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TEMPORAL PARAMETERS OF VOICELESS STOPS IN A SPEAKER WITH BROCA'S APHASIA AND APRAXIA OF SPEECH: A SINGLE CASE STUDY

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Abstract
This study analyses several temporal parameters of voiceless stops [p, t, k] in the spontaneous speech of a speaker with Broca's aphasia and apraxia of speech at three different moments of his language impairment. The main goal is to determine how damaged these sounds are in relation to their realisation without pathology, as well as to outline their evolution after twenty-two months of therapy. The variables studied have been the duration of the selected consonants, their closure duration and voice-onset time (VOT) duration. Statistical results reveal that temporal parameters show higher values than those found in speakers without language disorder, and that values tend to decrease with rehabilitation, especially for the bilabial realisation. Temporal variations depend upon place of articulation and voicing maintenance or weakening. Moreover, it was also found that the main improvements took place during spontaneous recovery, and that the bilabial realisation differs from the alveolar and velar ones in terms of acoustic characterization, since the former shows higher durational values, as well as more significant improvements.

Keywords: Stops; Acoustics; Aphasia; Broca; Duration.

Parámetros temporales de las oclusivas sordas en un hablante con afasia de Broca y apraxia del habla: estudio de caso

Resumen: Este trabajo pretende analizar los parámetros temporales de las consonantes oclusivas sordas [p, t, k] en el habla espontánea de un hablante con afasia de Broca y apraxia del habla en tres momentos diferentes de su enfermedad, a fin de determinar el nivel de deterioro respecto a su producción sin patología, así como su evolución tras veintidós meses de terapia logopédica. Las principales variables estudiadas han sido la duración consonántica, la duración de la fase de silencio y del VOT (*Voice Onset Time*). Los resultados estadísticos indican que los parámetros temporales presentan valores mayores a los observados en hablantes sin patología y que estos van en descenso a lo largo de la rehabilitación, especialmente para la realización bilabial. Las variaciones en la duración dependen, fundamentalmente, del punto de articulación y de los procesos de mantenimiento o debilitamiento de la sonoridad. Además, se ha advertido que las principales mejoras se han producido durante el periodo de recuperación espontánea y que las características acústicas de la realización bilabial se diferencian de las de las consonantes dental y velar, siendo la primera la que presenta los valores de duración más altos, así como los patrones de mejora más significativos.

Palabras clave: Oclusivas; Acústica; Afasia; Broca; Duración.

Paràmetres temporals de les oclusives sordes en un parlant amb afàsia de Broca i apràxia de la parla: estudi de cas

Resum: Aquest treball pretén analitzar els paràmetres temporals de les consonants oclusives sordes [p, t, k] en la parla espontània d'un parlant amb afàsia de Broca i apràxia de la parla en tres moments diferents de la seva malaltia, per tal de determinar el nivell d'afectació respecte a la seva producció sense patologia, així com la seva evolució després de vint-i-dos mesos de teràpia logopèdica. Les principals variables estudiades han estat la durada consonàntica, la de la fase de silenci i la del VOT (*Voice Onset Time*). Els resultats estadístics indiquen que els paràmetres temporals presenten valors més alts als que s'han observat en parlants sense patologia i que disminueixen al llarg de la rehabilitació, especialment en el cas de realitzacions bilabials. Les variacions en la duració depenen, fonamentalment, del punt d'articulació i dels processos de manteniment o debilitament de la sonoritat. A més, s'ha constatat que les principals millores s'han produït durant el període de recuperació espontània i que les característiques acústiques de la realització bilabial es diferencien de les de les consonants dental i velar, de tal manera que és la primera la que presenta els valors de duració més alts i els patrons de millora més significatius.

Paraules clau: Oclusives; Acústica; Afàsia; Broca; Duració.

1. Introduction

Throughout the evolutionary process of human communication, speech has acquired a fundamental role as the main tool of expression. Speakers shape and coordinate their articulatory gestures and adjust sounds to what they wish to convey, as well as to the communicative situation in which a given speech act takes place. However, linguistic abilities can get significantly impaired when speakers suffer from traumatic brain injuries or neurological disabilities. As a result, the sounds they produce are also affected both articulatorily and acoustically.

This research aims to study voiceless stops [p, t, k] in the spontaneous speech of a Spanish speaker with Broca's aphasia at three different moments of his impairment, from the onset to twenty-two months after having been following speech therapy rehabilitation. The main objective is to determine their level of phonetic damage and evolution by analysing their acoustic properties in relation to temporal parameters: that is, segmental duration, VOT duration –defined as the interval between the release of a stop and the onset of voicing (Martínez Celdrán and Fernández Planas, 2007, p. 66)– and closure duration. The study is based on the extensive literature on these sounds and adds a comparative and longitudinal analysis in order to provide a greater understanding of their development in aphasia, unlike the cross-sectional approach of most of the previous research.

The paper consists of five sections. The first part focuses on the main impairments in Broca's aphasia, the acoustic properties of voiceless stops in speakers with and without the language impairment and the general recovery patterns. The second section outlines the hypotheses, which are followed by the method and phonetic and statistical analyses in the third part. Then, the results and a discussion of the data are presented in the fourth and fifth sections. Finally, conclusions are put forward, as well as several directions for future research.

1.1. Main impairments in Broca's aphasia

Neurolinguistics has defined aphasia as an acquired language deficit resulting from a focal damage in the brain. According to some studies (Gorno Tempini and Santos Santos, 2015), there are three brain areas related to specific aphasic syndromes: atrophy in the left posterior frontal and in the insular regions usually result in a non-fluent or agrammatic aphasia, bilateral atrophies in the anterior temporal lobe are related to semantic aphasia, and lesions in the left temporo-parietal regions are related to the logopenic variant of aphasia. Thus, all linguistic components (phonetic, phonological, morphological, syntactic, and pragmatic) may be impaired, as well as oral and written expression and comprehension skills (González Lázaro and González Ortuño, 2012; Papathanasiou *et al*., 2017).

When treating aphasia, it is important to determine which language functions are still preserved or damaged, so as to outline the diagnosis and treatment to be applied[1]. This paper will focus on characterising Broca's aphasia as it is the one diagnosed to the speaker under study. Most authors (Basso, 2003; Potagas *et al*., 2017; González Lázaro and González Ortuño, 2012; Helm-Estabrooks and Albert, 2005) agree that Broca's aphasia occurs when the lower part of the left frontal lobe (i.e. Broca's area) gets atrophied. It is, thus, a non-fluent variant of aphasia. These speakers lack fluency, their oral expression is based on short, effortful sentences and may present paraphasias at a phonological level –substitutions, omissions, transpositions or addition of phonemes– and a phonetic one –errors in those sounds that require coordination of several articulators such as voiced or nasal ones, for example (Blumstein, 1998). Hence, prosodic features

[1] The taxonomic classification associated with the neo-connectionist model of Norman Geschwind and collaborators is the most widely accepted and used currently in the West (Basso, 2003; Helm-Estabrooks and Albert, 2005). However, Basso (2003) warns that "there is no absolute relationship between the locus of the cerebral lesion and the pattern of cognitive impairments" (p. 38), so it is necessary to pay attention to the specific symptomatology of each speaker at the time of the study or diagnosis.

are often affected too. Furthermore, oral and written agrammatism can manifest itself in systematic omissions of function words, misuses of inflectional and derivational morphology, lack of subordination and spelling errors such as omissions or substitutions. As far as comprehension is concerned, it is usually a well-preserved function.

Due to these articulatory dysfunctions, Broca's aphasia often develops alongside apraxia of speech (AOS), an acquired disorder that affects the correct planning and coordination of the movements necessary for speech (National Institute of Deafness and Other Communication Disorders [NIDCD], 2017). It should be noted that the impairment is not rendered by direct damage to the articulatory muscles, but by a neurological disorder. According to Basilakos (2018), speakers' utterances lack fluency and often include systematic prolongations, interruptions, and repetitions as a result of their difficulty in producing a given sound. Furthermore, apraxia, unlike aphasia, is characterised by distorted sounds resulting in substitutions and additions. That is why making a differentiated diagnosis between apraxia and aphasia can be oftentimes hard for therapists. Not only many symptoms coincide, but also both disorders tend to occur together after a stroke.

Thereupon, several causes can lead to aphasia: strokes, which are responsible for approximately half of the cases; traumas; crises (infections, epilepsy, etc.) and tumours, as well as progressive neurodegenerative diseases, such as Alzheimer's disease (Helm-Estabrooks and Albert, 2005).

Lastly, Broca's aphasia is divided into two subtypes depending on the extent and severity of the lesion. Broca's aphasia type I is characterised by mild sequelae in the articulation, rapid recovery and very moderate agrammatism. Conversely, in Broca's aphasia type II the lesion extends beyond Broca's area and causes severe sequelae and slow recovery (Basso, 2003; González Lázaro and González Ortuño, 2012).

1.2. Voiceless stops in Spanish[2]

From an articulatory approach, voiceless oral stops are characterised by a closure in the vocal tract, followed by an abrupt explosion that releases the air contained. Thus, Hidalgo Navarro and Quilis Merín (2004) recognise three distinct phases in the articulation of these sounds: implosion, occlusion, and explosion. As for the occlusion, several articulators can take part in the closure: the lips /p/, the tip of the tongue and the inner face of the upper incisors /t/, or the back of the tongue and the soft palate /k/. Also, the vocal folds remain fairly close to each other –though not completely closed– and do not vibrate, which distinguishes them from their voiced counterparts /b, d, g/[3].

Acoustic correlates of these three phases manifest themselves in the spectrogram as rapid transitions of the preceding and following formants (implosion), as a white area without energy that coincides with the closure of the articulators (occlusion), and as a vertical line or bar with energy at different frequencies that corresponds to the abrupt separation of the articulators (explosion) (Quilis, 1981).

Regarding their distribution, some authors agree that their production is explosive [p, t, k] when they hold a prenuclear position (Quilis, 1981; Hidalgo Navarro and Quilis Merín, 2004), whereas in postnuclear position, the outcome varies considerably. Nonetheless, Machuca (1997) notices that when they are part of the syllable onset, these sounds do not only maintain –that is, they keep the correspondence with their phonemes /p, t, k/– but they can also undergo weakening processes which result in a voiced, approximant, or fricative production. According to her results, the outcome tends to be voiced in intervocalic position or after a nasal, approximant when the sounds

[2] The following review focuses on research conducted on Standard Peninsular Spanish, since this is the variety spoken by the participant.

[3] Some researchers argue that sonority is not a distinguishing feature of voiced and voiceless oral stops and advocate for other properties such as duration. See Martínez Celdrán and Fernández Planas (2007) or Martínez Celdrán (1993, 1997) for a broader discussion on this subject.

are between vowels, and fricative after a velar fricative consonant or when they are merely velar, that is without being in a fricative context.

1.2.1. Closure duration

In order to acoustically characterise stops, Martínez Celdrán and Fernández Planas (2007) agree that the three phases are relevant[4]. Regarding the closing phase (occlusion), it is essential to consider several investigations conducted by Martínez Celdrán where closure duration seems to be a distinguishing feature for tense and lax stops.

In a first paper from 1993, the author analysed how the sounds [p], [pp] and [β] are perceived in several sequences such as [kapa], [kappa] and [kaβa]. He concluded that the mean values for closure duration go from 70 to 140 ms for the voiceless bilabial and from less than 70 ms for the voiced one. As for the geminate, the minimum duration is 150 ms, but it can be lengthened overtime.

Moreover, in a later study from 1997, the author got similar mean intervals (voiceless closure duration: 75-79 ms *vs*. voiced closure duration: 28-31 ms) and highlighted the influence of the stop consonant on the length of the preceding nasal: the greater the tension, the shorter the duration of the nasal. Therefore, it can be assumed that /p, t, k/ have longer closing phases as opposed to /b, d, g/.

1.2.2. VOT duration

With respect to the release phase (explosion), many studies have argued that in Spanish VOT (Voice Onset Time) might be able of setting stop consonants apart according to their voicing features (Castañeda Vicente, 1986) and place of articulation (Asensi *et al*., 1997; Castañeda Vicente, 1986; Martínez Celdrán and Fernández Planas, 2007; among others). According to the results listed in Table 1, VOT values increase as the place of articulation (PA) moves from the lips to the velar area.

Authors	Position	[p]	[t]	[k]
Asensi *et al*. (1997)	Initial and intervocalic	14,7	20,2	35,4
Castañeda Vicente (1986)	Initial	6,5	10,4	25,7
Martínez Celdrán and Fernández Planas (2007)	Unspecified	14	20	35

Table 1. Mean values for VOT duration in milliseconds for [p, t, k] in relation to its position in the word. The values correspond to different studies conducted for Standard Peninsular Spanish.

Further analyses also note that the sex of the speaker can have an influence on VOT duration (Asensi *et al*., 1997). Thus, a female voice might show higher VOT duration values than the male one. Likewise, Castañeda Vicente (1986) observes a slight influence of the quality and stress of the following vowel on the VOT: VOT values are higher when the syllable is unstressed and if it is followed by a back vowel (the more posterior the vowel, the higher the values). Still, they do not find evidence showing that the position of voiceless stops in the word could alter VOT duration values.

Another issue worth highlighting is how speed might affect VOT duration. Miller *et al*. (1986) studied the production of /bi/-/pi/ sequences at different speeds for English (fast= 100-300 ms;

[4] Despite how important transitions are to discriminate between the three sounds /p, t, k/, this paper will not analyse them as it does not meet our objectives.

medium= 300-500 ms; slow= 500-700 ms) and concluded that as speed decreases, both syllable duration and VOT value increase, especially for the voiceless segment /pi/.

In relation to voicing and VOT in Spanish[5], Castañeda Vicente (1986) argues that stops show polarization of voicing contrast (positive or negative) depending when the glottal pulses begin. If they begin before the release phase, the segment will be voiced and the VOT values will be negative. Conversely, if they begin afterwards, the sound will be voiceless and the values positive. In addition, voiceless stops show slightly longer VOT durations than their voiced counterparts and their weakened/sonorised realisations (Machuca, 1977).

For spontaneous speech, Machuca (1997) found similar values to those presented above for laboratory speech. According to her results, mean VOT values for voiceless stops are 12.63 ms for [p], 18.47 ms for [t] and 27.69 ms for [k].

1.2.3. Segmental duration

When it comes to the length of stops, it is widely accepted that total duration varies as a function of closure duration. That is, the longer the closure, the longer the duration of the consonant. Consequently, not only do voiceless stops show longer closures than voiced stops, but they are also longer as single consonants. Gibson *et al*. (2015) found significant results proving this premise and demonstrated that voiceless stops last up to 89 ms in word initial position whereas voiced stops just last 69 ms.

Similarly, the same authors, who only studied bilabial and velar productions, observed how the place of articulation can have a slight amount of influence on segmental duration: a mean of 85-90 ms is documented for bilabials, while velars can last up to 100-105 ms[6]. That is, the more posterior the place of articulation, the longer the duration of the consonant.

As for spontaneous speech, segmental duration shows similar results to those already discussed (Machuca, 1997). Still, the author highlights some regular influence of the preceding context on the duration of the consonant. As Table 2 shows, voiceless stops decrease in duration when they are preceded by a nasal consonant, but they increase after an obstruent or a fricative. However, no significant differences are observed due to place of articulation or rhyme complexity.

Preceding consonant	[p]	[t]	[k]
Nasal	56,25	56	60,25
Liquid	75,25	72,5	70
Fricative	75,5	72,75	73
Obstruent	63	90,25	90
Vowel	71,25	68,25	67,75

Table 2. Mean values for consonant duration in milliseconds for [p, t, k] as a function of the preceding context. The results are extracted from Machuca (1997, Appendices, p. 1, 23, 43, 63).

Machuca also reported results showing a reduction in segmental duration when the voiceless stop undergoes a weakening process. Even so, weakened voiceless stops still present higher values than voiced realisations, i.e., those that come from voiced phonemes and, thus, from a

5 As mentioned above, the voicing contrast for stops is a complex subject addressed by a great number of studies. However, this paper will only focus on the acoustic correlates of voicing in VOT given the stated objectives. See Martínez Celdrán and Fernández Planas (2007) or Martínez Celdrán (1993, 1997) for a more extensive discussion on the subject.

6 Since Gibson *et al*. (2015) do not present exact data for [p] and [k] temporal values, but a graph with a 10 ms space interval, the values have been roughly delimited to 5 ms in order to make the extracted data more precise. Thus, the exact means lie between the intervals provided.

maintenance process. Overall, the author concludes that her results for spontaneous speech meet the acoustic cues that can distinguish between /p, t, k/ for laboratory speech.

1.3. Voiceless stops in Broca's aphasia

Speech errors for a speaker with aphasia can be both phonological and phonetic in nature. This is why aphasiology has deeply studied the type of errors that are commonly present depending on the lesion and disorder. According to Blumstein (1998), while phonological paraphasias appear in most aphasias, especially in fluent ones, those that are phonetic in nature are more widespread in anterior aphasias, in which there is more difficulty in articulating sounds fluently and with coordination. Therefore, given the difficulty in producing voiced sounds while maintaining a closure in the oral cavity, researchers have studied the VOT as a means to accurately determine the type of impairment specific to each aphasia.

To begin with, VOT holds positive or negative values with minimum overlap depending on whether the segment is voiceless or voiced. Phonetic errors will be identified by values falling beyond the expected or acceptable range, but without reaching those from the opposite category (Blumstein *et al*., 1980). Thus, several studies have ascertained the presence of phonetic errors in English patients with Broca's aphasia that manifested themselves as overlaps between voiceless and voiced values (Baum *et al*., 1990; Blumstein *et al*., 1980; Tuller, 1984). The same was also observed in other languages such as Thai, Turkish or Taiwanese (Tsiara, 2019), as well as for patients with apraxia of speech (Basilakos, 2018). Nonetheless, these results do not entail a merge or combination of both categories at the phonological level, but they simply confirm the presence of large motor coordination deficits (Tuller, 1984). However, it is worth noting that the voicing contrast in English stops is largely dependent on VOT duration –voiced stops have a shorter VOT than voiceless stops– unlike other languages such as Spanish, where the main difference relies on the timing of glottal pulses onset (Gibson *et al*., 2019).

Thereupon, this overlap does not seem to occur in all languages. After studying VOT in Greek speakers with non-fluent aphasia, Tsiara (2019) found only a minimal overlap of the bilabial plosive and none of the alveolar or velar. Similarly, Marczyk (2015) did not observe any overlaps of VOT values for non-fluent aphasia in Spanish, but rather parameters moved around positive or negative ranges depending on whether the production was voiceless or voiced, as is expected for speakers without language disease. Such results might point at an equivalence between Spanish and Greek in terms of their voicing contrast features for stops, in contrast to what is observed was English, Turkish or Taiwanese.

What Marczyk (2015) also mentions, just as all the authors cited above, is an increase in VOT duration in aphasic productions, especially in voiceless ones. Blumstein *et al*. (1980) indicate that, despite finding an increase in duration, VOT values for voiceless stops in Broca's aphasia does not exceed 150 ms. This parameter, then, might distinguish aphasic productions from those typical from dysarthria, i.e., a motor speech disorder resulting from lesions in the articulators (Blumstein, 1998). As far as Spanish is concerned, Marczyk reported a difference of 5.6 ms between the control group's productions and the Broca's ones. According to her data, in absolute initial position, mean VOT values for voiceless stops were 10.91 ms for the control group and 15.04 ms for Broca. On the other hand, in stressed syllable onset position the former got 11.88 ms and the latter increased to 19.04 ms.

Moving to the different places of articulation, Marczyk and Machuca (2018) analysed the temporal parameters of intervocalic obstruents in Spanish speakers with Broca's aphasia and apraxia of speech. As in the studies mentioned before, the authors reported slightly higher mean VOT values for speakers with aphasia in comparison with the control group: aphasia, [p]= 15 ms; [t]= 19 ms; [k]= 37 ms *vs*. control, [p]= 12 ms; [t]= 20 ms; [k]= 30 ms.

In addition, Baum and Ryan (1993) studied how such an increase in VOT duration values may also be affected by fluctuations in speed of utterance. As expected, they concluded that VOT values for each segment increased as speed dropped, being the voiceless and velar ones the longest in duration. Also, they observed that phonetic errors in Broca's aphasia tend to worsen at a faster speed and that these speakers can still modify their speed of utterance, but to a lesser degree than speakers without language disorder.

As VOT duration values increase in aphasic speakers, segmental duration also does so. Marczyk and Machuca (2018) confirm that voiceless stops have the longest durations in patients with aphasia, with a mean of 200 ms for voiceless stops and 144 ms for voiced stops. Furthermore, Marczyk (2015) observed that it is Broca's patients who present the highest values (with a mean of 109.20 ms for voiceless stops placed in between sonorant segments and 120.41 ms in syllable onset position), compared to the groups with conduction aphasia (71.80 ms and 84.13 ms) and to control groups (105.17 ms and 98.9 ms). It is noteworthy that the author also found a significant influence of some phases of the method on segmental duration: plosives tend to be longer in reading tasks than in repetition tasks. These results were also reported by Williams and Seaver (1986) when studying consonant and vowel duration in aphasics' spontaneous speech: "although the spontaneous speech of Broca's aphasics is typically perceived as labored, such is not always the case for single-word productions" (p. 178-179).

Finally, as for error distribution, most authors agree that Broca's aphasics tend to make a greater number of errors in syllable onsets, especially in absolute initial position, due to their difficulty in initiating speech (Marczyk, 2015; Tuller, 1984), and their inadequate articulatory tension (Marczyk and Baqué, 2015). According to the latter authors, the most common errors in initial position are segmental substitutions, which are present in more than 50% of the reported cases, followed by elisions, distortions, contextual substitutions, and additions. As far as substitutions are concerned, devoicing errors are particularly noteworthy, as opposed to sonorizations and spirantisations, which seem to be less common. This tendency was corroborated in Marczyk's (2015) study too. She pointed out that the probability of finding a sonority-related error is 2.5% and only 0.2% of these cases would be instances of sonorizations. Yet, the few sonority errors that she found were in initial position. Similarly, as for substitutions errors related to manner of articulation, she gave an account of 89/260 (34.2%) cases of spirantisations and noticed that the likelihood of finding this type of error decreased considerably down to 1.9% compared to a 10% likelihood for occlusivisations.

1.4. Recovery patterns in aphasia

In order to rehabilitate aphasia's speech, it is important to consider recovery patterns in relation to time and treatment. Firstly, it is widely accepted that several factors may influence the prognosis of recovery, and in most cases, it is difficult to establish a clear pattern. According to González Lázaro and González Ortuño (2012), there are four categories that might predict patients' evolution and recovery: brain damage, personal history, environment and physiological conditions and language rehabilitation. However, the extent to which each factor may affect aphasia recovery is a subject of great discussion in the literature (Basso, 2003).

Secondly, it has been shown that initiating speech therapy during the period of spontaneous recovery can have beneficial effects on recovery, as it is throughout these first 2-6 months after the onset that much of the improvement occurs (Basso, 2003). Several research reports significant improvements lasting up to twelve months post-onset in those patients who began treatment after their stroke and kept on it during the period of spontaneous recovery (Taylor Sarno, 1998). Conversely, detrimental effects may be observed if the time between the onset and the start of therapy is too long, being only 5% of such patients the ones expected to show significant improvements (Basso *et al*., 1979).

This is why González Lázaro and González Ortuño (2012), Papathanasiou *et al*. (2017) and Basso (2003) vouch that aphasia should be treated and rehabilitated. They even state that, in comparison with untreated aphasia, any type of therapy –professional or non-professional– is more effective. For treated aphasia, the frequency and intensity of such therapy seems to be a decisive factor for recovery: the longer and more intense the therapy, the better the prognosis of recovery (Worrall *et al*., 2017). Despite that, it is still not possible to set an optimal number of sessions that would work for every patient, so treatment should always be established according to the needs and particularities of each one of them. In this regard, a research by Basso *et al*. (1979) gave an account of 281 Italian speakers who, despite having started treatment after spontaneous recovery, improved their language skills by attending sessions from three to five times per week for at least six months. According to her results, 59% of the patients with moderate non-fluent aphasia improved their ability to express themselves orally, while only 13% of the severe non-fluent patients were able to recover their oral skills. Overall, authors and therapists have sufficiently demonstrated how beneficial therapy is when treating aphasia, although bearing in mind the effects that severity and time elapsed post-onset can have on recovery.

With respect to improvements in language skills, Basso *et al*. (1979), Basso (1992) and Taylor Sarno (1998) observed that oral expression generally shows greater deficits and less improvements than comprehension. By studying three groups of Dutch speakers with post-stroke aphasia (fluent, non-fluent and mixed) over 12 months, Prins *et al*. (1978) confirmed that the highest improvements were found in comprehension, as opposed to spontaneous speech productions. Additionally, in relation to articulation and phonemic paraphasias, the average improvement of the three groups was minimal and not significant, and they even observed a deterioration in phoneme preservation.

2. Hypotheses

On the basis of the reviewed literature, four hypotheses are extracted as follows:

(a) Segmental, closure and VOT duration values are expected to decrease from the first session to the last. Overall, duration values might vary as a function of time under treatment, which would translate as an improvement in the speaker's oral expression.

(b) The highest rate of errors (sonorisations and fricativisations) is expected to be found in the first sample and to decrease as the speaker progresses through treatment. Even so, a low percentage of sonorisations is anticipated given aphasics' difficulty in producing voiced realisations.

(c) As for the preceding context, it is expected to affect the overall duration of stops. Those preceded by nasal segments are anticipated to show the shortest duration, as opposed to those preceded by obstruents, which will have the highest values.

(d) Consonant and VOT duration values will depend upon place of articulation and whether maintenance or weakening processes occur, as indicated in the literature. By extension, it is expected that closure duration will be shorter in those realisations that have weakened compared to those that have maintained as voiceless.

3. Method

3.1. Participant

This paper is based on three speech samples from a 44-year-old speaker of Standard Peninsular Spanish who was diagnosed with severe Broca's aphasia and apraxia of speech after having a stroke in January 2017. According to the initial medical examination (see Appendix 1), the speaker presented oral language deficits, lacked fluency, and based his responses on *yes* or *no*. The most efficient communication was done through writing.

Immediately after the stroke, the speaker started speech therapy for two hours every week and kept on it to the present day. In January 2018, after twelve months under treatment, a reduction in the initial aphasic symptoms was observed, especially regarding oral communication and the ability to create and organize speech. Nonetheless, instances of agrammatism and phonetic paraphasias were still present.

Concerning the present study, it could not be determined whether the patient specifically worked on the production of plosives in his rehabilitation sessions, as there was no record in the speech therapy report. However, it has been assumed that these sounds were treated by the speech therapist either directly or indirectly, since part of his treatment focused on working on speech, narration and comprehension skills through reading and writing tasks, on producing isolated sounds (alveolar: l-d-r, consonant clusters...), and on formal discourse (information extracted from the medical examination attached in Appendix 1).

3.2. Data collection and corpus

This longitudinal study consists of three interviews done at different moments of the speaker's disorder. Data recordings were done in the anechoic chamber found in the Speech Treatment Service (*Servei de Tractament de la Parla*) in Autonomous University of Barcelona. The first one took place in June 2017, five months after having suffered the stroke and starting treatment; the second was recorded in February 2018, after thirteen months under treatment; and the third was done in October 2018, that is, after twenty-two months of therapy. The time period between recordings was eight months from the first to the second, and nine months from the second to the last. In each session, the speaker was instructed to perform different tasks concerning oral expression and skills: description of pictures, reading, repetition of isolated words and conversation with the interviewer on everyday topics for approximately 45 minutes.

With respect to the present study, we have only examined conversational tasks given our objectives. Specifically, the analysis focuses on the duration of voiceless stops in simple syllable onsets both in word initial and word medial position. Differences in word position have not been considered since it did not meet the objectives of this paper. Complex onsets have not been considered either, because errors in consonant clusters are of a different type in aphasia. Words where the speaker hesitates or stutters have been excluded from the analysis too, as well as those where the speakers' voices overlap.

All in all, this renders a total of 726 items, which have been classified according to temporal values: closure duration, segmental duration and VOT duration. Recall that neither consonant duration nor closure duration could be analysed in 148 stops, as they were preceded by a pause, and it is impossible to define the length of this phase without a preceding context. As for closure duration, 7 examples with fricativisation[7] and 4 cases with audible silences (i.e. with successive bursts) were ruled out. Thus, segmental duration was analysed in 578 items, whereas closure duration was examined in 567 cases. In regard to VOT, the total number of items analysed was 719, since the 7 fricativised stops were also excluded. Finally, the number of items extracted from the first session has been slightly lower compared to the second and the third. This is due to the minutes devoted to each conversation, being the first one the shortest of them all, followed by the third and then, the second, which was the longest (see Appendix 2 for a more detailed sample of the number of items analysed in relation to temporal parameters, sessions, places of articulation, preceding contexts and maintenance or weakening processes).

[7]Audible friction noise was found in seven stops in which neither the closing nor the release phases were present. Therefore, we could only analyse segmental duration for these seven items.

3.3. Phonetic and statistical measurements

The speech samples were segmented using Praat speech analysis software (Boersma and Weenink, 2019). The parameters labelled in the signal were consonant voicing, preceding context and place of articulation. The labelling was divided into three tiers according to the place of articulation (tier "phones"), the preceding context and voicing (tier "oclusivas"), and the closing phase and VOT (tier "parametros"). The latter was also used to mark those stops that presented friction or short successive bursts in the closing phase. This labelling is illustrated in Figure 1 with the segmentation of a voiceless velar stop under a weakening process (i.e., sonorisation).

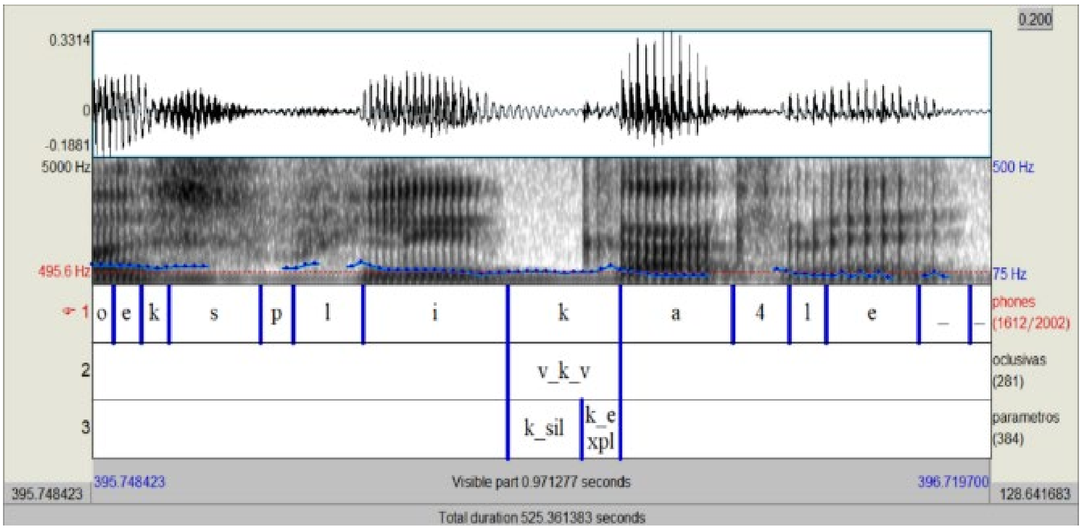

Figure 1. Segmentation of a weakened voiceless velar stop in a simple syllable onset from the word *explicarle*.

Duration values were extracted automatically after labelling the corpus. The extracted data accounted for temporal parameters of consonants, closing phases and VOT. As indicated in Figure 1, consonant duration was marked out from the beginning of the white area without energy – corresponding to the closure of the articulators– to the beginning of glottal pulses from the following vowel. The closing phase was defined by this white area with no energy ("k_sil" in Figure 1) and, finally, VOT was measured from the beginning of the release phase to the beginning of glottal pulses ("k_expl" in Figure 1).

As for voicing parameters, it was considered that the stop had weakened[8] when a continuous prolongation of the melodic contour was observed throughout the segment up to the following vowel (see Figure 1). Otherwise, in the absence of these f0 variations at some point of the segment, it was concluded that the stop was voiceless and, that it had maintained its voicing feature. Recall that the voicing feature and how it manifests itself in stop consonants is an extensive and complex subject that would require a different and exclusive study. Therefore, according to the reviewed literature and in response to the objective of this paper (i.e. to analyse the temporal parameters of voiceless stops), this has been the only criterion used to distinguish between voiceless realisations that have maintained and those that come from a weakening process.

[8] The label 'sonorised stop' or 'weakened stop' will be used interchangeably in this paper. However, it is worth noting that a weakened stop could result in either a voiced, an approximant or a fricative production (Machuca, 1997).

Finally, variations in mode of articulation were identified when consonants had lost their acoustic characteristics and presented friction noise. Such examples were considered fricativisations and, thus, only segmental duration could be analysed.

As for the variables, we studied both phonetic categories based on the acoustic characteristics of the sounds observed in the spectrogram and duration values as a function of place of articulation, preceding context, session, and voicing process (maintenance or sonorisation).

Once the data was extracted, a set of ANOVA tests were carried out with RStudio software (RStudio Team, 2015) so as to analyse probability values, means and deviations for each of the variables. The purpose of the analysis was to ascertain to what the extent the independent variables (i.e., preceding context, place of articulation, maintenance or weakening process and number of session) had influence over the three dependent variables (i.e., segmental duration, closure duration and VOT duration). Thus, the statistical analysis was structured into four sections according to the four independent variables. Finally, a Pearson's chi-square test ($\chi 2$) was done to identify any relationship between three of the categorical variables. For that purpose, the type of process has been taken as the dependent variable, whereas the independent variables have been the number of the session and the place of articulation.

4. Results

In response of the hypotheses presented, the sections below report the results for duration values as a function of the session, the preceding context, the place of articulation and the process. The percentage of errors per session according to hypothesis (b) is also discussed.

4.1. Hypothesis (a): temporal values as a function of the session

4.1.1. Segmental duration

Table 3 presents the mean values and standard deviations for segmental duration as a function of the session and the place of articulation. A progressive decrease in mean duration is observed from the first session to the last for both the bilabial and the dental productions. Conversely, the velar stop shows a slight increase in values from the first session to the second and a decrease from the second to the third. Furthermore, although there is a significant influence of the session on segmental duration ($F(2, 576)= 8.817$, $p < 0.05$), relevant differences are only observed for [p] between the first and third session ($F(4, 574)= 3.017$, $p < 0.05$), as well as between the second and third ($F(4, 574)= 3.017$, $p < 0.05$). As for [t] and [k], differences in values across the three sessions are not significant ($p > 0.05$).

	[p]		[t]		[k]	
	mean	sd	mean	sd	mean	sd
Session 1	144,2	68,5	103,1	46	98,4	31,2
Session 2	129,6	45,6	102,5	34,5	113,5	40,5
Session 3	105,5	38,5	91	34,6	100,6	33,4

Table 3. Mean values and standard deviations in milliseconds for segmental duration as a function of the session and the place of articulation.

4.1.2. Closure duration

Values for closure duration are reported in Table 4. The results reveal a highly significant decrease in mean values and standard deviations for [p] from the first session to the third ($F(4, 563)= 3.217$, $p < 0.05$). On the other hand, regarding [t] and [k], there was a slight increase ($p > 0.05$) in values between the first and second session, and a non-significant decrease ($p > 0.05$) between the second and third. Once again, the bilabial stop is the only one presenting relevant variation in temporal values.

	[p]		[t]		[k]	
	mean	sd	mean	sd	mean	sd
Session 1	131	67,6	79,5	43,8	70,4	27,9
Session 2	111	40,8	79,7	35,9	83,2	38,7
Session 3	90,4	38,5	67,4	34,5	70,4	30,6

Table 4. Mean values and standard deviations in milliseconds for closure duration as a function of the session and the place of articulation.

4.1.3. VOT duration

In relation to VOT duration, no significant differences were found for each of the consonants across the sessions ($F(4, 715)= 1.251$, $p > 0.05$). That is, VOT duration for [p], [t] and [k] maintained its mean values throughout the three sessions, as shown in Table 5.

	[p]		[t]		[k]	
	mean	sd	mean	sd	mean	sd
Session 1	15,5	6,4	23,1	14,8	32,2	10,5
Session 2	18,9	9,5	23,3	8,3	31,9	10,1
Session 3	16	6	24,4	12	31,4	10

Table 5. Mean values and standard deviations in milliseconds for VOT duration as a function of the session and the place of articulation.

4.2. Hypothesis (b): sonorisation and fricativisation errors

Results show that the total percentage of sonorisation errors was 18.3%. As for their distribution over the sessions, there was a significant difference between the first and second ($p < 0.05$), with the first session having the highest number of sonorisations (39.4%) and the second showing the lowest (12.3%). As for the third session, there is a slight increase ($p > 0.05$) of 2.8% in relation to the second session, although it is still significantly lower ($p < 0.05$) than the one observed in the first session. Overall, the percentage of sonorisations for each specific plosive across the three sessions follows the pattern explained above, with no significant differences between them (Figure 2).

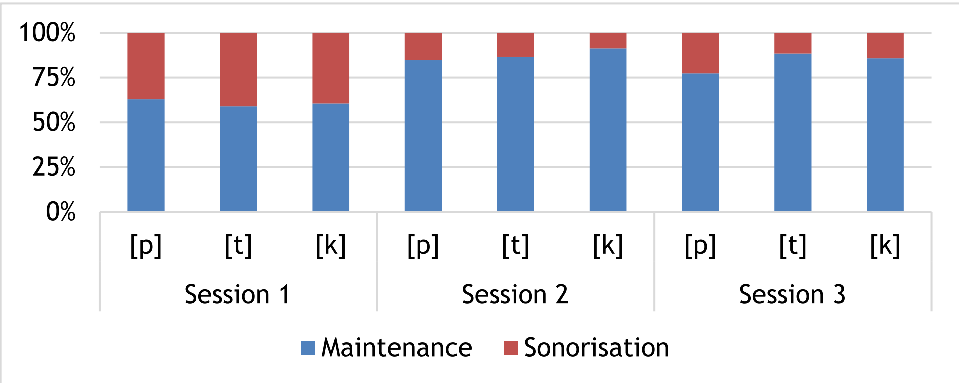

Figure 2. Percentage of maintained and sonorised stops in relation to the place of articulation and the session.

Furthermore, the total percentage of fricativisation errors was 1.21% and were only produced in the dental stop. Its distribution throughout the three sessions is quite similar to what was observed for sonorisation errors: in the first session, the percentage reported was 1.9%, in the second session it was 0.8%, and 1.2% in the third one. It is also worth noting that 71.4% of these cases resulted from a stop following a fricative consonant. In the remaining cases, the stop held a postvocalic position.

Finally, short successive bursts were also found in the closing phase of [t]. However, this type of realisations only occurred in the first session and did not exceed 0.7% of the total number of the items analysed.

4.3. Hypothesis (c): temporal values as a function of the preceding context

4.3.1. Segmental duration

Figure 3 shows mean values and deviations for segmental duration as a function of the preceding context and the place of articulation. It is observed that [p] and [t] duration reach the highest values after a vowel, although the difference is not significant ($p > 0.05$). Both bilabial and dental realisations have significantly shorter duration when preceded by a nasal consonant compared to when they are placed after a vowel ($F(8, 570)= 1.715$, $p < 0.05$). However, no relevant differences in duration for these two stops are observed when comparing the nasal context with the rest of the contexts ($F(8, 570)= 1.715$, $p > 0.05$). Regarding [k], on the one hand, the longest duration is reported when the consonant is preceded by a lateral consonant, although values are not significant either ($p > 0.05$). On the other hand, the consonant tends to be shorter when it is preceded by a tap in comparison to the values obtained in postvocalic position ($F(8, 570)= 1.715$, $p < 0.05$).

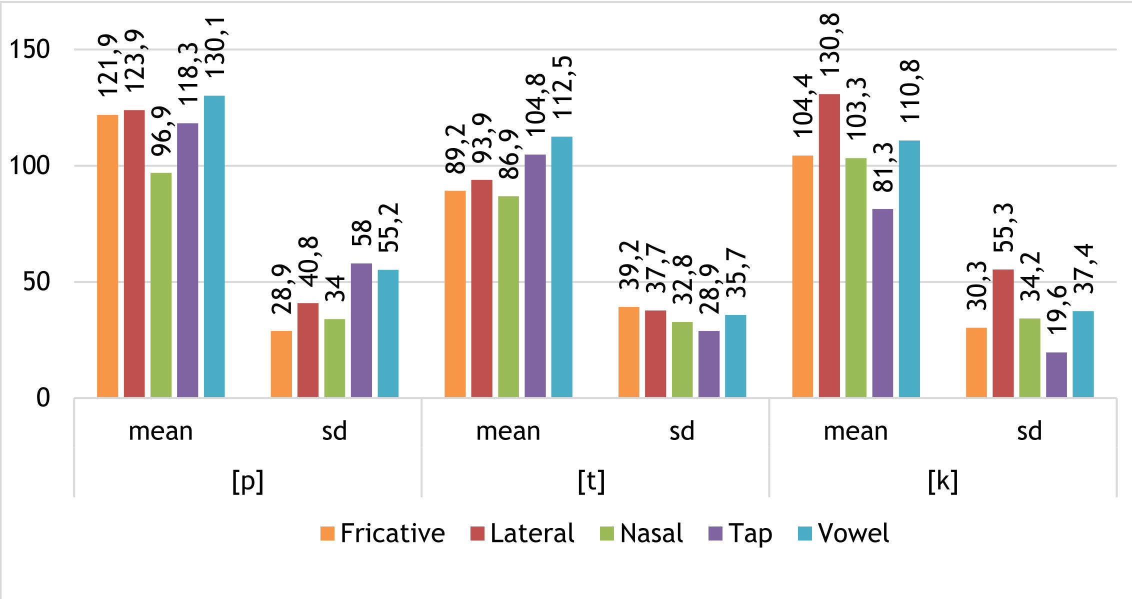

Figure 3. Mean values and standard deviations in milliseconds for segmental duration as a function of the preceding context and the place of articulation.

4.4. Hypothesis (d): temporal values as a function of the place of articulation and the process

4.4.1. Segmental duration

Firstly, means show an influence of place of articulation on segmental duration ($F(2, 576)= 16.84$, $p < 0.05$), being the bilabial realisation the longest and the dental the shortest: [p], mean= 123.2 ms; SD= 50.4 > [k], mean= 105 ms; SD= 36.3 > [t], mean= 98.1 ms; SD= 37.1. Nonetheless, results observed for each of the sessions (Table 3) show that significant differences ($F(4, 574)= 3.017$, $p < 0.05$) are just found between [p] and [t] in sessions 1 and 2, as well as between [p] and

[k] in session 1. Conversely, in the third session, temporal values between the three plosives are considerably similar ($p > 0.05$), despite maintaining the scheme [p] > [k] > [t].

Secondly, the voicing process (maintenance or sonorisation) shows strong effects on segmental duration ($F(1, 577)= 17.66$, $p < 0.05$). Overall, mean duration for voiceless stops that maintain their voicing features is 110.1 ms, while those under sonorisation reach 91.6 ms on average. Likewise, Figure 4 shows that there are also differences in duration as a function of the process in all three realisations and across the three sessions. Despite that, recall that only the bilabial realisation in the first session shows significant results ($F(4, 574)= 1.009$, $p < 0.05$). As for the rest of the stops and sessions, values tend to be closer to one another ($p > 0.05$), although

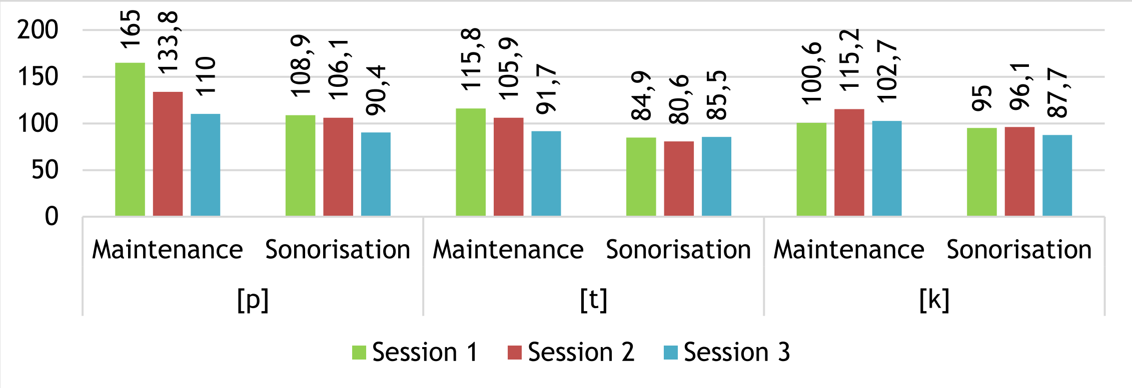

Figure 4. Mean values in milliseconds for segmental duration as a function of the voicing process, the place of articulation and the session.

realisations that have maintained as voiceless keep presenting higher values than the sonorised ones.

4.4.2. Closure duration

As for closure duration as a function of the place of articulation, Table 4 shows differences in values for [p] versus [t] and [k] across all the sessions ($F(4, 563)= 3.217$, $p < 0.05$). [p] has the longest closure duration, whereas values for [t] and [k] in the three sessions are almost equivalent ($p > 0.05$). Thus, it does not seem that closure duration is a parameter that can distinguish between the latter two consonants. Mean values obtained for each of the consonants are 107 ms for [p], 74.8 ms for [t] and 75.1 ms for [k].

Regarding the effects of the process, results for closure duration are equivalent to those observed for segmental duration. On the one hand, there seems to be an effect of the process on closure duration values ($F(1, 566)= 12.34$, $p < 0.05$). Consonants that maintain as voiceless have longer closing phases than sonorised ones: maintenance, mean= 85.7 ms; SD= 43.9 *vs*. sonorisation, mean= 70.0 ms; SD= 23.2. On the other hand, significant values ($F(4, 563)= 1.223$, $p < 0.05$) are only present in the bilabial stop from session 1. Differences for the rest of the sessions and stops are minimal ($p > 0.05$). Despite that, stops under maintenance keep being longer than sonorised ones.

4.4.3. VOT duration

According to the data extracted, place of articulation shows strong effects on VOT duration ($F(2, 717)= 135.4$, $p < 0.05$). The bilabial stop has the lowest values (mean= 17.1 ms; SD= 7.8), followed by the dental (mean= 23.7 ms; SD= 11.0) and the velar, which shows the longest (mean= 31.8 ms; SD= 10.1). Variations in VOT duration as a function of the place of articulation were observed across all three sessions with significant differences in all the cases ($F(4, 715)= 1.251$, $p < 0.05$). Table 5 illustrates the scheme [p] < [t] < [k] for VOT duration in the three sessions.

With respect to the voicing process, Figure 5 shows that VOT duration for stops that have maintained as voiceless is longer than the one for sonorised ones ($F(1, 718)= 4.869$, $p < 0.05$):

maintenance, mean= 25.1 ms; SD= 11.7 *vs*. sonorisation, mean= 22.5 ms; SD= 10.2. Yet, variations in relation to the process and the place of articulation across the three sessions are minimal ($F(4, 715)= 0.924$, $p > 0.05$). Finally, it has also been noticed a slight inversion ($p > 0.05$) of the duration pattern for [p] in the third session and for [k] in the second session. That is, VOT duration for sonorised [p] and [k] appears to be longer than their maintained counterparts.

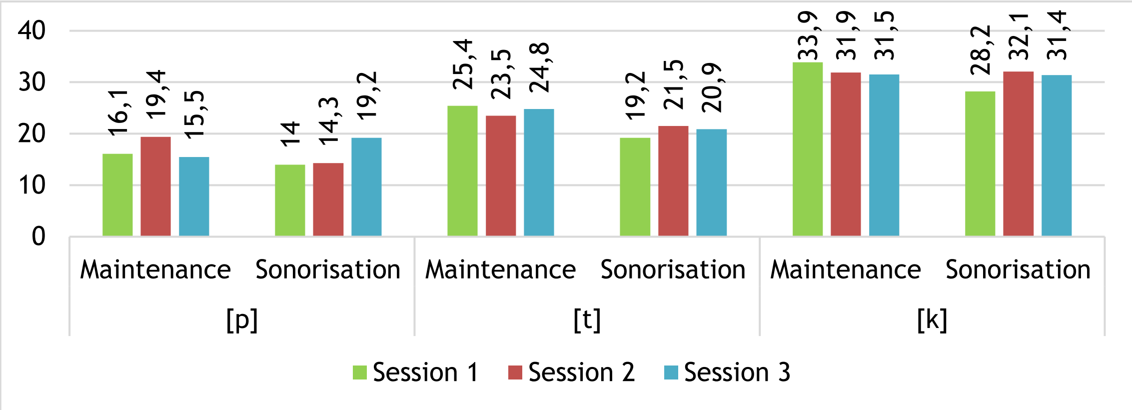

Figure 5. Mean values in milliseconds for VOT duration as a function of the voicing process, the place of articulation and the session.

5. Discussion

Results report that temporal parameters of voiceless stops in a speaker with Broca's aphasia and apraxia of speech are slightly longer than those observed in non-pathological speakers, in accordance with Marczyk (2015) and Marczyk and Machuca (2018). This is especially noticeable for segmental duration values, according to which the aphasic realisation reaches 108.8 ms on average, compared to 89 ms in non-pathological speech (Gibson *et al*., 2015). Likewise, longer segments are observed in the three places of articulation: pathology, [p]= 123.26 ms; [t]= 98.14 ms; [k]= 105 ms *vs*. non-pathology, [p]=68.25 ms; [t]= 71.95 ms; [k]= 72.2 ms (Machuca, 1997).

As for closure and VOT duration, values for the aphasic realisations are slightly longer, although not excessively. The closing phase of our speaker reaches a mean of 85.64 ms, whereas the one reported by Martínez Celdrán (1997) arrived to 75-79 ms. On the other hand, VOT duration for the three stops lasts 24.17 ms on average, in contrast to the values found in non-pathological speakers, which was 20.18 ms (Asensi *et al*., 1997; Castañeda Vicente, 1986; Martínez Celdrán and Fernández Planas, 2007). At the same time, VOT duration values in the aphasic speech are considerably similar to those reported by Marczyk and Machuca (2018) in speakers with language disorder: 23.67 ms.

With regard to place of articulation, our data is in agreement with the literature that the more posterior the place of articulation, the longer the VOT. The pattern [p] < [t] < [k] for VOT was observed in all the sessions. Still, as for closure and segmental duration, the pattern seems to be different. Closure duration values for [p] are always longer than for the rest of the stops ([p] closure > [t] and [k] closure). In that view, closure duration may be considered a distinguishing feature between [p] and [t, k] in our participant. Similarly, in our speakers' speech, segmental duration for [p] is always longer than for [t] and [k], whereas values for [t] tend to be lower than for [k]. These results contrast with Gibson *et al*. (2015), whose segmental duration values in non-pathological speech still follow the pattern [p] < [t] < [k].

Moving to the voicing process (maintenance or sonorisation), overall duration of stops that have maintained as voiceless is longer than the ones under sonorisation, in line with Machuca's (1997) results in spontaneous speech without pathology. These differences in duration are observed for all the temporal parameters analysed: closure, VOT, and segmental duration. Even so, there are also instances where VOT duration for sonorised realisations is higher or quite similar to those found in maintained stops. Therefore, before drawing any conclusions, it would be necessary to compare the current results with temporal values for devoiced stops and those that have maintained as voiced in the same speaker in some future research.

As for the preceding context, results for [p] and [t] agree with Machuca (1997) that there is a reduction in segmental duration when the consonant is preceded by a nasal sound. On the contrary, duration values for the velar show that the reduction occurs after a tap in this speaker. Moreover, and in contrast to Machuca (1997), no increase in duration was observed when consonants were preceded by fricatives.

Recovery patterns observed follow different trends depending on the variables considered. On the one hand, closure and segmental duration show significant improvements for the bilabial stop from the first session –five months after the onset– to the third session –twenty-two months later. This data seems to confirm that improvements in oral production in aphasia can extend up to twelve months after the stroke, in line with Taylor Sarno (1998). In our participant, improvements have been observed up to 22 months later. Despite that, recall that the pattern observed for the dental and velar stops is closer to the results by Prins *et al*. (1978), who reported minimal improvements and deterioration in their patients throughout twelve months of treatment.

On the other hand, percentages of sonorization and fricativisation errors present a decrease from session 1 to session 2, and an increase from session 2 to session 3. This may indicate that much of the improvement took place during the period of spontaneous recovery, in accordance with Basso (2003), and continued up to thirteen months after the stroke. Afterwards, though, no noticeable improvement was observed.

Finally, fricativisation errors were minimal (1.21%) and much lower than the 34.2% observed in Marczyk (2015), which may indicate that mode of articulation for plosives is a well-preserved feature in this speaker. In relation to sonorisations, it is noteworthy that the percentage observed in this paper (18.3%) is much higher than what Marczyk found in aphasic speech (0.2%), which could denote the presence of phonological paraphasias in our speaker. This assumption follows the fact that speakers with major motor impairments tend to have greater difficulty in synchronising the action of the vocal folds and the articulators, which is necessary to produce sonority (Blumstein, 1998). Therefore, in the event of greater motor impairments, we suppose that the rate of sonorisations would have been lower. However, further analyses of consonant devoicing should be left to a follow-up study in order to confirm the pattern observed.

6. Conclusions

According to the results obtained and the predictions put forward in the hypotheses, the following conclusions can be drawn. Beginning with temporal values as a function of the session –hypothesis (a)– there is an improvement in the production of the voiceless bilabial stop throughout the three sessions, which manifest itself as a decrease in closure and segmental duration mean values. However, results for the dental and velar realisations indicate that improvements are minimal and non-significant. Perhaps this could be attributed to the law of maximum contrast that Jakobson (1974) put forward, whereby consonant acquisition may begin with plosives, specifically with the bilabial /p/. Similarly, when consonant production is damaged and regained due to language disorders like aphasia, the voiceless bilabial stop may be the one showing the best improvements in rehabilitation. An additional explanation would respond to the fact that the articulators and movements used to produce the bilabial are more visible to the patient and, therefore, easier to imitate. At any rate, further and more rigorous research of these different improvement patterns should be carried out in a future study. As for VOT duration, it tends to maintain the same values along the sessions and be slightly longer than that found in non-pathological speech.

Regarding sonorisation and fricativisation errors –hypothesis (b)– no steady decrease across the sessions has been observed, in contradiction to our hypothesis. Main improvements occurred during spontaneous recovery and continued up to thirteen months of treatment (from session 1 to session 2). After the second session, no apparent improvements were found, but a slight deterioration. In addition, a high rate of sonorisations was observed, in contrast to the hypothesis.

Moreover, it was found that the context exerts a small amount of influence over segmental duration of [p] and [t] when preceded by a nasal sound. However, the results are neither significant nor consistent enough to confirm its influence on the duration of stops, as put forward in hypothesis (c).

In accordance with hypothesis (d), the duration of sonorised stops is shorter than those that have maintained as voiceless, especially for the bilabial stop. Also, results confirm that VOT duration is determined by the place of articulation in aphasic speech, just as in speakers without aphasia. As for segmental duration, place of articulation seems to affect its values since it is the bilabial realisation that presents the longest duration, in comparison to the dental and the velar. This observation is in contrast to the reviewed literature and may respond to the longer closure duration values of [p] in this speaker.

Based on the results and the patterns observed, there seems to be a differentiated realisation of these sounds. On the one hand, the bilabial realisation has the highest segmental and closure duration means across the three sessions, and it is also the only one showing significant improvement patterns. As for the progress in the production of [t] and [k], it tends to be minimal or invariable. Likewise, differences between duration values as a function of the voicing process are particularly significant in the bilabial stop, especially in the first session, as opposed to what was observed for the dental and the velar. Since there are no recordings of the speaker prior to the stroke, it is impossible to determine what was the initial level of impairment of the three realisations. However, in comparison to the values reported by the reviewed literature for non-pathological speech, it is the acoustic characteristics of the bilabial that have changed the most immediately after the stroke, as well as throughout the treatment. Thus, there seems to be a division between the bilabial and the dental-velar realisations which is particularly salient in the first session and becomes less clear as the speaker progresses through treatment.

7. Limitations and future directions

Some limitations of this study should be taken into account. First, as for VOT duration, it has been shown that its values can vary depending on the stress or quality of the following vowel. Castañeda Vicente (1986) reported longer VOT values when the consonant was part of an unstressed syllable and when followed by a back vowel. However, the literature on such an influence is both extensive and diverse which is why it has not been considered a highly relevant factor in the research –see Machuca (1997) for a more rigorous review on the subject. Second, previous studies have shown that speakers with aphasia tend to produce more errors in syllable onsets and when trying to initiate speech (Marczyk, 2015; Marczyk and Baqué, 2015; Tuller, 1984). Although the reviewed literature does not point at errors related to temporal parameters, it would be interesting to make the distinction between stops in word initial and word medial position when analysing duration values, as well as sonorisation and fricativisation errors. By doing so, a more complete picture would emerge.

Finally, a follow-up study should be carried out aiming at confirming the patterns and tendencies found in the paper. Research should consider voiced and devoiced stops so as to compare their duration values with the ones found for voiceless stops. This would be important to determine the type of paraphasias present in the speaker, as well as the presence or absence of different recovery patterns between these sounds that may affect their evolution after the stroke. In addition, it is also suggested that the nasal sounds [m, n, ŋ] and the labiodental fricative [f] are included in the analysis in order to confirm and understand the latter observation. This could provide a better understanding of the recovery patterns in this type of patients and help therapists apply more efficient rehabilitation techniques.

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References

Asensi, L., Portolés, S. & Río, A. del. (1997). Barra de explosión, VOT y frecuencia de las oclusivas sordas del castellano. *Estudios de fonética experimental*, 9, 221-242.

Basilakos, A. (2018). Contemporary approaches to management of post-stroke apraxia of speech. *Seminars in Speech and Language*, 39 (1), 25-36. https://doi.org/10.1055/s-0037-1608853

Basso, A. (1992). Prognostic factors in aphasia. *Aphasiology*, 6 (4), 337-348. http://dx.doi.org/10.1080/02687039208248605

Basso, A. (2003). *Aphasia and its therapy*. Oxford University Press.

Basso, A., Capitani, E. & Vignolo, L. A. (1979). Influence of rehabilitation on language skills in aphasic patients: A controlled study. *JAMA Neurology*, 36 (4), 190-196. https://doi.org/10.1001/archneur.1979.00500400044005

Baum, S. R. & Ryan, L. (1993). Rate of speech effects in aphasia: Voice onset time. *Brain and Language*, 44 (4), 431-445. https://doi.org/10.1006/brln.1993.1026

Baum, S. R., Blumstein, S. E., Naeser, M. A., & Palumbo, C. L. (1990). Temporal dimensions of consonant and vowel production: An acoustic and CT scan analysis of aphasic speech. *Brain and Language*, 39 (1), 33-56. https://doi.org/10.1016/0093-934X(90)90003-Y

Blumstein, S. E. (1998). Phonological aspects of aphasia. In M. Taylor Sarno (Ed.), *Acquired aphasia* (3rd ed., pp. 157-185). https://doi.org/10.1016/B978-012619322-0/50008-7

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 (2), 153-170. https://doi.org/10.1016/0093-934X(80)90137-6

Boersma, P. & Weenink, D. (2019). Praat: Doing phonetics by computer (Version 6.1.05) [Computer program]. University of Amsterdam. Retrieved from http://www.praat.org

Castañeda Vicente, M. L. (1986). El V.O.T de las oclusivas sordas y sonoras españolas. *Estudios de fonética experimental*, *2*, 91-110.

Gibson, M., Fernández Planas, A. M., Gafos, A. & Remirez, E. (2015). Consonant duration and VOT as a function of syllable complexity and voicing in a sub-set of Spanish clusters. *INTERSPEECH-2015*, 1690-1694. https://doi.org/10.21437/Interspeech.2015-389

Gibson, M., Sotiropoulou, S., Tobin, S. & Gafos, A. I. (2019). Temporal aspects of word initial single consonants and consonants in clusters in Spanish. *Phonetica*, 76 (6), 448-478. https://doi.org/10.1159/000501508

González Lázaro, P. & González Ortuño, B. (2012). *Afasia: De la teoría a la práctica*. Editorial Médica Panamericana.

Gorno Tempini, M. L. & Santos Santos M. Á. (2015). Primary progressive aphasia. In A. Toga (Ed.), *Brain mapping. An encyclopedic reference* (Vol. 3, pp. 653-663). https://doi.org/10.1016/B978-0-12-397025-1.00074-9

Helm-Estabrooks, N. & Albert, M. L. (2005). *Manual de la afasia y de terapia de la afasia* (2nd ed.). Editorial Médica Panamericana.

Hidalgo Navarro, A. & Quilis Merín, M. (2004). *Fonética y fonología españolas* (2nd ed.). Tirant Lo Blanch.

Jakobson, R. (1974). *Lenguaje infantil y afasia* (Translated from: *Langage enfantin et aphasie*). Ayuso. (Original published in 1969).

Machuca, M. J. (1997). *Las obstruyentes no continuas del español: Relación entre las categorías fonéticas y fonológicas en habla espontánea* [PhD dissertation, Universidad Autónoma de Barcelona]. Retrieved from https://ddd.uab.cat/record/37091

Marczyk, A. K. (2015). *Déficits de la composante phonético-phonologique dans l'aphasie et stratégies compensatoires: Analyse acoustique et perceptive de productions consonantiques de sujets hispanophones* [PhD dissertation, Universidad Autónoma de Barcelona]. Retrieved from https://ddd.uab.cat/record/165717

Marczyk, A. & Baqué, L. (2015). Predicting segmental substitution errors in aphasic patients with phonological and phonetic encoding impairments. *Loquens*, 2 (2). https://doi.org/10.3989/loquens.2015.023

Marczyk, A. & Machuca, M. J. (2018). Temporal control in the voicing contrast: Evidence from surgery-related apraxia of speech. *Clinical Linguistics & Phonetics*, 32 (2), 148-165. https://doi.org/10.1080/02699206.2017.1334091

Martínez Celdrán, E. (1993). La percepción categorial de /b-p/ en español basada en las diferencias de duración. *Estudios de fonética experimental*, 5, 223-239.

Martínez Celdrán, E. (1997). La duración de la nasal precedente como índice de la tensión de las oclusivas españolas. In R. Escavy Zamora, E. Hernández Sánchez, J. M. Hernández Terrés & M. I. López Martínez (Eds.), *Homenaje al profesor A. Roldán Pérez* (Vol. 1, pp. 331-339). Universidad de Murcia.

Martínez Celdrán, E. & Fernández Planas, A. M. (2007). *Manual de fonética española. Articulaciones y sonidos del español*. Ariel.

Miller, J. L., Green, K. P. & Reeves, A. (1986). Speaking rate and segments: A look at the relation between speech production and speech perception for the voicing contrast. *Phonetica*, 43 (1-3), 106-115. https://doi.org/10.1159/000261764

National Institute of Deafness and Other Communication Disorders (2017, October). *Apraxia del habla*. U.S. Department of Health and Human Services, National Institutes of Health. Retrieved in February 2020 from https://www.nidcd.nih.gov/es/espanol/apraxia-speech

Papathanasiou, I., Coopens, P. & Davidson, B. (2017). Aphasia and related neurogenic communication disorders: Basic concepts, management, and efficacy. In I. Papathanasiou and P. Coopens (Eds.), *Aphasia and related neurogenic communication disorders* (2nd ed., pp. 3-14). Jones & Barlett Learning.

Potagas, C., Kasselimis, D. S. & Evdokimidis, I. (2017). Elements of neurology essential for understanding the aphasias. In I. Papathanasiou and P. Coopens (Eds.), *Aphasia and related neurogenic communication disorders* (2nd ed., pp. 37-61). Jones & Barlett Learning.

Prins, R. S., Snow, C. E. & Wagenaar, E. (1978). Recovery from aphasia: Spontaneous speech versus language comprehension. *Brain and Language*, 6 (2), 192-211. https://doi.org/10.1016/0093-934X(78)90058-5

Quilis, A. (1981). *Fonética acústica de la lengua española*. Gredos.

RStudio Team. (2015). RStudio: Integrated Development Environment for R. Boston, MA: RStudio, Inc. [Computer program]. Retrieved from http://www.rstudio.com

Taylor Sarno, M. (1998). Recovery and rehabilitation in aphasia. In M. Taylor Sarno (Ed.), *Acquired aphasia* (3rd ed., p. 595-631). https://doi.org/10.1016/B978-012619322-0/50008-7

Tsiara, J. (2019). *Analysis of VOT in Greek patients with non-fluent aphasia* [Master's thesis, Universiteit van Amsterdam]. UvA Scripties. Retrieved from https://scripties.uba.uva.nl/search?id=696062

Tuller, B. (1984). On categorizing aphasic speech errors. *Neuropsychologia*, 22 (5), 547-557. https://doi.org/10.1016/0028-3932(84)90019-8

Williams, S. E. & Seaver, E. J. (1986). A comparison of speech sound durations in three syndromes of aphasia. *Brain and Language*, 29 (1), 171-182. https://doi.org/10.1016/0093-934X(86)90041-6

Worrall, L., Sherratt, S. & Papathanasiou, I. (2017). Therapy approaches to aphasia. In I. Papathanasiou and P. Coopens (Eds.), *Aphasia and related neurogenic communication disorders* (2nd ed., pp. 109-127). Jones & Barlett Learning.

Appendix 1

Below, there is a copy of the medical examination that the patient got by the speech therapist in January 2018. Recall that the patient started therapy immediately after the stoke (in January 2017) but changed centres after a year under treatment (in January 2018). Since it was not possible to obtain the very first examination, the one provided below corresponds to the second speech therapist he visited and was done after having been following speech rehabilitation for twelve months.

The examination shows the symptoms that the patient presented immediately after the stroke, as well as the improvements and disabilities still present after twelve months under treatment. It also describes the type of exercises he worked on.

Initial examination: Patient with oral language impairment, non-fluent (severe Broca's aphasia). Yes/no responses with gestural help. Simple oral comprehension preserved. Oriented in time and space. He cannot repeat. Apraxia of speech. He communicates by means of writing on a board. He is aware of his difficulties. Speech therapy is recommended.
Examination at the beginning of treatment: Patient with non-fluent aphasia (motor aphasia) and with great language impairment that has been improving. Currently, he can communicate through speech, which contains informative content and is fairly structured. He still presents anomia, agrammatism and phonetic paraphasias. Comprehension is preserved. TOKEN comprehension test= 34,5 (36-29: high. absent) (screening test). There are still some errors in complex orders and complex conceptual material.
Treatment: The patient began treatment in January 2018. We have worked on: ▪ Vocabulary and lexical access. ▪ Discourse, narration, and comprehension through reading and writing tasks which consisted of:

- Comprehension questions with increasing complexity,
- Summaries and narrations of the texts,
- Grammatical exercises,
- Phonemic corrections,
- ...

- Narration of stories with different verb tenses to reinforce discourse structure and correct agrammatisms.
- Production of isolated sounds (alveolar: l-d-r, consonant clusters...) and formal discourse.
- Tasks to improve memory.
- Calculation
- ...

Appendix 2

The following tables show in detail the number of items that have been analysed in this study in relation to temporal parameters, sessions, places of articulation, preceding contexts and the voicing process (maintenance or sonorisation).

		***n* items**			
		[p]	**[t]**	**[k]**	**Total**
Session 1	Fricative	1	6	2	9
	Lateral	2	0	1	3
	Nasal	3	19	1	23
	Tap	1	1	8	10
	Vowel	20	13	26	59
	Total	27	39	38	104
Session 2	Fricative	9	18	9	36
	Lateral	1	6	2	9
	Nasal	9	26	11	46
	Tap	3	8	15	26
	Vowel	37	39	43	119
	Total	59	97	80	236
Session 3	Fricative	6	27	7	40
	Lateral	2	3	3	8
	Nasal	10	24	7	41
	Tap	1	2	15	18
	Vowel	34	31	66	131
	Total	53	87	98	238
Total		**139**	**223**	**216**	**578**

Table 6. Number (*n*) of items in relation to the session, the place of articulation and the preceding context.

	n closing phases			
	[p]	**[t]**	**[k]**	**Total**
Session 1	27	33	38	98
Session 2	59	95	80	234
Session 3	53	84	98	235
Total	**139**	**212**	**216**	**567**

Table 7. Number (*n*) of closing phases in relation to the session and the place of articulation.

	n release phases (VOT)			
	[p]	**[t]**	**[k]**	**Total**
Session 1	41	40	56	137
Session 2	87	107	94	288
Session 3	87	90	117	294
Total	**215**	**237**	**267**	**719**

Table 8. Number (*n*) of release phases (VOT) in relation to the session and the place of articulation.

		n voicing processes			
		[p]	**[t]**	**[k]**	**Total**
Session 1	Maintenance	17	23	23	63
	Sonorisation	10	16	15	41
Session 2	Maintenance	50	84	73	207
	Sonorisation	9	13	7	29
Session 3	Maintenance	41	77	84	202
	Sonorisation	12	10	14	36
Total		**139**	**223**	**216**	**578**

Table 9. Number (*n*) of voicing processes (maintenance or sonorisation) in relation to the session and the place of articulation.