durations in milliseconds for Greek voiced consonant in word-initial position followed by a stressed [a]. Accumulated results from Kollia (1993), Botinis (2001) and Antoniou (2010). The asterisk (*) represents that the study has not investigated the given stop consonant, thus no results.

	Voice Onset Time (msec)		
Study	[b]	[d]	[g]
Kollia (1993)	-105	-106	-101
Botinis (2001)	-140	*	*
Antoniou (2010)	-124	-132	*

6. The present study

Thus far the experimental studies presented have measured VOT productions of aphasic patients in word-initial position through repetitions of monosyllabic words. Stimuli typically consisted of monosyllabic real words containing in initial stop consonant [i.e. p, t, k, b, d, g] followed by the vowel [a] or every vowel of the language under investigation. Patients were asked to repeat the test words. Often (e.g. English and Thai studies) the test words were put in a carrier phrase such as the word "this" in order to ensure that the deficit was not due to an overall deficit in initiating speech at least for the non-fluent aphasic patients.

However, this methodological approach might be facing two limitations. The first one has to do with ecological validity. Closed-test repetition tasks have low ecological validity and often cannot be generalized to real-life situations. They are highly structured and allow only a limited spectrum of errors to occur. To tackle this limitation we chose to investigate the spontaneous speech productions of non-aphasic patients instead of replicating a monosyllabic repetition task for the Greek language. Still, one could claim that spontaneous speech cannot control which words are produced and that words produced in a running sentence are not the same as words in isolation and this can potentially lead to a great overall disadvantage.

That is true. We cannot control which words are produced in spontaneous speech but we can control the phonemic environment preceding and following the plosives under investigation. To be more specific, we chose to test each plosive at intervocalic position and set as the controlled environment the vowel preceding and the vowel following each plosive. In simpler words, we chose our testing environment not to be word-oriented but instead vowel-oriented. We aimed to collect 40 occurrences of plosives preceded and followed by a vowel per participant, which sums to a 2,400 VOT tokens of the plosives in total. Given that the previous studies have managed to analyze a number of 240 VOT tokens (English study) to a maximum of 1440 tokens (Turkish study), we think that spontaneous speech analysis is a possible alternative approach to the current research.

A second limitation in the previous studies' methodological approach has to do with the position of the plosive. All previous studies have tested the plosives in word-initial position. However, if the deficit is indeed phonetic in nature then non-fluent aphasic patients should perform similarly in word-initial and word-medial position. Instead, if the errors are concentrated only in word-initial position such an outcome could reflect a number of affected processes such as sentence planning processes, word/lexical availability, morphosyntactic problems etc. That is why with the current study we chose to investigate the plosives [p], [t]. [k], [b], [d], [g] in both intervocalic word-initial and intervocalic word-medial position. Another practical reason behind why we chose to investigate plosives in both word-initial and word-medial position is because in Greek, words that start with voiced consonants are rather infrequent. Therefore, the novelty of the present research lies in its different methodological approach and the cross-linguistic contraposition.

7. Methodology

7.1. Participants

Twenty native speakers of Greek served as subjects in the experiment. Half of them (n=10) were patients with Broca's aphasia (mildly impaired) and the other half were healthy participants who served as the control group. The two groups were matched for age, sex, handedness and educational level. The data for patients and controls are part of an ongoing project and the data had been collected by prof. Spyridoula Varlokosta of University of Athens and her team from 2011 to 2015. These data are part of the **THALES** project: *"Levels of impairment in Greek aphasia: Relationships with processing deficits, brain region, and therapeutic implications."* The THALES data consist of audio files of spontaneous narration of 4 different stories narrated by 28 participants: 22 aphasic patients, 6 cardiac patients and 14 healthy speakers.

The inclusion criteria for the Broca's patients were to be aged above 18, to be native speakers of Greek and to be clinically diagnosed by the hospital center. The diagnosis to each patient was further supported by the Greek adaptation of the Boston Diagnostic Aphasia Examination (Tsapkini, Vlachou & Potagas 2010, Goodglass & Kaplan, 1972). Exclusion criteria were that patients should not be registered with: severe history of neurological diseases, recent psychiatric history, hearing deficits, severe visuo-perceptual disorders and severe motor disability. Participants have been recruited to the Aiginiteio

University Hospital in Athens, Greece. The control group (healthy participants) were recruited from several districts around Athens, Greece. Patients' participation in the study was subject to requirements of the medical Ethical Committees of the Aiginiteio Medical Centre and the Ethical Committee of the Faculty of Medicine, the Faculty of Philosophy, Department of Linguistics of the National and Kapodistrian University of Athens, Greece.

7.2. Procedure & Stimuli

Participants, both aphasics and healthy controls, were asked to narrate 4 different stories. Each story is going to be analyzed in depth in the current subsection. All subjects were tested individually. Subjects were also tested in one session; each story was produced after the other in one go. Participants were given instruction by the researcher who tested them. The instructions are provided below.

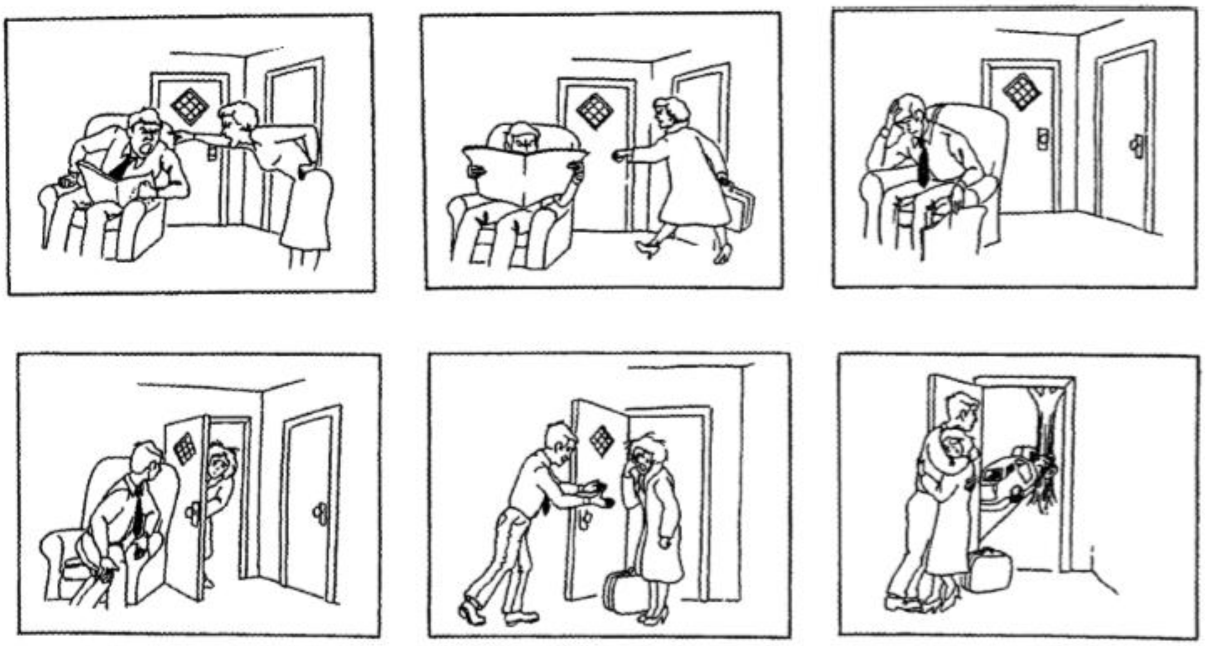
Aphasic patients were tested in the rooms where they were hospitalized, while healthy participants were tested primarily in a sound-proof room in the laboratory of the University of Athens, Greece. A few exceptions consisted of healthy speakers who were the patients' caretakers and were recorded at the cafeteria of the hospital. As a consequence, some of those recordings were noisy and thus excluded from the analysis of this experiment. The data was not collected by us instead, from Prof. Spyridoula Varlokosta and her team. To the best of our interest, we kept the material that was optimal for phonetic analyses where audio quality is extremely important. By optimal audio quality, we mean all the recordings that could be processed by the Praat software ((Boersma & Weenink, 2019); the wide-band pattern and amplitude display of the plosives under investigation had to be evident/clear.

Prior to testing, subjects were asked to narrate a story as a warm-up. This practice phase was meant to familiarize the subjects with the task and to make sure there would be a smooth recording/testing time. The narrations of the warm-up story were not recorded nor taken into analysis. In what follows, the four different stories are explained in detail, plus the practice/warm-up story:

0. Preliminary story – Warming up

Before narrating the four test stories, participants completed a warm-up, practice story. The warming-up session was about narrating a simple story, “the fight” by Nicholas & Brookshire (1993) with the visual support of six images (Figure 4). The results of this trial were not recorded nor were they part of the analysis and results of the current study.

Figure 4. Images illustrating “The fight” by Nicholas & Brookshire (1993).



A. Narration of a personal story

Aphasic patients were asked to narrate their personal medical story. This means they were asked to narrate their stroke story, when and how it happened before being admitted to the hospital clinic. Healthy participants were asked to narrate a personal accident that had happened in their lives (this varied from car accidents, to breaking a bone, to dental surgeries). The instruction given in Greek was the following:

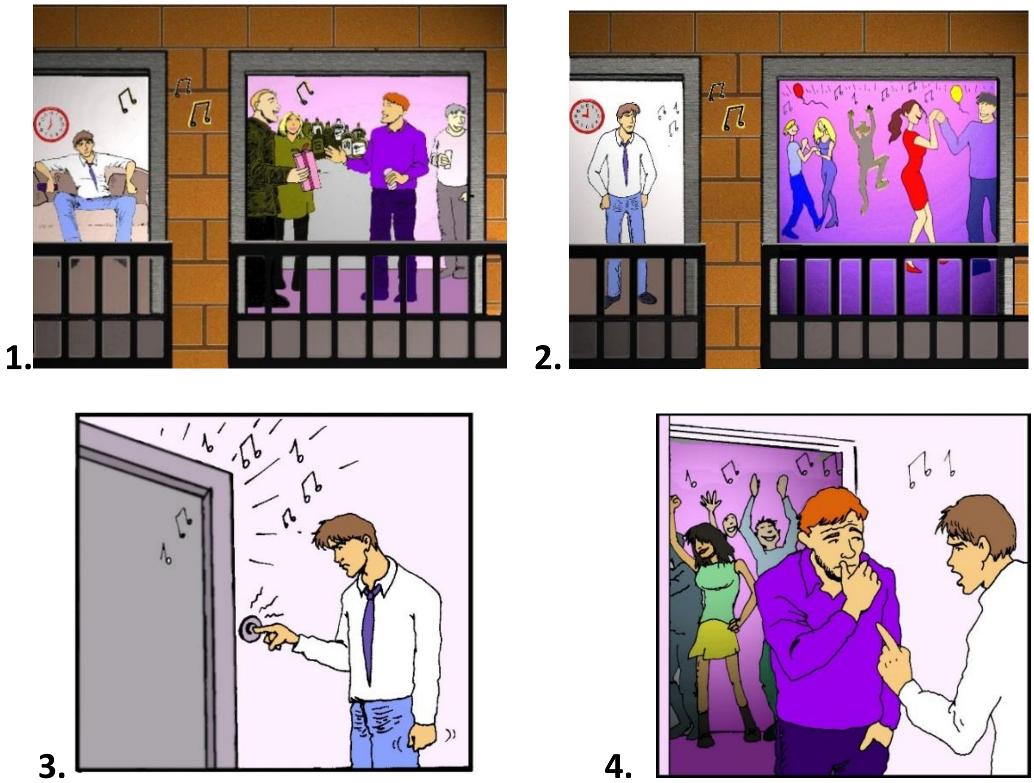
Researcher’s instruction*:* ‘Πείτε μου τι συνέβη όταν πάθατε το εγκεφαλικό/ κάποιο ατύχημα’. *“Tell me what happened when you had the stroke/accident”*.

B. <u>Narration of a story with the support of visual material: “the party”.</u>

This task involved the narration of a story (new to the patient) with the support of images. Patients were presented with 6 pictures that were illustrating a brief and simple story titled “the party” (Figure 5). The pictures were placed in front of the patient in the right order and the patient was asked to narrate the Party story in her/his own words while looking at the pictures. This is a semi-spontaneous speech method, as it is elicited by situational pictures. The instruction given in Greek was:

Researcher's instruction: ‘Οι εικόνες αυτές δείχνουν μια ιστορία. Κοιτάξτε πρώτα όλες τις εικόνες και πείτε μου την ιστορία με αρχή, μέση και τέλος.’ *"These pictures show/illustrate a story. Look at all the pictures first and tell me the story with a beginning, middle and end."*

Figure 5. Supporting material of the “Party”.



5. 

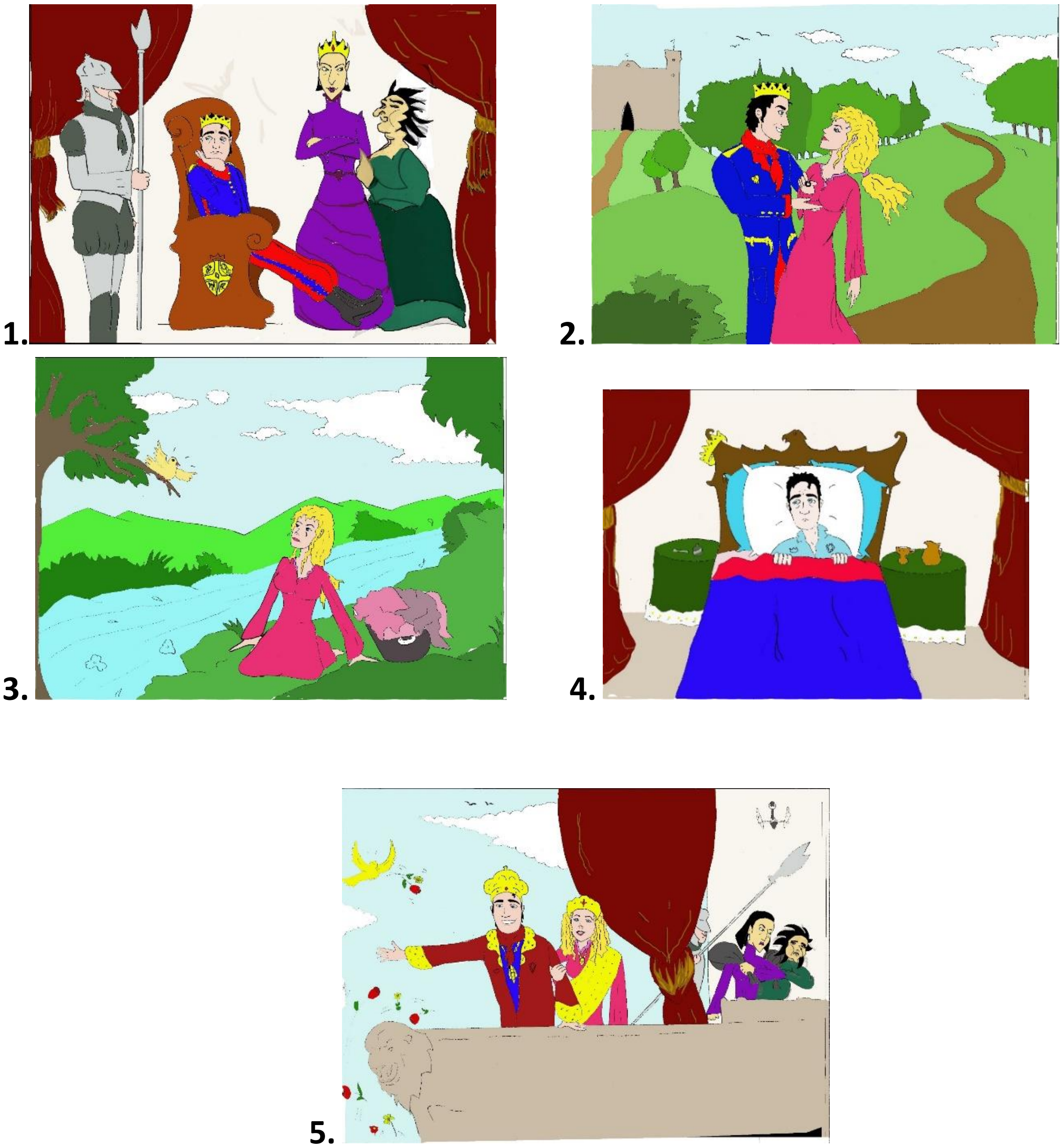
6. 

C. <u>Re-narration of an original story with the support of images.</u>

The patient listened to a pre-recorded story “The ring” while simultaneously looking at 5 pictures (Figure 6). The pictures were unknown to the patient and they were placed in the right order in front of the participant while the recording of the story was playing. Immediately afterwards, the patient was asked to re-narrate the story while looking at the pictures provided to him/her.

Researcher’s instruction: ‘Πρόκειται να ακούσετε μια ιστορία για το τι συμβαίνει σε αυτές τις εικόνες. Ακούστε προσεχτικά την ιστορία και μόλις τελειώσει θα σας ζητήσω να την επαναλάνετε όσο το δυνατόν πιο ολοκληρωμένα.’ *“You are about to hear/ to listen to a story describing what is going on in the pictures in front of you. Listen carefully to the story and once the recording is finished I would like you to repeat it as thoroughly as possible.”*

Figure 6. Supporting material of the story “the ring”.



D. <u>Re-narration of a popular story without the support of images</u>

The patient listened to a pre-recorded well known and popular story, the Hare and Tortoise, Aesop’s fable (see Appendix 1), and afterwards was asked to narrate what s/he had heard.

Researcher's Instruction: ‘Πρόκειται να ακούσετε μια ιστορία. Ακούστε την προσεχτικά και μόλις τελειώσει θα σας ζητήσω να την επαναλάβετε όσο το δυνατόν πιο ολοκληρωμένα.’

“You are about to listen to a story. Listen carefully, and once it's over, I'll ask you to repeat it as thoroughly as possible."

7.3. Analysis

7.3.1. Transcription & Annotation of the data

The procedure of transcribing and measuring the VOT values was the following. The audio recordings (raw data) were uploaded to, transcribed and annotated with the Praat software (Boersma & Weenink, 2019). The acoustic measurements of VOT were based on (a) waveform representations, (b) wideband spectrographic analyses and (c) the recognition of each plosive/sound by a native speaker of Greek (namely the author of this thesis).

VOT, as already mentioned, is determined to be the time of the release of the burst and the onset of glottal pulsing of the vowel that follows (Lisker & Abramson, 1964; 1967). The instant of release was identified by “*the onset of a burst of frication noise following the closure interval and contaminant abrupt rise in amplitude”* (Gandour & Dardarananda, 1984, p. 181). The instant of the release was assigned with 0. Voicing preceding the burst (voicing lead) was identified by *“the sudden onset of low energy striations in the absence of acoustic energy in the formant frequency range”* (Lisker & Abramson, 1964, p. 389) and was assigned with minus [-]. Voicing following the burst (voicing lag) was identified by *“the sudden onset of vertical striations in the second and higher formants”* (Lisker & Abramson, 1964, p. 389) and was assigned with a plus [+] (Lisker & Abramson, 1964, p. 389).

Moreover, the transcription was performed at the phonemic level and involved a fixed/ controlled phonemic environment. Every plosive under investigation ([p], [t], [k], [b], [d], and [g]) had to be preceded and followed by any of the Greek vowels ([a], [o], [i], [e], [u]). Thus, only the plosives at intervocalic position were taken into analysis. If a stop consonant was not preceded and followed by a vowel, it was excluded from the analysis.

Important is to pinpoint, that we did not neglect from our analysis the position of the plosive word-wise, even though the “plosive environment” was not word-oriented but vowel-oriented, as mentioned above. To be specific, we transcribed if the plosive occurs at (a) intervocalic word-initial or (b) intervocalic word-medial position. The reason behind this is that if the deficit is phonetic in nature then non-fluent aphasics should exhibit similar VOT patterns for both intervocalic word-initial and intervocalic word-medial positions. Instead, if the errors are concentrated only in word-initial position such an outcome could reflect a number of affected processes such as sentence planning processes, word/lexical availability, morphosyntactic problems etc.

40 tokens per plosive (10 from each story, 4 stories in total) per participant were measured. This measurements summed to 2,400 VOT tokens in total for both groups (see Figures 7 and 8 for an example of the annotation concept). If a plosive was in intervocalic word-initial position then a dot [.] was transcribed before the plosive and after the vowel preceding it (Figure 8), if not the dot was not annotated and that meant that the plosive is in word-medial position.

Figure 7. Intervocalic word-medial annotation of [k] produced by healthy participant c124, extracted from the story "the ring". The plosive is proceeded by the vowel [e] and followed by the vowel [i]. Attached is the plus sign to indicate that voicing follows the burst of the plosive. The Greek word *«εκεί»* means *"there".*

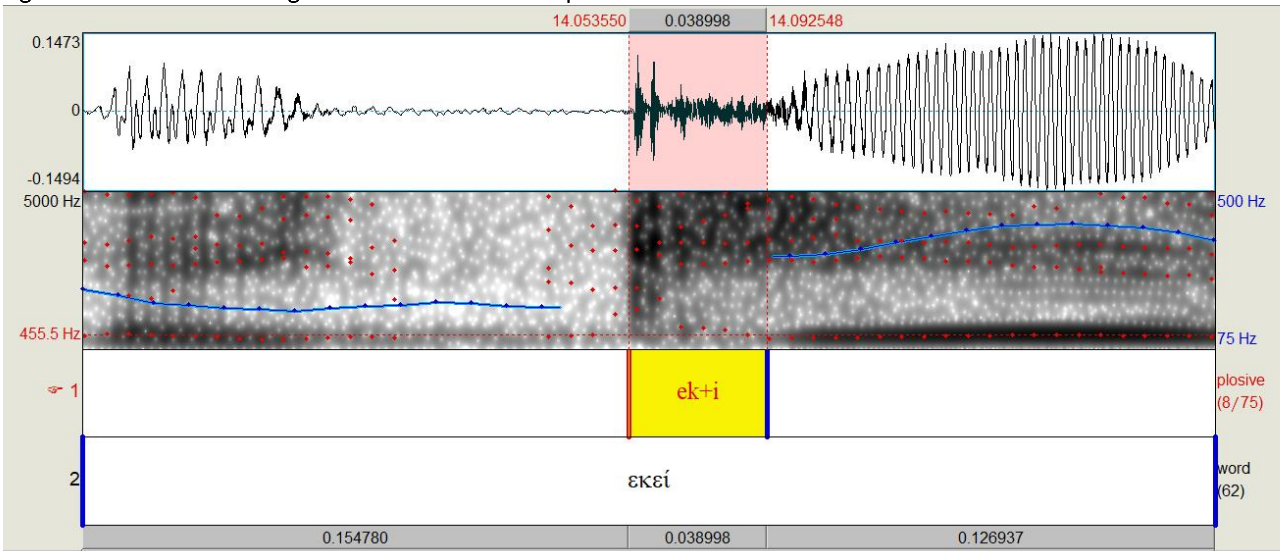
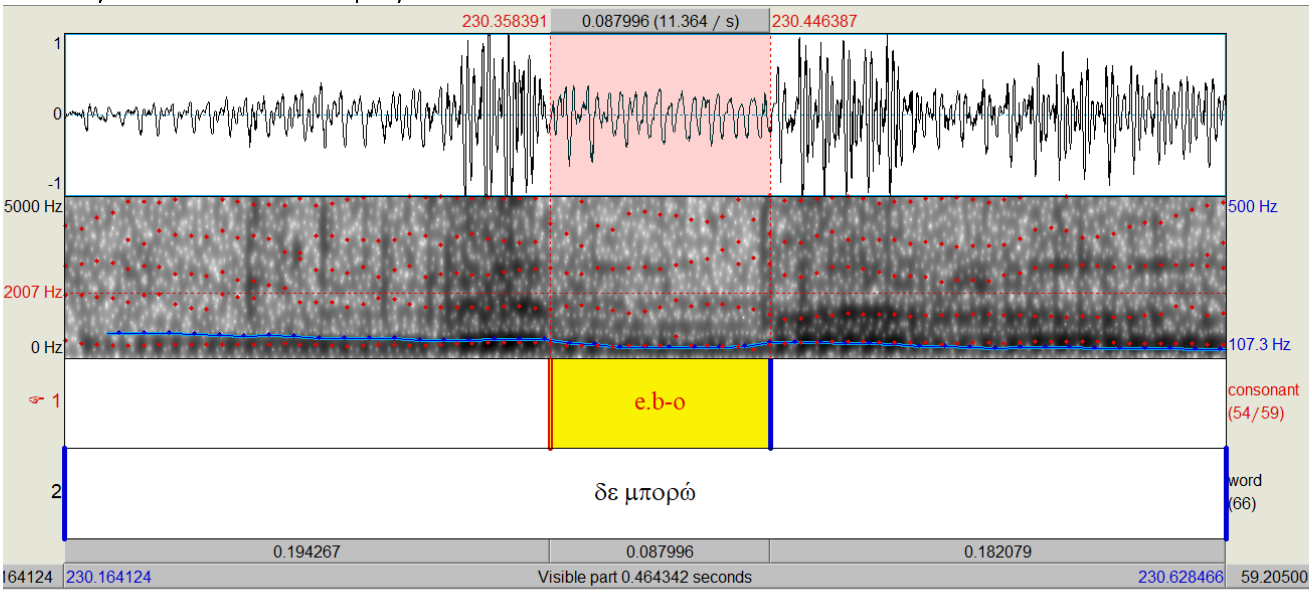


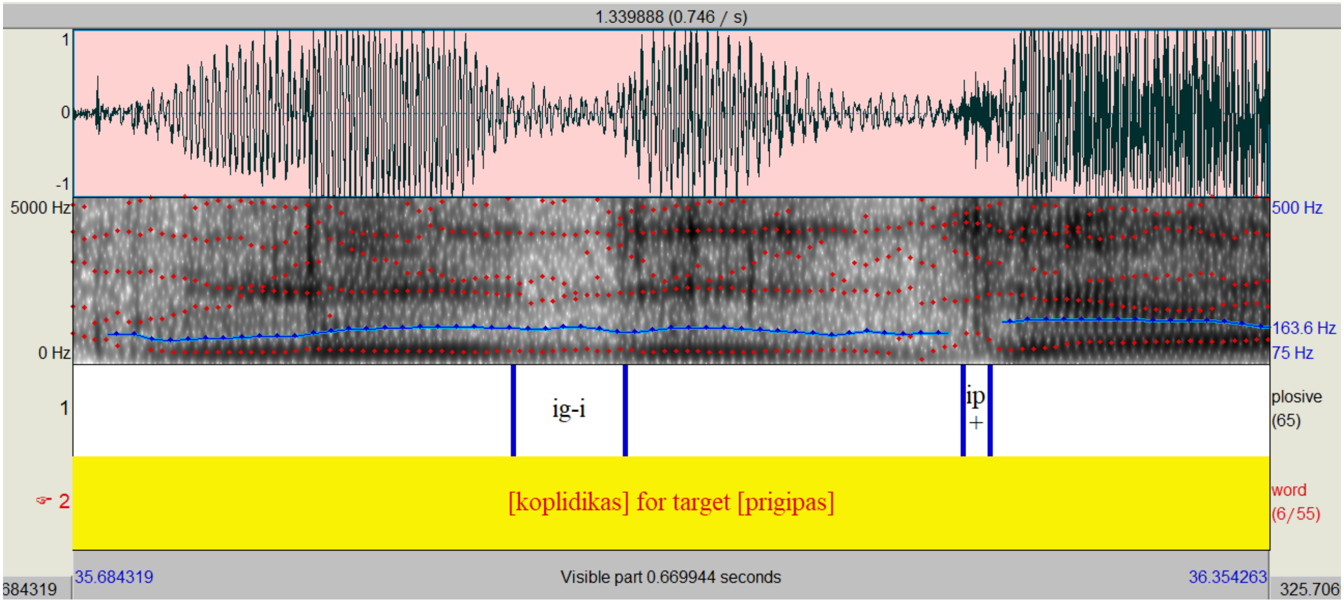
Figure 8. Intervocalic word-initial annotation of [b] produced by healthy participant c118, extracted from the story “the hare and the tortoise”. The plosive is proceeded by vowel [e] and followed by the vowel [o]. Attached is the minus sign to indicate that voicing precedes the burst of the plosive. The dot denotes the word boundary. The Greek words *«δε μπορώ»* mean *“I cannot”*.



Moreover, with regard to aphasic patients’ productions, we included phonological paraphasias and neologisms in our analysis; because these errors reflect a deficit in retrieving the word form from the memory and not a failure in producing the individual sounds. The type of speech error would vary from word to word, within and between aphasic patients. For instance, one aphasic participant, for the target word [‘prigipas] which means *prince* in Greek, produced the nonsense word [ko’plidikas] (Figure 9). There appears a change in the place of articulation for the word-initial target front bilabial [p] to a back velar [k] (substitution error known as backing). Syllable addition was also evident from the word-initial target [pr-] being epenthesized by the vowel [o] leading to the [ko-pli-] production by the aphasic patient. Fronting also appears at word medial position where instead of the back velar target [g] the patient is replacing it with the alveolar front [d] plosive. Another example of phonological substitution errors we came across was “reverse stopping” – the process where a stop phoneme would be substituted by a fricative sound e.g. [d] → [δ] or [t] → [θ].

Our approach was to transcribe the target consonant, even though the patient was producing a different sound. So, even though the actual production was for instance [d] instead of a target [g], we transcribed the [d] as a [g]. The reason behind such decision was that we aim to focus on VOT measurements alone and not the nature of the substitution error. In a future study it would be interesting to zoom on the different substitution errors and under what environment and circumstances they appear

Figure 9. An example of phonological substitution errors produced by aphasic patient a303. The target word was [‘prigipas] but instead the patient produced the nonsense word [ko’plidikas].



7.4. Experimental Design

This section presents a layout of the experimental design and statistical analysis of the current study. The first step was to create a table with all the information obtained from the Praat transcription. The column *Subject* contains the information of each participant individually (e.g. c108, c124 etc.). The column *group* stands for the type of participant, healthy or aphasic, while the column *file* refers to which story each production belongs to. *T1* is the onset time of the plosive and *t2* is the offset time, both in milliseconds. The column *Text* stands for the annotated text. The column *V1* contains the vowel preceding the plosive, while the column *V2* the vowel following the plosive. The column *Boundary* refers to whether the plosive is in word-initial or word medial-position. The column *C* contains the type of consonant [b], [d], [t], [d], [k] or [g], *voiced* stands for voicing, voiced or voiceless to be specific. Last but definitely not least the column *VOT* stands for Voice Onset Time and is the computed time in milliseconds.

The data was statistically analyzed with the R program (R Core Team, 2019) by using a linear mixed-effects model (lmer). The formula of the experimental design was the following and included the undermentioned factors:

```
library (lmerTest)
ThesisModel <- lmer (formula = VOT ~ group * voiced * place +
    (1 + voiced * place| subject), data = table, REML = TRUE)
```

VOT is the numeric dependent variable which was measured in milliseconds. Predictors of the model were the following. *Group*, a binary categorical between-participants predictor stands for the type of participant, meaning either Broca's patient or healthy control, whose contrasts were abbreviated as A: -0.5 (for aphasic patients) and H: +0.5 (for healthy controls). *Voiced* is a binary within-participants predictor which stands for the type of voicing: voiced or voiceless consonant (expressed through yes [=voiced] or no [=voiceless] and whose contrasts were Y: -0.5, N: +0.5). *Place* of articulation is a within-participants predictor. Due to the nature of the experiment, the data was unbalanced, forcing *place* of articulation to have a three-way contrast per type of plosive between the categories labial, dorsal and coronal. This three-way contrast in order to sum to 0 was first set to -1/3 for coronal, +2/3 for dorsal and +1/3 for labial because universally dorsal consonants have the longest VOT out of them all; and then the second summing to 0 contrast was set with +0.5 for coronal and -0.5 for labial again because universally labial consonants have the smaller VOT.

````
```{r}
contrast <- cbind (c(-1/3, +2/3, +1/3), c(+1/2, 0, -1/2))   # coronal, dorsal, labial
colnames (contrast) <- c("-LC+D", "-L+C")
contrasts (table$place) <- contrast
```
````

The results from the **group x voicing** interaction were to answer the first research question, whether aphasic patients produce longer VOTs than healthy controls. The **group x voicing x place** of articulation interaction were to shed light into whether there is a difference between populations and the degree of overlapping of VOT categories between the two populations.

8. Results

8.1. Report of the statistical analysis

The statistical analysis was performed with a linear mixed-effects regression model, as established in subsection 7.4. For the first research question '*Do Greek non-fluent aphasic patients produce longer VOTs than healthy controls?*' the research question answering predictor is **group**. Our Greek non-fluent aphasic patients did not perform significantly different than our Greek healthy speakers (estimate= -7.4msec, t[17.2] = -1.27, p=0.22, 95% confidence interval [henceforth c.i.]= -19.6 . . 4.9). This means that the group effect even though a bit longer for the aphasic patients, it is not significant and therefore no generalizations are possible.

Furthermore, the interaction **group x voicing x place** of articulation answers the second research question '*Do Greek non-fluent aphasic patients maintain discrete VOT categories or do they exhibit overlapping of VOT categories in comparison to healthy controls?'.* Our non-fluent aphasic patients maintained discrete VOT categories, similar to our Greek healthy controls; except for the labial place of articulation. A comparison between the labial versus coronal places of articulation revealed that our Greek non-fluent aphasic patients exhibited an overlapping of VOT categories for the labial place of articulation. Greek non-fluent aphasic patients produced the voiced labial plosive [b] with both negative and positive VOT values, instead the healthy speakers produced [b] with voicing lead (negative VOT values) and the [p] with voicing lag (positive VOT values). The voicing effect [b → p] had an estimate of 56.2msec, t[12.5]=2.0, 95% c.i.= -4.4 .. 117.0msec and a marginally significant *p*-value of 0.06 (p=0.06). This statistical result complements Figure's 11 in that the aphasic patients are devoicing some of their [b]s. Thus, we can conclude that Greek non-fluent aphasic patients maintain discrete VOT categories for the coronal and dorsal places of articulation similarly to Greek healthy speakers and their French counterparts, however they exhibit marginally overlapping of VOT categories for the labial place of articulation.

8.2. Mean VOTs and SD of plosives in intervocalic word-initial position

Table 4 provides a summary of the VOT productions of the healthy speakers and aphasic patients in intervocalic word-initial position. The first column contains the consonants analyzed in the current experiment; labial [p] and [b], coronal [t] and [d] and dorsal [k] and [g], while the second column (group) shows the type of participants (H: healthy or A: aphasic). The third column shows how many observations out of the total of 2913 VOT tokens belong to each consonant separately per group. The number of observations per consonant is important to be provided since the measurements emerge from spontaneous speech and even though our initial goal was to analyze and compare equal productions per consonant and group that was not practically feasible. Our initial goal was to have 10 productions per consonant and per story, meaning a minimum of 40 productions of the same plosive per participant. There was a divergence in the number of production of consonants because the voiced consonants were rather sparse/infrequent in the data, especially at intervocalic word-initial position. Thus, having equal numbers of observations per plosive was not feasible and that is why we are providing the total number of each consonant produced, as well.

Table 4. The numbers of observations, means and standard deviations of coronal, labial and dorsal consonants in intervocalic word-initial position. Group is sub-divided into H: healthy and A: aphasic participants, the numbers of observations per group is provided out of the 2913 VOT tokens in total, the mean VOT values and VOT standard deviations per group are provided in milliseconds.

CONSONANT	GROUP	OBSERVATIONS /2913	MEAN VOT (msec)	STANDARD DEVIATION (msec)
Labial **p**	H	193	10.19	±37.45
	A	181	16.96	±49.90
Labial **b**	H	**34**	**-63**.16	±75.80
	A	**79**	**-11**.97	±104.79
Coronal **t**	H	220	17.95	±27.81
	A	248	33.99	±45.21
Coronal **d**	H	2	-52. 10	±27.06
	A	3	-97.03	±58.76
Dorsal **k**	H	226	18.52	±33.65
	A	218	37.26	± 39.67
Dorsal **g**	H	1	Null	Null
	A	0	Null	Null

8.2.1. Distributions of VOT productions in intervocalic word-initial position

The distributions of VOT productions of each consonant in intervocalic word-initial position are illustrated in this subsection. Axis x shows the distribution of VOT values per plosive per group in milliseconds and axis y the number of occurrences per plosive and group. Figure 10 shows the frequency distribution of VOT values for the bilabial voiceless plosive ([p]) for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number of 374 occurrences for both groups.

No overlapping of VOT categories or phonetic substitution was found in the [p] plosive category. The values for the bilabial voiceless [p] lie close to zero or in the short voicing lag region with a maximum of 48msec and 60msec for healthy controls and aphasics, respectively. This variation between some productions being close to zero and others having short lag values may stem from the fact that some [p]s were aspirated, a phenomenon that happens/occurs especially when the voiceless bilabial is followed by the vowel [i]. Notably, the difference between the two populations lies in the fact that the [p] productions of aphasic patients were wider, -32msec to +60msec, than their healthy counterparts' interval which was from -27msec to +47msec.

Figure 10. Distribution of VOT productions for [p] in intervocalic word-initial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).

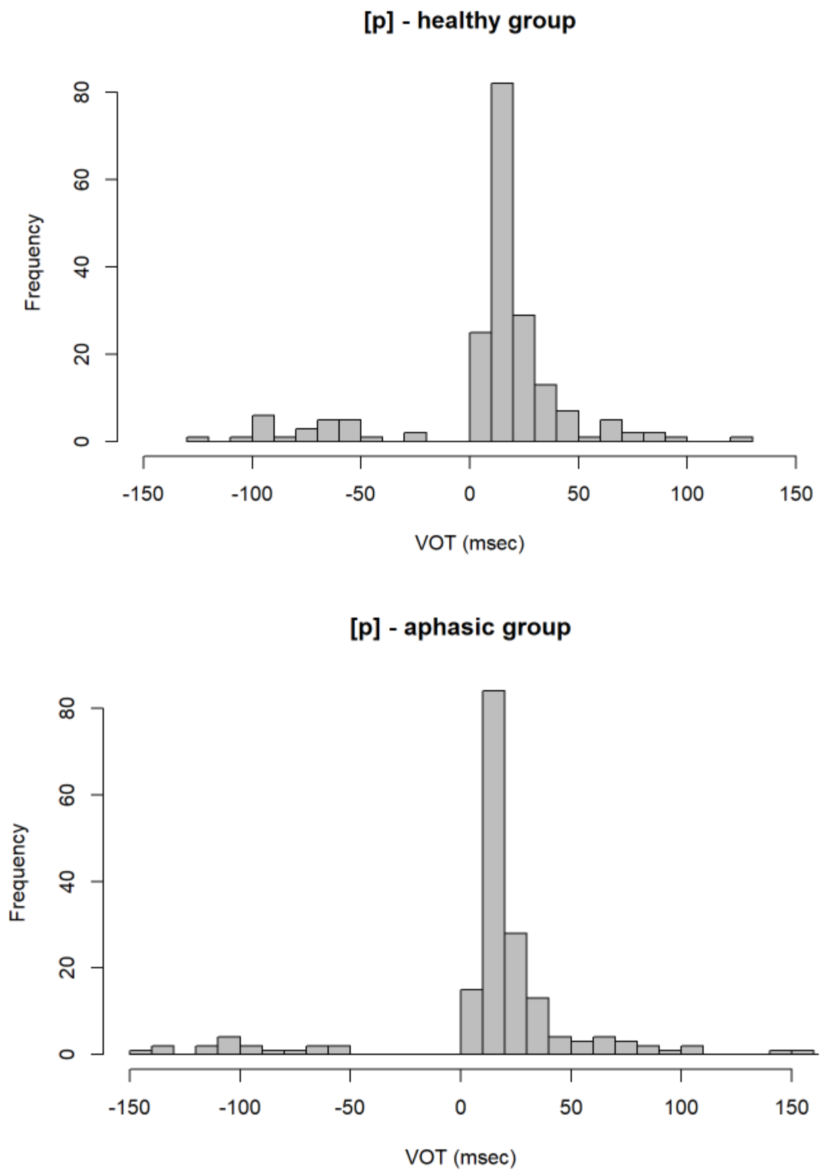
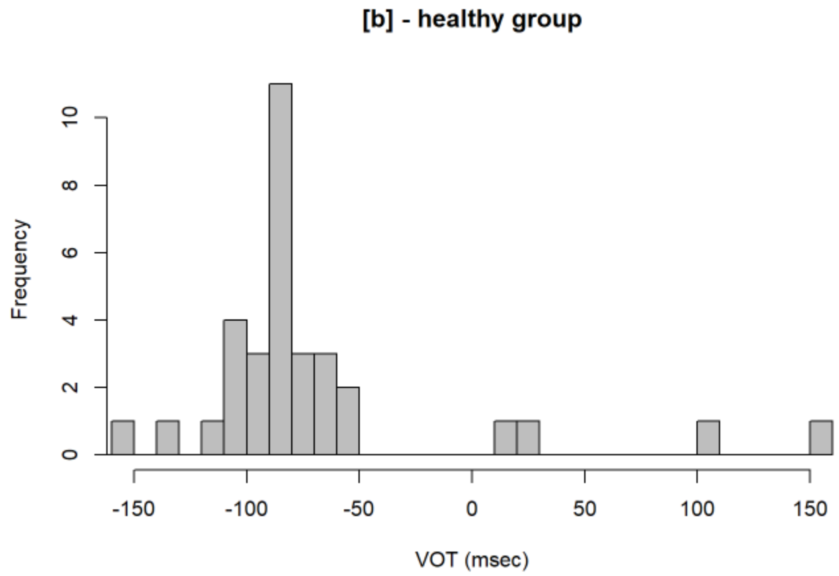


Figure 11 shows the frequency distribution of VOT values at the bilabial voiced [b] place of articulation for the healthy group (upper histogram) and the non-fluent aphasic patients (lower histogram). For [b] the results between healthy and aphasic participants are divergent. The distribution of VOT productions of [b] for healthy participants are unimodal and lie in the voicing lead region for the healthy controls ranging from -138 to 12.67msec instead, the distribution is bi-modal for the aphasic group with its values ranging from -204msec to +181msec. The fact that two peaks emerge for the aphasic group is of great importance. The first peak is concentrated around approximately -100 to -50msec while the second peak has most of its instances occurring approximately at around +50 to +100msec. Do all aphasic patients produce equally negative and positive values for the [b] targets? Or do some aphasics produce negative and others positive values? Moreover, can the positive values be considered a phonemic substitution error? Meaning are the erroneous aphasic [b] positive values close to the healthy speakers [p] values? Or does the range of the erroneous positive [b]s lie outside of the p overall value range? Further investigation was put forth starting with Table 5 which provides the values of VOT productions of [b] for each participant individually.

Figure 11. Distribution of VOT productions for [b] in intervocalic word-initial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).



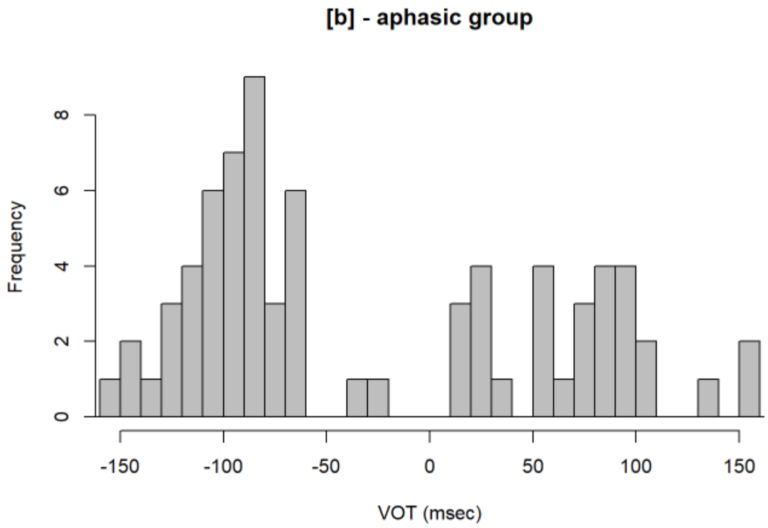


Table 5. Individual productions of [b] in intervocalic word-initial position produced by healthy controls.

Productions of [b] per participant HEALTHY GROUP			
Participant	**Observations /2913**	**Mean VOT (msec)**	**SD (msec)**
c108	1	-61.91	Null
c114	4	-99.87	±38.28
c118	9	-89.27	±15.83
c124	1	-59.48	Null
c303	3	-23.55	±105.88
c904	1	-63.68	Null
c905	1	-76.83	Null
c914	7	-58.11	±53.06
c915	7	-51.29	±133.46
c917	0	Null	Null

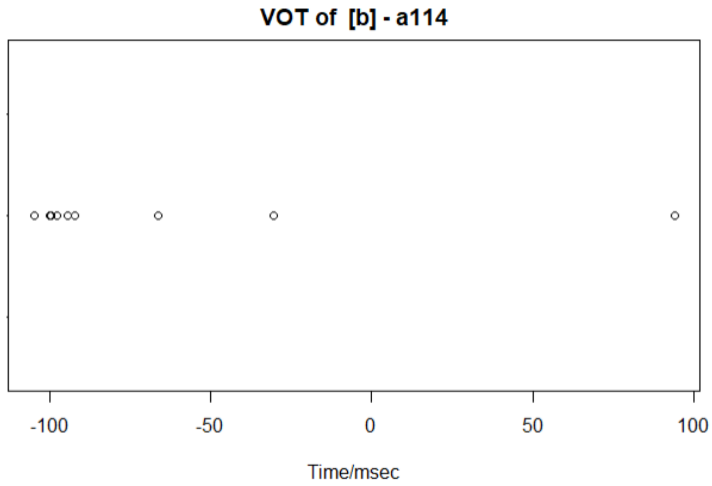
Tables 6. Individual productions of [b] in intervocalic word-initial position produced by aphasic patients.

Productions of [b] per participant **APHASIC GROUP**			
Participant	**Observations /2913**	**Mean VOT (msec)**	**SD (msec)**
a109	3	-77.11	±13.79
a114	9	-65.91	±64.47
a124	1	**12.03**	Null
a134	13	**-19.79**	±108.05
a301	5	**2.28**	±81.49
a303	4	-34.95	±125.27
a906	4	**1.73**	±136.63
a912	21	**61.91**	±82.56
a916	17	**-45.23**	±111.07
a917	2	-143.07	±86.72

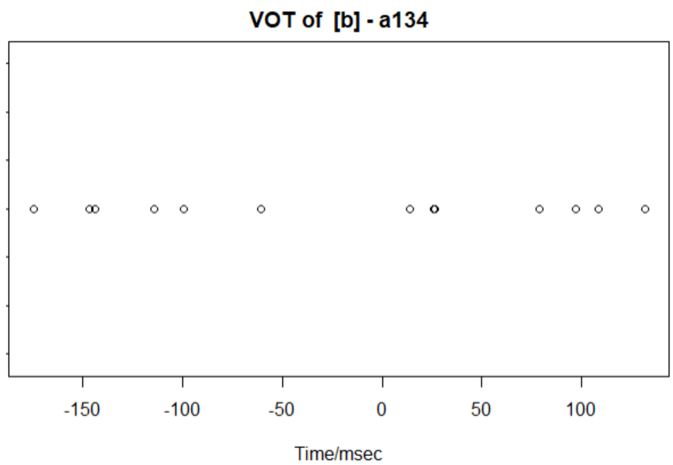
Looking at each participant's performance individually, we can see that healthy controls produce convergent negative VOT values. Next, looking at the aphasic patients' performance it is evident that not every aphasic patient exhibited positive means for [b] targets, only subjects a124, a301, a906 and a912. For fine-grained results the plots of every aphasic participant were drawn. Two things can be seen straight away. 1) Most patients produce negative values for the [b] plosive and 2) the aphasics who exhibit positive values produce negative values as well (meaning not only positive values). The scatterplots of the patients who produced positive values are provided.

Patients a114 (+94msec) and a124 (+12msec) had one positive VOT production each. Half of the productions of a906 aphasic patient were positive, however this 50% is a percentage out of the small number of 4 [b] productions in total. Patient a912 produced the biggest amount of [b]s (n=21), where approximately 60% (n=12) of her/his productions were positive. The positive productions ranged from +10 to +103msec. This broad range of values falls within the [p] values ranges (+30 to +50 msec) but also far from it as well. Since the positive values of [b] do not fall into its counterpart [p] values range solely, but instead they are equally distributed from 0 to +100msec this could verify that the error is phonetic and triggered by a deficit in the articulatory programming of non-fluent aphasic patients. Lastly, aphasic a916 comes to verify the above notion. Her/his positive values range from +60msec to +100msec which fall far from the [p] values. Taking also into account the single positive productions of a114 and 124 patients which are way far from the [p] range values, this could mean that a phonemic substitution deficit is rejected.

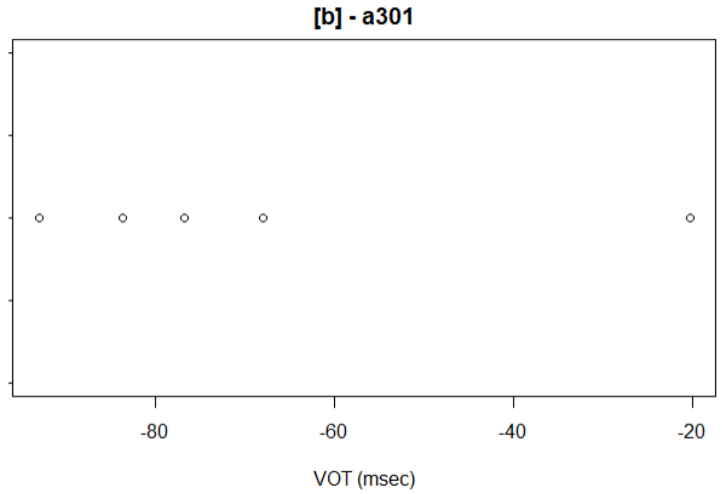
Plot 1. [b] productions of aphasic patient a114.



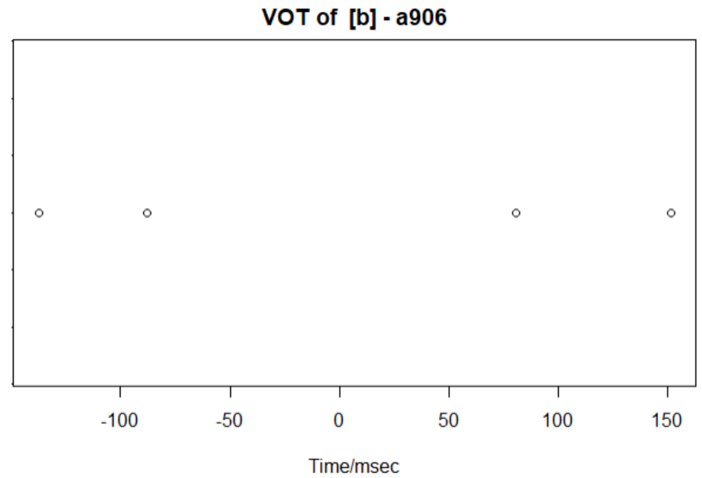
Plot 2. [b] productions of aphasic patient a134.



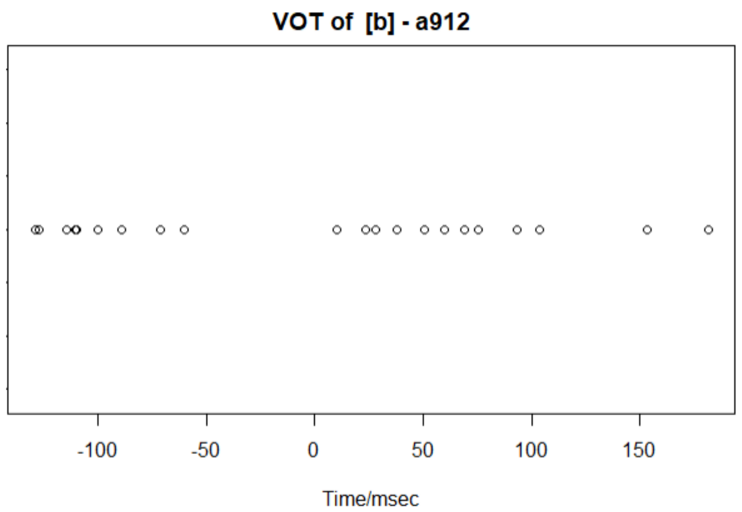
Plot 3. [b] productions of aphasic patient a301.



Plot 4. [b] productions of aphasic patient a906.



Plot 5. [b] productions of aphasic patient a912.



Plot 6. [b] productions of aphasic patient a916.

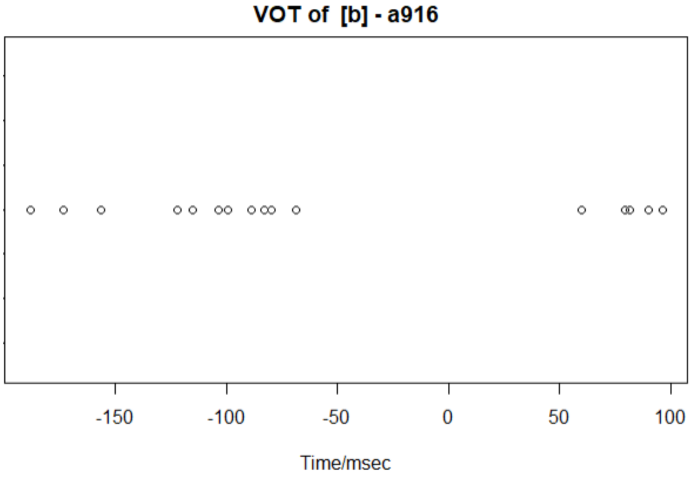
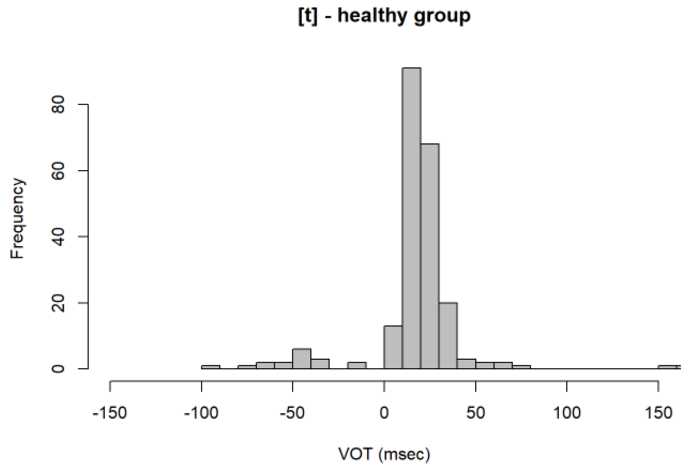


Figure 12 illustrates the frequency distribution of VOT values at the coronal voiceless ([t]) place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number of 468 occurrences for both groups in intervocalic word-initial position. No overlapping of VOT categories or phonemic substitution was found in the [t] plosive category. The values for the coronal voiceless [t] lie close to a mean of +17msec (short voicing lag) with a minimum of -94msec and a maximum of +176msec for the healthy speakers and a mean of +34msec with a minimum of -153msec and a maximum of +165msec for the aphasic patients. Notably, the difference between the two populations lies in the fact that the [t] productions of aphasic patients (SD: ±34msec, interval: -12 to +80 msec) were wider and longer than their healthy counterpart (SD: ±28msec, interval: -10 to +45 msec), yet not significant larger.

Figure 12. Distribution of VOT productions for [t] in intervocalic word-initial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).



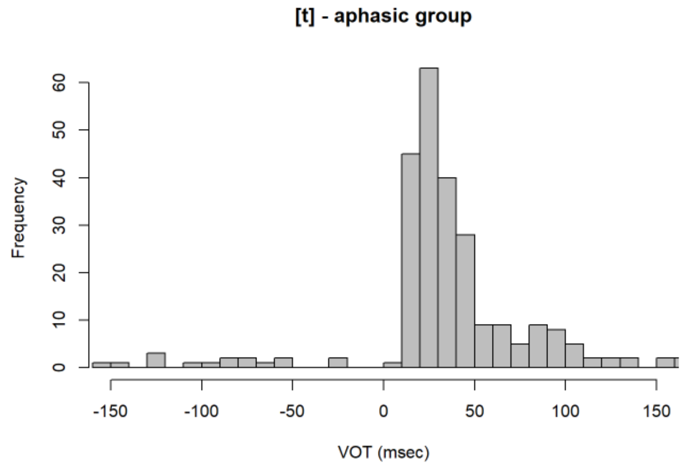
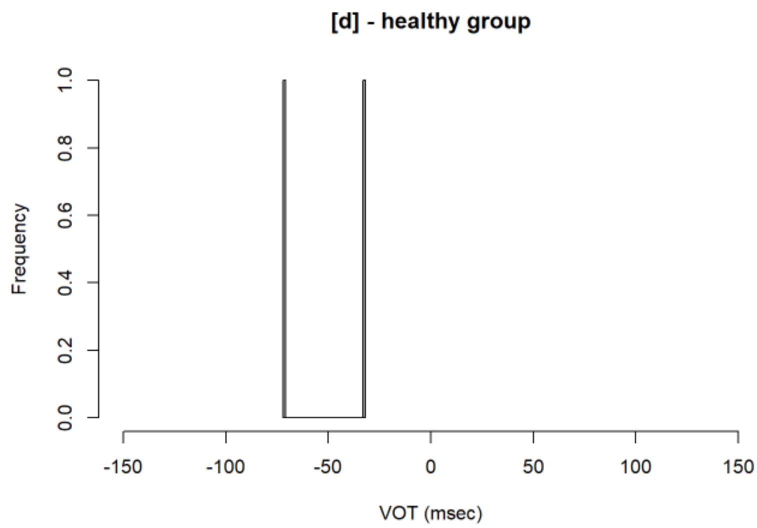


Figure 13 illustrates the frequency distribution of VOT values at the coronal voiced ([d]) place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number of 5 occurrences in total for both groups in intervocalic word-initial position. No overlapping of VOT categories or phonetic substitution was found for the [d] plosive category. The values for the coronal voiced [d] lie close to a mean of -52msec (long lead voicing) with a minimum of -71msec and a maximum of -33msec for the healthy speakers and a mean of -97msec with a minimum of -132msec and a maximum of -29msec for the aphasics patients. Notably, the difference between the two populations lies in the fact that the [d] productions of aphasic patients (SD: ±97msec, interval -155 to -39msec) were wider and longer than their healthy counterpart (SD: ±52msec, interval -80 to -25msec), yet not significant larger.

Figure 13. Distribution of VOT productions for [d] in intervocalic word initial-position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).



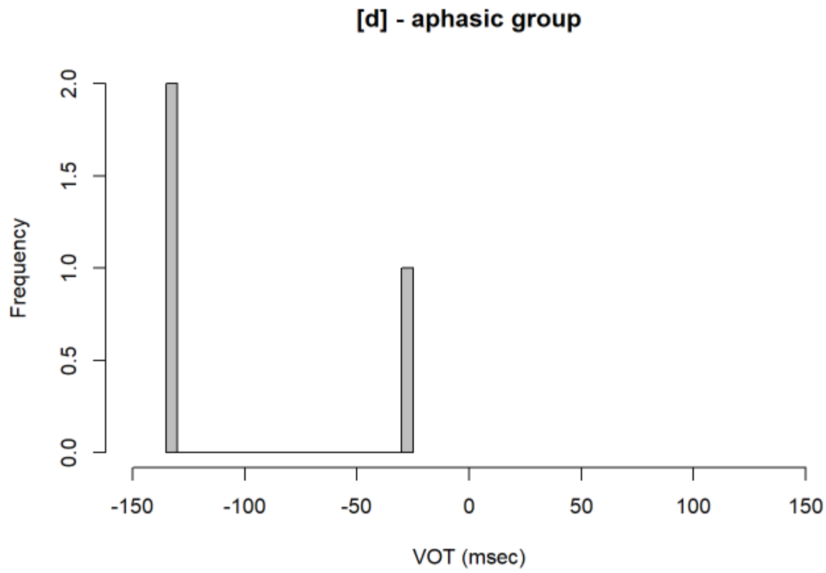
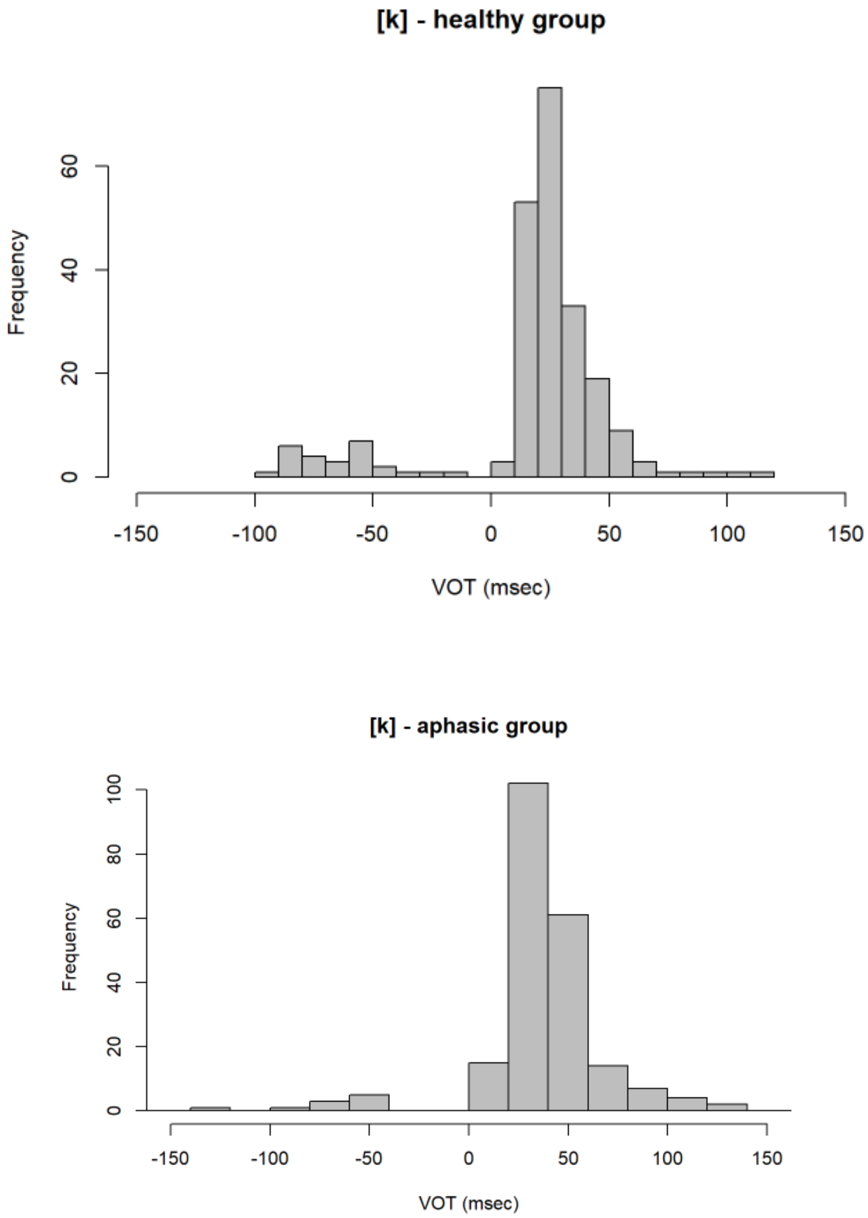


Figure 14 depicts the frequency distribution of VOT values at the dorsal voiceless ([k]) place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number of 444 occurrences for both groups in intervocalic word-initial position. No overlapping of VOT categories or phonemic substitution was found for the [k] plosive category between the two populations. The values for the dorsal voiceless [k] lie close to a mean +19msec (short voicing lag) with a minimum of -100msec and a maximum of +119msec for the healthy speakers and a mean of +38msec with a minimum of -195msec and a maximum of +260msec for the aphasics patients. Notably, the difference between the two populations lies in the fact that the [k] productions of aphasic patients (SD: ±37msec, interval: -2 to +77 msec) were slightly wider and longer than their healthy counterpart (SD: ±19msec, interval: -15 to +52msec), yet not significant larger.

Last but not least, with regard to the intervocalic and word initial position subsection, no results can be provided for the dorsal voiced [g] plosive because for the healthy group we had only one occurrence/observation (-76msec) and zero observations in the aphasic group. A possible explanation for this outcome may be that in Greek words starting with [g] are rather infrequent.

Figure 14. Distribution of VOT productions of [k] in intervocalic word-initial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).



8.2.2. Mean VOTs and SD of plosives in intervocalic word-medial position

Table 7 provides a summary of the VOT productions of the healthy speakers and aphasic patients in intervocalic word-medial position. The type of plosive, number of VOT tokens, mean VOTs in milliseconds and standard deviations in milliseconds are provided.

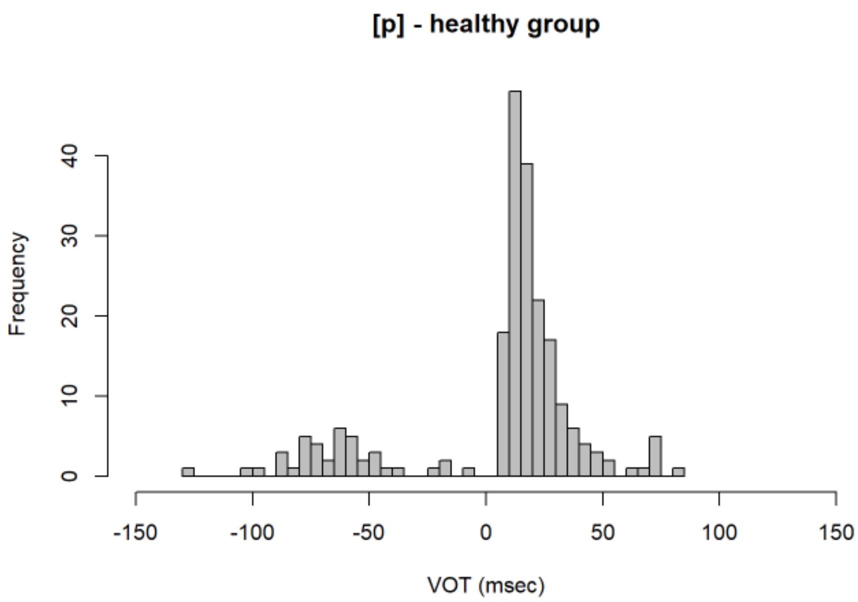
Table 7. The numbers of observations, means and standard deviations of coronal, labial and dorsal consonants in intervocalic word-medial position. Group is sub-divided to H: healthy and A: aphasic participants, the number of observations per group is provided out of the 2913 in total, the means and standard deviations per group are provided in milliseconds.

CONSONANT	GROUP	OBSERVATIONS /2913	MEAN VOT (msec)	SD (msec)
Labial **p**	H	216	6.28	± 37.03
	A	196	10.15	± 67.95
Labial **b**	H	12	-78.89	± 13.29
	A	6	-104.7	± 38.29
Coronal **t**	H	196	14.07	± 32.65
	A	233	17.51	± 56.67
Coronal **d**	H	164	-69.91	± 29.05
	A	109	-75.61	± 42.12
Dorsal **k**	H	172	20.04	± 32.48
	A	150	37.93	± 44.18
Dorsal **g**	H	27	-75.35	± 34.11
	A	27	-74.72	± 38.94

8.2.3. Distributions of VOT productions in intervocalic word-medial position

Figure 15 illustrates the frequency distribution of VOT values at the labial voiceless [p] place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of 442 occurrences in total for both groups in intervocalic word-medial position. No overlapping of VOT categories or phonetic substitution was found for the [p] plosive category. The values for the labial voiceless [p] lie close to a mean of 6 (close to 0 voicing) with a minimum of -127msec and a maximum of 80msec for the healthy speakers and a mean of +10msec with a minimum of -226msec and a maximum of +238msec for the aphasics patients. Notably, the difference between the two populations lies in the fact that the [d] productions of aphasic patients (SD: ±68msec, interval -58 to +78msec) were wider than their healthy counterpart (SD: ±37msec, interval -30 to +43msec), yet not significant larger.

Figure 15. Distribution of VOT productions for [p] in intervocalic word-medial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).



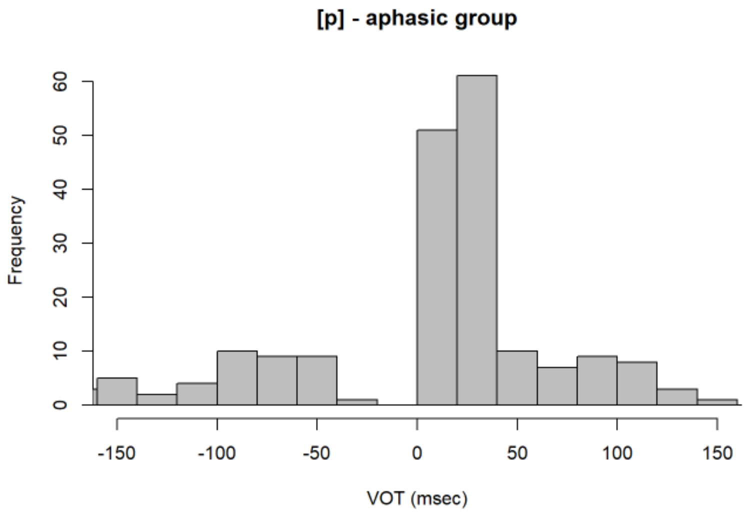
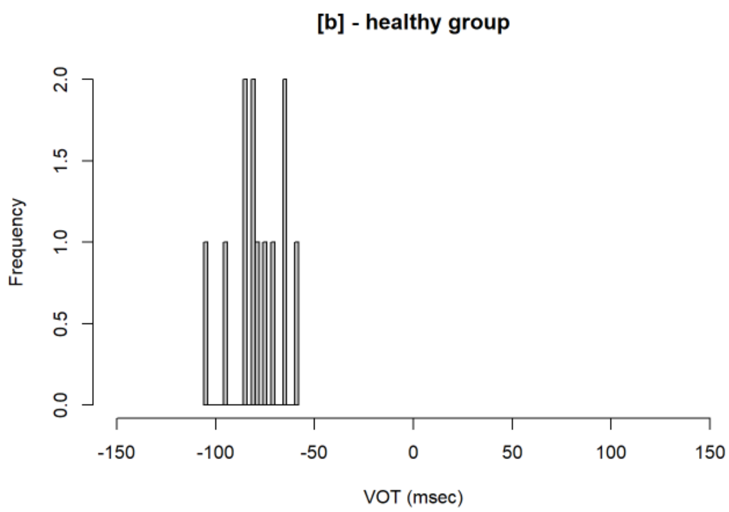


Figure 16 provides the frequency distribution of VOT values at the labial voiced plosive [b] place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number of 18 occurrences for both groups in intervocalic word-medial position. No overlapping of VOT categories or phonetic substitution was found for the [b] plosive category. The values for the labial voiced [b] lie close to a mean of -79msec (long lead voicing) with a minimum of -105msec and a maximum of -60msec for the healthy speakers and a mean of -105msec with a minimum of -166msec and a maximum of -67msec for the aphasics patients. Notably, the difference between the two populations lies in the fact that the [b] productions of aphasic patients (SD: ±38msec, interval -143 to -66msec) were wider than their healthy counterpart (SD: ±13msec, interval -92 to -66msec), yet not significant larger.

Figure 16. Distribution of VOT productions for [b] in intervocalic word-medial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).



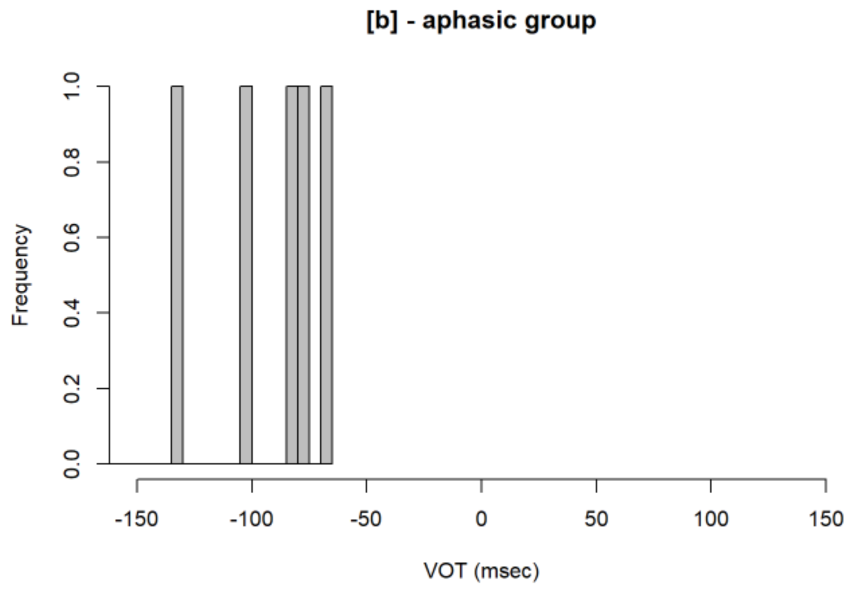


Figure 17 shows the frequency distribution of VOT values at the coronal voiceless [t] place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number of 429 occurrences for both groups at intervocalic and word medial position. No overlapping of VOT categories or phonetic substitution was found for the [t] plosive category. The values for the coronal voiceless [t] lie close to a mean of +14msec (short lag voicing) with a minimum of -85msec and a maximum of +95msec for the healthy speakers and a mean of +17msec with a minimum of -204msec and a maximum of +155msec for the aphasics patients. Notably, the difference between the two populations lies in the fact that the [t] productions of aphasic patients (SD: ±57msec, interval -39 to +74msec) were wider and longer than their healthy counterpart (SD: ±33msec, interval -18 to +47msec), yet not significant larger.

Figure 17. Distribution of VOT productions for [t] in intervocalic word-medial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).

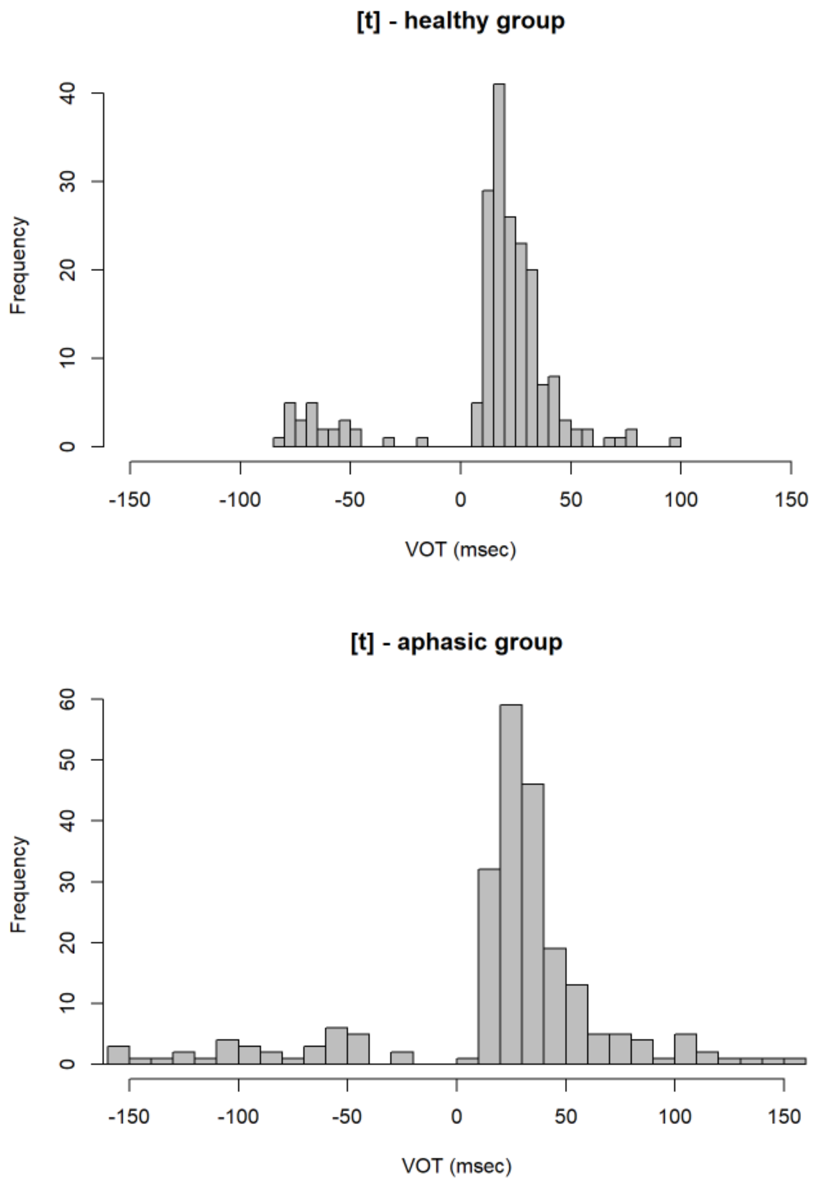


Figure 18 shows the frequency distribution of VOT values at the coronal voiced plosive [d] place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number 273 occurrences for both groups in intervocalic word-medial position. No overlapping of VOT categories or phonetic substitution was found for the [d] plosive category. The values for the coronal voiced [d] lie close to a mean of -70msec (long lead voicing) with a minimum of -143msec and a maximum of +111msec for the healthy speakers and a mean of +75msec with a minimum of -152msec and a maximum of +121msec for the aphasics patients. Notably, the difference between the two populations lies in the fact that the [d] productions of aphasic patients (SD: ±42msec, interval -118 to -33msec) were wider than their healthy counterpart (SD: ±29msec, interval -99 to -41msec).

Figure 18. Distribution of VOT productions for [d] in intervocalic word-medial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).

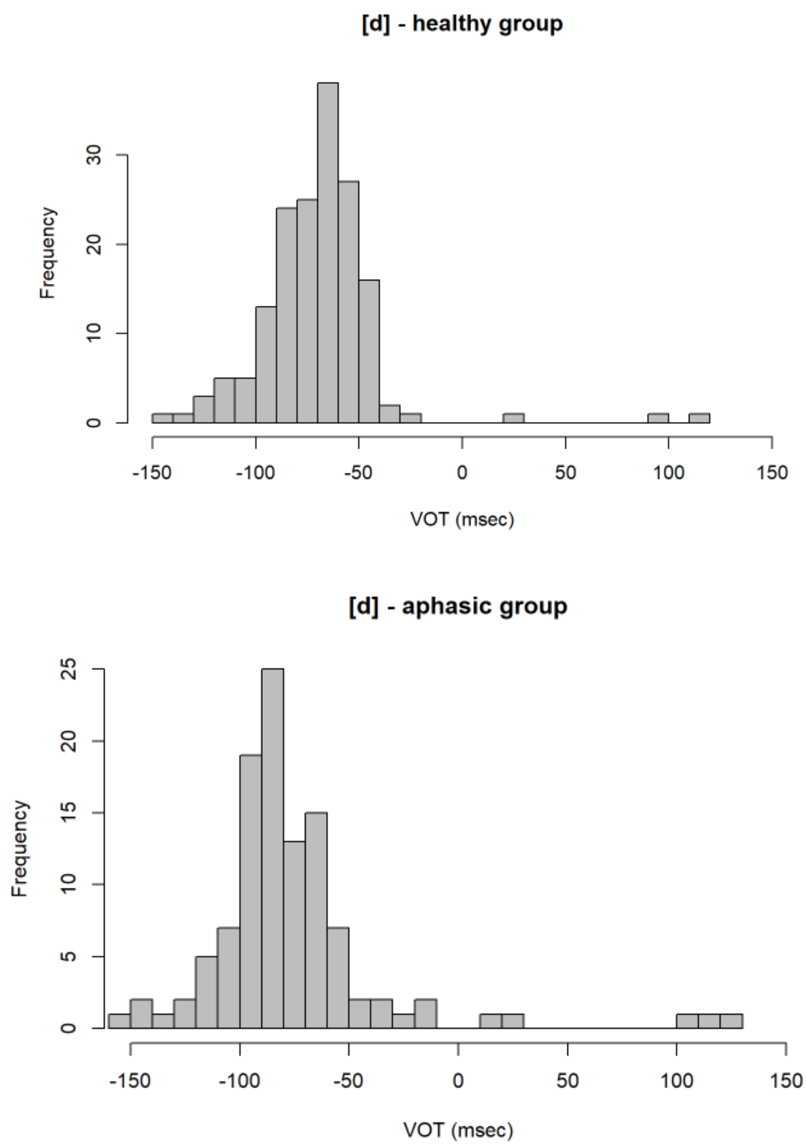


Figure 19 shows the frequency distribution of VOT values at the dorsal voiceless plosive [k] place of articulation for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number 322 occurrences for both groups in intervocalic word-medial position. No overlapping of VOT categories or phonetic substitution was found for the [k] plosive category. The values for the dorsal voiceless [k] lie close to a mean of +20msec with a minimum of -85msec and a maximum of +85msec for the healthy speakers and a mean of +38msec with a minimum of -124msec and a maximum of +164msec for the aphasics patients. Notably, the difference between the two populations lies in the fact that the [k] productions of aphasic patients (SD: ±44msec, interval -6 to - +82msec) were wider and longer than their healthy counterpart (SD: ±32msec, interval -12 to +52msec).

Figure 19. Distribution of VOT productions for [k] in intervocalic word-medial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).

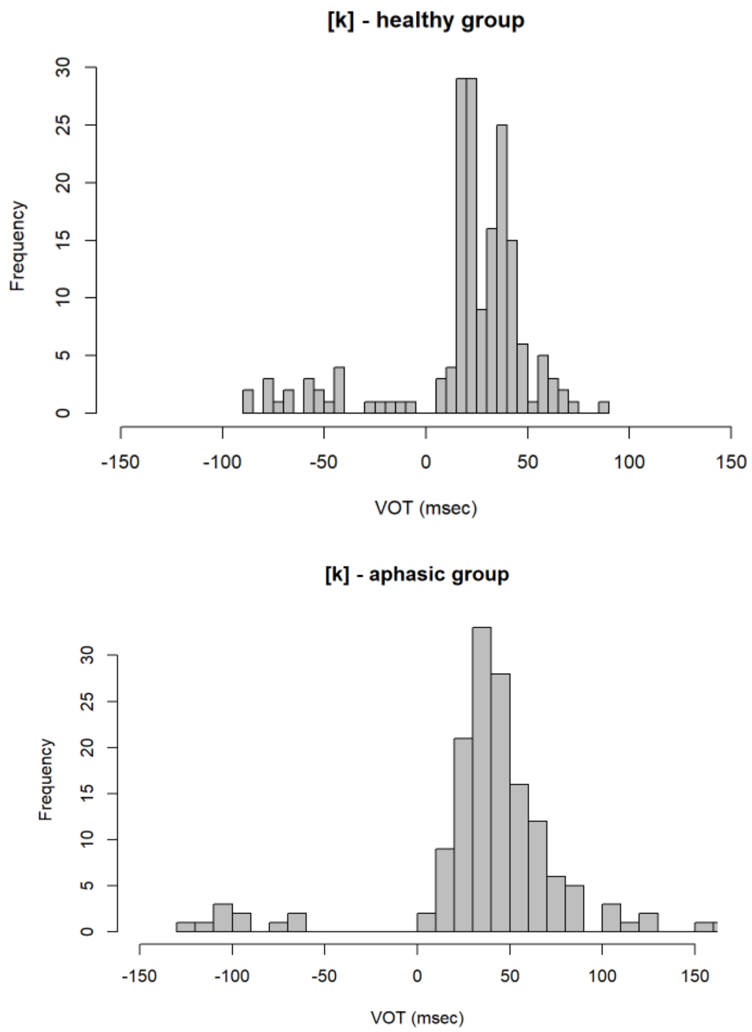
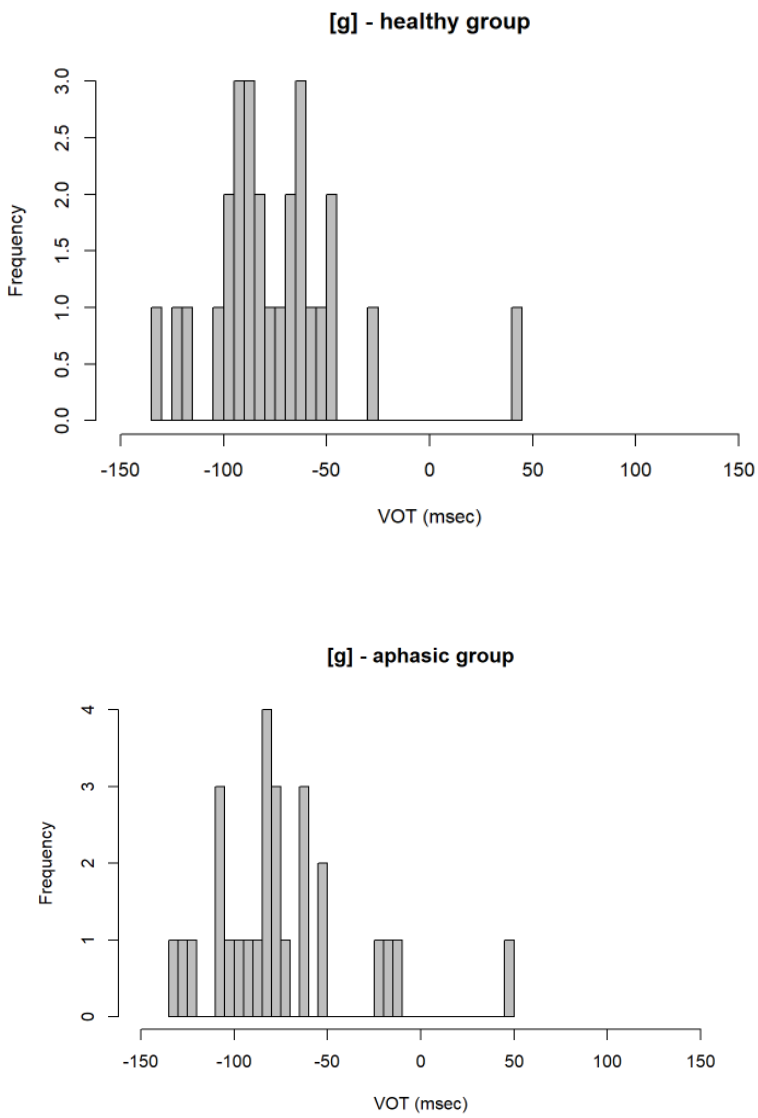


Figure 20 provides the frequency distribution of VOT values at the dorsal voiced plosive [g] for healthy speakers (n=10, upper histogram) and non-fluent aphasic patients (n=10, lower histogram) out of a number of 54 occurrences for both groups at intervocalic and word medial position. No overlapping of VOT categories or phonetic substitution was found for the [g] plosive category. The values for the dorsal voiced [g] lie close to a mean of -75msec with a minimum of -132msec and a maximum of +45msec for the healthy speakers and a mean of -75msec with a minimum of -133msec and a maximum of +45msec for the aphasics patients. Notably, the two groups' productions are almost identical.

Figure 20. Distribution of VOT productions for [g] at intervocalic and word medial position for Greek healthy speakers (upper histogram) versus Greek non-fluent aphasic patients (lower histogram).



9. Discussion & Conclusions

The main goal of our study was to investigate the VOT productions of Greek non-fluent aphasic patients in order to find out whether they maintain distinct VOT categories similar to healthy controls and their French counterparts (Ryalls, Provost a& Arsenault, 1995) or if they exhibited overlapping of VOT categories similar to their English counterparts (Blumstein et al., 1980). We also attempted to look into the type of speech errors –if any– Greek non-fluent aphasics produce. If their VOT productions fell into the normal range of the opposite category (e.g. a [b] target produced as [p] and vice versa), then this is considered a phonological error. On the contrary, if the VOT values fell between the normal ranges of the two categories, then this overlapping of VOT categories is considered a phonetic error.

The overall results of the present study revealed that Greek non-fluent aphasic patients maintain distinct VOT categories similar to healthy controls. The unimodal distributions of VOT productions observed by the histograms of every plosive (sections 8.2.1 and 8.2.3) and verified by the statistical analysis' results (section 8.1.); suggest that Greek non-fluent aphasic patients maintain two distinct regions [3] for voiced and voiceless consonants. However, with the difference that the range of each category was slightly bigger/wider for the aphasic patients in contrast to healthy speaks, yet this difference was not significant (p-value>0.05). For example, the VOT value of the alveolar voiceless [t] ranges from -10 to +45 for a healthy Greek speaker and from -12 to +80msec for a Greek non-fluent aphasic patient and for its voiced counterpart plosive [d] from -80 to -25msec for a Greek healthy speaker and from -155 to -39msec for a Greek aphasic patient. According to the literature, the longer VOTs produced by non-fluent patients may be triggered by their laborious and slow speech language patterns; the underlying reason of which is proposed to be a deficit in the articulatory planning of speech sounds (Goodglass & Kaplan, 1972; Blumstein et al., 1974; 1980).

The findings –of distinct VOT categories– are consistent with the findings of the French language (Ryalls, Provost & Arsenault, 1995), in that French non-fluent aphasic patients maintained two distinct categories, as well; in contrast to English non-fluent patients who exhibit speech errors, namely overlapping of VOT categories (Blumstein et al., 1980). One of the suggestions behind why Greek and French non-fluent aphasic patients

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[3] with the exception of VOT productions of the voiced labial [b] plosive for the aphasic group. We are going to address that in detail below.

maintain discrete VOT categories had to do with the phonetic similarities between the two languages. In both languages, voiced stop consonants are produced with a voicing lead (negative VOT values) and voiceless consonants are produced with a voicing lag (positive VOT values); instead, in English voiced consonants are produced with a short voicing lag (positive values) and voiceless consonants with a long voicing lag (positive values). Perhaps the fact that Greek non-fluent patients (and French) have to produce longer VOT ranges for all three places of articulation (labial*[4], alveolar, velar) may not trigger the production of speech errors. We also hypothesize that the severity of aphasia played a role for this result. Our Greek non-fluent aphasics were mildly impaired, so were their French counterparts (Ryalls, Arsenault & Provost, 1995); instead, for the English Broca's patients, the classification of their severity was not provided by Blumstein and her colleagues (1980).

Moreover, Greek voiceless targets were produced with VOT values similar to those of Greek healthy speakers by all patients and for every place of articulation. The length of VOT values for voiceless plosives, even though a bit longer, follows the universal pattern of increased lag times from labials to velars. On the contrary, the VOT productions of Greek voiced stop consonants revealed a degree of variability across subjects and places of articulation. All participants (both groups) maintained discrete VOT categories for the voiced alveolar and velar places of articulation, however with the exception of the labial place of articulation. Greek non-fluent aphasic patients exhibited an overlapping of VOT categories for the labial place of articulation, as evident from Table 6, the histogram in Figure 11, the plot representations (Plot 1-6) and the marginally significant p-value=0.06 emerged from the statistical analysis.

The voiced labial plosive [b] has a mean VOT value of -63msec (voicing lead) at intervocalic word-initial position and its homorganic voiceless [p] has a mean VOT of +10msec (voicing lag) at intervocalic word-initial position for Greek healthy speakers. The [b] productions of Greek aphasic patients were produced with both negative and positive values as evident from Table 4 and Figure 11. This means that some of the aphasic patients' [b] productions fell into the opposite category (positive VOT) something that is atypical given that Greek healthy speakers produce [b] with a voicing lead. To be able to identify the type of speech error; if Greek aphasics were substituting [b]s with [p]s or if they were producing [b]s with positive values falling anywhere along the VOT spectrum due to a deficit in the

[4] The results of the labial place of articulation were marginally non-significant having a p-value=0.06.

articulatory programming (Goodglass & Kaplan 1972; Blumstein, 1980), further analysis was put forth. The mean VOT values, standard deviations and plots were provided for each Greek aphasic patient individually.

Our results revealed that 6 out of our 10 in total non-fluent aphasic participants produced negative and positive VOT values for the voiced labial place of articulation (and not vise versa). This means that some of the aphasic patients' [b] productions were devoiced. According to Katz (2000, p. 318) *"non-fluent aphasics do not lose the capability to produce traditional phonetic features (e.g. voicing, place or manner); rather they can implement these features in some environments and not others".* This statement was verified from our results in that the same aphasic would produce/exhibit both negative and positive values for a [b] target.

Regarding the type of speech error exhibited in the labial place of articulation in intervocalic word-initial position, the plots (section 8.2.1) revealed that Greek non-fluent aphasic patients did not make substitution errors; the [b] values were not concentrated only in the range of the [p] VOT values (-27 to +47msec). The positive productions of our aphasic patients were spread throughout the VOT continuum exhibiting overlapping of VOT values between and outside the VOT values of the normal ranges of the two categories [b – p]. We hypothesize that this is a phonetic error triggered by a timing impairment in the co-ordination of the articulators (the tongue and the larynx) and thus the deficit is phonetic in nature. This suggestion is in alliance with previous literature (Blumstein et al., 1974; 1980; Katz, 2000).

Nevertheless, the question of why the labial place of articulation exhibits overlapping of VOT categories at word-initial position and why the alveolar and velar places of articulation maintain discrete categories in the same position, needs to be addressed. It is possible that a limitation in our methodological approach plays a big part for this outcome. We chose to analyze spontaneous speech productions for all the reasons mentioned in section 6. However, spontaneous speech analysis is not optimal for eliciting sufficient data because for instance, for the velar [k – g] place of articulation we had only 1 production of [g] for the healthy individuals in intervocalic word-initial position and 0 from the aphasic patients, and for the alveolar [d] place of articulation our data had only 5 productions in total for both populations. We hypothesize that if we had more voiced occurrences in word initial-position, there would have been an overlapping of VOT categories in the alveolar and velar places of articulation in intervocalic word-initial position. Yet, this conclusion is drawn with great caution, is speculative and not significantly proven from our statistical analysis.

Lastly, we investigated the VOT productions of plosives in intervocalic word-initial position and in intervocalic word-medial position. Our Greek non-fluent aphasic patients and our Greek healthy speakers maintained distinct VOT categories in intervocalic word-medial position for both voiced and voiceless categories and for all three places of articulation. The overlapping of VOT values for the voiced labial place of articulation was evident only in the intervocalic word-initial position and not in the intervocalic word-medial position as seen in Figures 11 versus Figure 16. This finding could possibly be linked to a potential morpho-phonological organization deficit and/or word retrieval deficit. Yet again, this is a speculation that was not investigated and is beyond the scopes of the present study.

In conclusion, the unimodal distributions of VOT values for both voiceless and voiced plosives and our statistical results, suggest that Greek non-fluent aphasic patients maintain distinct VOT categories similar to Greek healthy controls. The VOT productions of Greek non-fluent aphasic patients were longer (yet not significantly longer from the healthy controls). We suggest that longer VOT values are due to the overall slow and laborious speech rate non-fluent aphasics exhibit (Blumstein et al. 1974; Katz, 2000). Further research investigating (a) the same topic in Greek with a different methodology and (b) the VOT productions of non-fluent aphasic patients in different languages should be put forth.

10. References

Antoniou, M., Best, C., Tyler, M., & Kroos, C. (2010). Language context elicits native-like stop voicing in early bilinguals' productions in both L1 and L2. *Journal of Phonetics*, *38*(4), 640–653. https://doi.org/10.1016/j.wocn.2010.09.005

Arvaniti, A. (1987). Timing of Consonant Clusters: A Study of Initial Consonant Clusters in Modern Greek. M.Phil. dissertation, University of Cambridge.

Arvaniti, A. (2001c). Comparing the Phonetics of Single and Geminate Consonants in Cypriot and Standard Greek. Proceedings of the Fourth International Conference on Greek Linguistics, 37–44. Thessaloniki: University Studio Press.

Arvaniti, A., & Joseph, B. (2004). Early Modern Greek /b d g/: Evidence from Rebetika and Folk Songs. *Journal of Modern Greek Studies*, *22*(1), 73–94.

Arvaniti, A. (2007). Greek Phonetics: the State of the Art. *Journal of Greek Linguistics, 8,* 97 - 207.

Baum, S. R. & Ryan, L. (1993). Rate of speech in aphasia: voice onset time. Brain and Language, 44, 431-445.

Boersma, Paul & Weenink, David (2019). Praat: doing phonetics by computer [Computer program]. Version 6.0.56, retrieved 20 June 2019 from http://www.praat.org/

Bortolini, U., Zmarich, C., Fior, R. & Bonifacio, S. (1995). Word-initial voicing in the production of stops in normal and preterm Italian infants. International Journal of Pediatric Otorhinolaryngolog y, 31, 191- 206.

Botinis, A., Fourakis M. & Prinou. I. (2000). Acoustic Structure of the Greek Stop Consonants. Glossologia, (11–12),167–200.

Botinis, A. (2001). Intonation. *Speech Communication*, *33*(4), 261–262. https://doi.org/10.1016/S0167-6393(00)00059-5

Blumstein, S. E. (1973). Some phonological implications of aphasic speech. *Psycholinguistics and aphasia.* The Hague: Mouton.

Blumstein, S. E., Cooper, W. E., Zurif, E. B., & Caramazza, A. (1977). The perception and production of voice onset time in aphasia. Neuropsycologia, 15(3), 371–383.

Blumstein, S. E., Cooper, W. E., Goodglass, H., Statlender, S., & Gottlieb, J. (1980). Production deficits in aphasia: a voice-onset time analysis. Brain and Language, 9, 153–170.

Fourakis, M. (1986). A timing model for word-initial CV syllables in Modern Greek. *The Journal of the Acoustical Society of America*, *79*(6), 1982–1986.

Fourakis, M., Botinis, A. & Nigrianaki, E. (2002). Χρονικά Χαρακτηριστικά των Συμφωνικών Ακολουθιών [ps], [ts] και [ks] στην Ελληνική: Timing Characteristics of the Consonant Sequences [ps], [ts]] and [ks] in Greek. Proceedings of the 6th International Conference on Greek Linguistics. [available at http://www.philology.uoc.gr/ conferences/6thICGL/]

Gandour, J., & Dardarananda, R. (1984). Voice onset time in aphasia: Thai. II. Production. Brain and Language, 23(2), 177–205.

Goodglass, H., & Kaplan, E. (1972). The assessment of aphasia and related disorders. Philadelphia: Lea and Febinger.

Holton, D., Mackridge, P., & Philippaki-Warburton, I. (1997). *Greek: a comprehensive grammar of the modern language*. London [etc: Routledge.

Horrocks, G. (1988). Brian D. Joseph and Irene Philippaki-Warburton, Modern Greek. London, Sydney, Wolfeboro (New Hampshire): Croom Helm, 1987. Pp. viii + 281. *Journal of Linguistics*, *24*(1), 243–247. https://doi.org/10.1017/S0022226700011701

Itoh, M., Sasanuma, S., Tatsumi, I., Murakami, S., Fukusako, Y., & Suzuki, T. (1982). Voice Onset Time characteristics in apraxia of speech. Brain and Language, 17, 193-210.

Katz, W. (2000). Anticipatory coarticulation and aphasia: implications for phonetic theories. *Journal of Phonetics, 28,* 313-334.

Kollia, H. B. (1993), Segmental duration changes due to variation in stress, vowel, place of articulation and voicing of stop consonants in Greek. Journal of the Acoustic Society of America, 93, 2298.

Kopkallı-Yavuz, H., Mavis, I. &, Akyildiz, D. (2011). Analysis of VOT in Turkish speakers with aphasia. Clinical Linguistics & Phonetics, 25(4), 287-301.

Lecours, A, R., & Lhermitte, F. (1968). Phonemic paraphasias: Linguistic structures and tentative hypotheses. *Cortex, 5,* 193 – 228.

Lisker, L., & Abramson, A. (1964). A Cross-language Study of Voicing in Initial Stops: Acoustical Measurements. *Word*, 20, 384-422.

Lisker, L., & Abramson, A. (1967). Some effects of context on voice onset time in English stops. Language and Speech, 10, 1-28.

Luria, A. R. (1966). *Higher cortical functions in man*. New York: Basic Books.

Maviş, I. & Toğram, B. (2009). *Language Assessment test for aphasia (ADD).* Ankara: Detay publishing.

Newton, B. (1972). *The generative interpretation of dialect : a study of Modern Greek phonology*. Cambridge [Eng: University Press.

Nicolaidis, K. (2002b). Consonant Lingual-Palatal Contact Patterns Produced by Hearing-Impaired Speakers: Two Case Studies. Recherches en Linguistique Grecque: Actes du 5e Colloque International de Linguistique Grecque, 119–122. Paris: L'Harmattan.

Öğüt, F. Kiliç, M.A., Engim, E. Z., Midilli, R. (2006). Voice Onset Time for Turkish consonants. *Speech communication, 48*, 1094-1099.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation f or Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ryalls, J., Provost, H., & Arsenault, N. (1995). Voice onset time production in French-speaking aphasics. Journal of Communication Disorders, 28(3), 205–215.

Su, Y., Chiu, M., Hsieh, F., & Li, S. (1992). An acoustic analysis of voice-onset time in Taiwanese aphasia. Acta Neurol Sinica, 1(1), 55–63.

Tsapkini, K., Vlachou, C. H. & Potagas, C. (2010). Adaptation and Validation of Standardized Aphasia Tests in Different Languages: Lessons from the Boston Diagnostic Aphasia Examination – Short Form in Greek. Behaviourial Neurology, 22(2-3), 111-119.

11. Appendix

Appendix 1. The hare and tortoise story in Greek followed by an English translation.

<u>Ο ΛΑΓΟΣ ΚΑΙ Η ΧΕΛΩΝΑ</u>

Θα σας διηγηθώ την ιστορία του λαγού και της χελώνας.

Ένα ανοιξιάτικο πρωινό στο δάσος, ένας λαγός είχε βγει απ'τη φωλιά του κι έκανε βόλτα για να βρει τίποτα να φάει. Καθώς περπατούσε, είδε μια χελώνα να περνάει αργά από κοντά του και του φάνηκε πολύ αστείο το περπάτημά της. Άρχισε, λοιπόν, να την κοροϊδεύει και να της λέει ότι ήταν πιο αργή απ'όλα τα ζώα, ακόμη κι από τα σαλιγκάρια.

Η χελώνα τότε σταμάτησε, γύρισε προς το λαγό και του είπε:

- Τι θα έλεγες, λαγέ, να τρέξουμε σ'έναν αγώνα δρόμου για να δούμε ποιός είναι πιο γρήγορος από τους δυο μας;

Ο λαγός βρήκε τόσο αστεία την πρόταση της χελώνας, που ξεκαρδίστηκε απ' τα γέλια. Όταν είδε, όμως, ότι η χελώνα ήταν σοβαρή και το εννοούσε, αποφάσισε να δεχτεί την πρόκληση. Έτσι, όρισαν την αλεπού, σαν το πιο έξυπνο ζώο που ήταν, για διαιτητή και αποφάσισαν να διαγωνιστούν το επόμενο πρωινό.

Πράγματι, το άλλο πρωί, συναντήθηκαν στην αφετηρία, όπου είχαν μαζευτεί όλα τα ζώα του δάσους για να τους παρακολουθήσουν. Η αλεπού έδωσε το σύνθημα και ξεκίνησε ο αγώνας. Η χελώνα, χωρίς να χάσει χρόνο, άρχισε να περπατάει, αργά βέβαια, αλλά σταθερά. Ο λαγός, βλέποντας το ρυθμό της αντιπάλου του και νυστάζοντας, μιας κι ήταν πολύ πρωί ακόμα, σκέφτηκε:

- Δεν πέφτω να κοιμηθώ λιγάκι, κι όταν ξυπνήσω θα τρέξω γρήγορα, όπως πάντα, και σίγουρα θα τερματίσω πρώτος.

Έτσι, η χελώνα συνέχισε να περπατάει, ενώ ο λαγός το έριξε στον ύπνο.

Αφού πέρασε αρκετή ώρα κι ο λαγός παρακοιμήθηκε, κάποια στιγμή ξύπνησε. Σηκώθηκε, λοιπόν, βαριεστημένα και άρχισε να τρέχει. Καθώς έτρεχε προς το τέρμα, του φάνηκε παράξενο που δε συνάντησε πουθενά τη χελώνα, αλλά σκέφτηκε προς στιγμή:

- Μάλλον κατάλαβε ότι θα έχανε τον αγώνα έτσι κι αλλιώς και τον εγκατέλειψε.

Φτάνοντας, όμως, στο σημείο του τερματισμού, είδε έκπληκτος τη χελώνα να τον περιμένει εκεί με μια θριαμβευτική έκφραση στο πρόσωπό της και όλα τα ζώα του δάσους να τη ζητοκραυγάζουν.

Έτσι η χελώνα κέρδισε το λαγό, όχι γιατί ήταν πιο γρήγορη απ'αυτόν, αλλά γιατί παρέμεινε πιστή στο σκοπό της και δεν καυχήθηκε για τις δυνάμεις της, όπως έκανε ο λαγός**.**

English Translation

THE HARE AND THE TORTOISE

I will narrate to you the story of the hare and the tortoise.

A breezy spring morning in the forest, a hare had come out of his nest and started around to find something to eat. As he was looking around, he saw a tortoise walking slowly towards him and he thought that her walk was really funny. He then began mocking her and bulling her by telling her that she was the slowest of all the animals, and as a matter of fact she is even slower than the snails.

The tortoise then stopped walking, turned towards the hare and said to him,

- What would you say, hare, if we compete with a running race and see who is the quickest between us?

The hare found her preposition so funny that he started crying with laughter! But when he realized that the tortoise was serious and meant what she said, he decided to accept the challenge. So they appointed the fox as the match referee, because she is the smartest in the kingdom of animals and decided to compete the next morning.

Indeed, the next morning, they met at the starting point, while all the forest animals had gathered to watch them compete. The fox gave the slogan and the race began. The tortoise, without losing time, began to walk, slowly, of course, but steadily. The hare, watching the rhythm of his opponent and sleeping, since he was still in the morning, and he thought:

- I could take a sweet nap, and when I wake up I will run fast, as always, and I will definitely finish first.

Thus, the tortoise continued to walk, while the hare feel asleep.

After a long time had passed and the hare was in deep sleep, he finally woke up. He got up feeling bored, and started running. As he ran towards the finishing line, it felt strange to him that he didn't meet the tortoise anywhere along the way, but he thought for a moment:

- She probably realized she'd lose the race anyway and quit.

But while he was approaching the finishing line, he saw the tortoise waiting there with a triumphant expression on her face and all the animals on the forest applauding her.

So the tortoise won the hare, and not because she was faster than him, but because she remained faithful and truthful to her goal and did not brag about her powers, as the hare did.