Consonant distortions in dysarthria due to Parkinson's disease, Amyotrophic Lateral Sclerosis and Cerebellar Ataxia

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Abstract

This paper addresses the presence and type of consonant distortions in speech of 79 French speakers with dysarthria due to Parkinson's disease (PD), Amyotrophic Lateral Sclerosis (ALS) and cerebellar ataxia (CA), and 26 control speakers. A total of 4990 consonants including selected occurrences of /d/, /g/, /t/, /k/ and /s/ in CV word-initial syllables, and /t/ in CV word medial and IP initial position were examined manually. Results show that the ALS group stands out with the more distorted consonants, while the PD and CA performed similarly. The distribution of the type of distortions differs also in the three dysarthric groups. While the most frequent type of distortion in ALS is incomplete closures of stops, devoicing of voiced consonant is the most frequent in the PD and CA groups. In the ALS group, distortions are also more uniformly distributed over consonant type and positions, while voiced consonants are more prone to distortion in PD and CA, as well as consonants in word medial position for PD. Finally, consonant distortions contribute strongly to perceived intelligibility and articulatory imprecision for the ALS and PD group.

Index Terms: dysarthria, consonant distortion, auditory-perceptual analysis

1. Introduction

Dysarthria is a cover term for a group of speech disorders caused by impaired muscular control due to a damage to the central or peripheral nervous system. The exact muscular impairment follows the underlying damage and causes different types of dysarthria. Among other levels of speech production, the impairment affects articulatory mechanism, causing reduced range, force, timing and precision of articulatory movements. One of the most common consequences is the presence of consonantal distortions, which is also one of the main features that are assessed in clinical practice. The question however remains whether such distortion profile can be used reliably to differentiate between different types of dysarthria, and if so, how do different consonant distortion profiles correlate to other speech characteristics.

In order the answer the above questions, the objective of this study is two-fold: (1) to investigate the presence and type of consonantal distortions in the speech of speakers with Parkinson's disease (PD), amyotrophic lateral sclerosis (ALS) and cerebellar ataxia (CA), and also healthy control speakers (HS); (2) to investigate the relation between consonantal distortions, intelligibility and perceived articulation imprecision in the dysarthric groups.

The three groups of dysarthric speakers, PD, ALS and CA are all associated with a different type of underlying neural cause and different type of dysarthria. PD is caused by basal ganglia damage, causing slowness in movement and movement initiation, rigidity, and is associated with hypokinetic dysarthria. ALS originates in upper and lower motor neuron damage, most typically manifests with muscle weakness and atrophy, and leads to a mixed type of dysarthria. CA results from cerebellar damage which disrupts coordination of muscular activity and causes ataxic dysarthria. Although these types of dysarthria differ in the exact speech profile, they all show articulatory difficulties with consonantal articulation. In their perceptual evaluation of altered speech dimensions [1], imprecision of consonants is ranked first for ALS and CA, and is ranked fourth (after prosodic features) for PD. Additionally, for the three dysarthria types, the perceptual scores on the feature 'imprecise consonants' are strongly correlated to intelligibility judgments (.91 for PD and ALS, .77 for CA) [1].

Several studies have described the types of consonant distortions, which can be observed in PD, ALS or CA, but little work has been done on French dysarthric speakers, and very few studies have compared the three dysarthria types on the same speech data. In PD, the described consonantal imprecisions usually include distortions based on the manner of articulation, with incomplete closure in stops, [2] [3] [4] [5] and on voice features, with voiceless stops being realized fully or partially voiced [4] [6]. Devoicing of voiced stops, fully or partially, is also noticed and constitutes one of the main feature of the 9 French speakers with PD of [7]. In ALS, imprecise consonants are hallmark feature, and also the one showing the greatest deterioration with the progression of ALS [8]. The most common types of distortions reported in the literature include changes in voicing, particularly voicing of syllable initial consonants [9] [10], in manner of articulation, affecting stops, nasals and affricates, and in place of articulation [9]. Less detail about the types of consonantal imprecision is known for CA, but consonant distortions contribute to the slurred aspect of ataxic dysarthria, with stops often described as fricated and unreleased [11].

In the following, we will investigate consonant distortions occurring in the reading of a text by a large cohort of French dysarthric speakers. Differences between ALS, PD and CA dysarthria profiles will be tested on the amount and types of consonantal distortions, and also according to their distribution. The nature of the target consonants (voicing, manner, place of articulation) and its positions in the word and sentence will then be examined. Finally, we will see how consonant distortions contribute to perceived alterations in the speech of the three dysarthria groups.

2. Methodology

2.1. Speakers

A total of 105 French speakers took part in this study, 79 with dysarthria due to PD, ALS or CA and 26 HS without any speech problems. All patients had their speech assessed and recorded at a neurological or voice and speech department of different hospitals [12]. An earlier perceptual evaluation of intelligibility and articulatory imprecision performed by 22 listeners revealed that they differed on these two measures [13]. Details of speakers are presented in Table 1.

	F *<age>*	*M* *<age>*	*Intell. score*	*Art. imp score*	*N*
PD	*8*	*23*	*.6*	*.7*	*31*
	<60-81>	*<48-85>*	*<0-2.8>*	*<.1-2.7>*	
ALS	*15*	*11*	*1.1*	*1.5*	*26*
	<50-89>	*<44-74>*	*<.1-2.6>*	*<.2-2.9>*	
CA	*9*	*13*	*.9*	*1.3*	*22*
	<33-79>	*<32-86>*	*<.2-1.7>*	*<.4-2.3>*	
HS	*15*	*11*	*0*	*.1*	*26*
	<33-76>	*<32-62>*	*<0-.2>*	*<0-.5>*	

Table 1. Number of speakers per group, by sex, with <age range> in years. Intelligibility (Intell.) and articulatory imprecision (Art. imp.) score (mean and <range>) are given. They were judged on a five-point scale, with 4 marking the poorest intelligibility and the greatest articulatory imprecision by 22 listeners.

2.2. Speech material

All participants read the same short story of 169 words [14]. In this story, we have been able to select 48 words with consonants that could be included in the analysis: 25 /t/, five /d/, five /k/, four /g/ and nine /s/. All the consonants except /t/s are in word initial position. For the /t/s, there was enough exemplars in the text to manipulate the position of the consonant: 4 /t/s are at the beginning of a word which is initial in a sentence, probably preceded by a pause, and thus initial in an Intonational Phrase (IPi), 13 /t/s are word-initial but IP medial (Wi), and 8 /t/s are word-medial (Wm).

		ALS	*CA*	*PD*	*HS*
position	IPi	103	85	123	104
	Wi	331	278	399	338
	Wm	206	173	247	208
voice	/d,g/	233	196	277	234
	/t,k/*	458	387	553	468
PoA	/k,g/	231	197	278	234
	/t,d/*	460	386	552	468
manner	/t/*	233	192	276	234
	/s/	331	278	399	338
Total = 4990		**1233**	**1033**	**1476**	**1248**

Table 2. *Number of tokens included in the different analyses for each of the speaker groups. The last line gives the total number of consonant tokens analyzed. (*= only /t/ in Wi position are included).*

Out of this consonant set, yielding to a total of 4990 tokens across all speakers, we grouped the consonants into different subsets to investigate the effect of a number of factors on consonant distortions. Table 2 shows the number of consonant tokens considered in each sub-analysis and the total number of consonants analyzed for each speaker group.

(1) Position in utterance: comparison of the realization of the consonant /t/ placed in word medial (Wm), word initial (Wi) and Intonational phrase initial (IPi) position

(2) Nature of the consonant: comparison of the realization of voiced (/d,g/) vs. voiceless (/t,k) consonants; of front (/t,d/) vs. back (/k,g/) consonants; and of stop (/t/) vs. fricative (/s/) consonants.

Note that for (2) the analyses include only the /t/s in Wi positions since the other consonants are also Wi.

2.3. Data analysis

The entire set of recordings was transcribed and segmented by using an automatic speech alignment system [15]. To avoid possible errors, the segmentation of the 4990 target consonants was nonetheless manually corrected.

An evaluation of the realization of the selected consonants was done by an expert speech and language therapist (first author).

Consonants were labeled as distorted or not based on visual inspection of their acoustic realization and perceptual assessment, and the types of distortion were categorized according to the following criteria:

Distortions linked to manner of articulation:

Incomplete closure (InClo): presence of noise or formants during the closure portion of the stops (i.e. spirantization and gliding)

Nasalization: presence of a strong nasal component

Stopping: presence of closure and/or burst in fricatives

Distortions linked to laryngeal articulation (voice):

Voicing: partial or total voicing of voiceless consonants

Devoicing: partial or total devoicing of voiced consonants.

Distortions linked to place of articulation:

Retraction: backing of the place of articulation

Other types:

Omission of a segment

Un-intelligible segment

3. Results and discussions

3.1. Distortions in the 4 groups over all consonants

Overall, few distortions are found in our data: only 8% of the 4990 consonants were categorized as distorted. The dysarthric patients produce almost all of these (with a rate of distortion of 10% when we exclude the control speakers), and only 4 cases are found in the control group. Within the dysarthric groups, the ALS produced the most distortions, with 18% of their consonants produced abnormally. CA and PD groups on the other hand presents quite a few cases, with distortions on only 6% and 7% of their consonants, respectively.

In addition to differences in the rate of distortions, the three dysarthric groups differ in the type of distortions. As shown in Table 3, the distortions in the ALS group most frequently concern the consonant manner of articulation (67%), followed by voice specification (37%). Distortions of manner and voice were reported previously as two of the most commonly observed speech characteristics in ALS [9]. Within the manner category, incomplete closure is the most common and nasalization very rare in our data. The latter is rather surprising since dysarthria in ALS is often characterized by a notable hypernasality [1]. This might suggest that the velopharyngeal impairment causing nasalization in ALS is more of a suprasegmental feature than a segmental one and it does not jeopardize the nasal/oral contrast of French stops. Nonetheless, comparison between groups on this feature shows that even if these cases of nasalization are rare, they occur in the ALS group only.

Distortions affecting voice for the ALS group are represented mainly by the voicing of voiceless consonants, which is consistent with earlier descriptions [9] [10].

	ALS (N=219)	*CA (N=59)*	*PD (N=99)*
Manner	**67%**	**27%**	**31%**
InClo	60%	22%	28%
Nasalization	5%	0%	0%
Stopping	2%	5%	3%
PoA	**3%**	**12%**	**3%**
Retraction	3%	12%	3%
Voice	**37%**	**53%**	**54%**
Devoicing	2%	29%	37%
Voicing	35%	24%	16%
Other	**5%**	**8%**	**13%**
Omission	3%	8%	12%
Unintell	1%	0%	1%

Table 3. Type of distortions, as a % of all the observed distortions in each speaker group.

Distortion patterns for the PD and CA groups show the reverse tendency than the one of the ALS, with more changes in voice features (54% of PD's distortions, 53% of CA's ones) than in manner (31% and 27% respectively). In both groups the change in voice occurs in both directions: voicing of voiceless consonants and devoicing of voiced consonants. However, the PD group differs from the CA group in the distribution of those: devoicing of voiced consonants is more frequent than voicing of voiceless consonants in the PD group, while the asymmetry is not so clear in the CA group. Within the few cases of distortion linked to manner of articulation in these two groups, the predominant distortion is incomplete closure, which was reported to be a typical characteristic of ataxic dysarthria and a frequent feature of hypokinetic dysarthria [2] [3] [4] [5] [6].

3.2. Position and nature of the distorted consonants.

In this section, we will evaluate whether some consonants and some positions are more prone to distortions according to the type of dysarthria.

3.2.1. Position of the target consonant

The rate of distortions of the consonant /t/ is compared here for /t/s placed Wm, Wi, or IPi position (Table 4). In the ALS group, word initial and word medial /t/s are distorted at a similar rate (23% of the Wm /t/s are distorted, and 18% of the Wi). On the contrary, in the PD group word medial /t/s are more frequently distorted than word initial /t/s, even though the rate of distortion in both cases is quite small. Most of the distortions in both word initial and medial positions for the ALS group are incomplete closures; while the distortions in word medial position for the PD group are either incomplete closure or voicing. PD is characterized by difficulties in initiating movement and the results show that for these speakers it is more difficult to make the occlusion and/or to stop and restart voicing in the Wm intervocalic position than in initial position, as was shown by [14].

	ALS	*CA*	*PD*
IPi	10%	1%	2%
Wi	18%	3%	1%
Wm	23%	4%	7%

Table 4: Rate of distortions for IPi, Wi and Wm /t/s

Another interesting point in this comparison is the behavior of the IP initial position for the ALS group. At the beginning of an Intonational phrase (thus preceded by a pause), /t/s are less distorted than in other position. While this trend needs to be confirmed in a more systematic investigation (with more IP-initial tokens), the fact that /t/s are more preserved in this prosodically important position (as shown for stress syllable by [5] for PD) could be exploited in rehabilitation.

3.2.2. Nature of the target consonant

In this section we test whether patients make more distortions on (a) voiced vs. voiceless consonants, on (b) front vs. back consonants, and on (c) stops vs. fricatives.

(a) As illustrated in Figure 1, voiced and voiceless consonants are both distorted to a similar degree for the ALS group (18 and 19%, respectively). For the other two groups, there is a clear asymmetry: voiced consonants are more prone to distortions than voiceless ones. For the PD group, these results replicate the results of [15] in French. Again, the differences in distortion type between the groups emerge: ALS patients do realize some voiced and voiceless stops with incomplete closure, while PD and CA patients tend to devoice voiced stops.

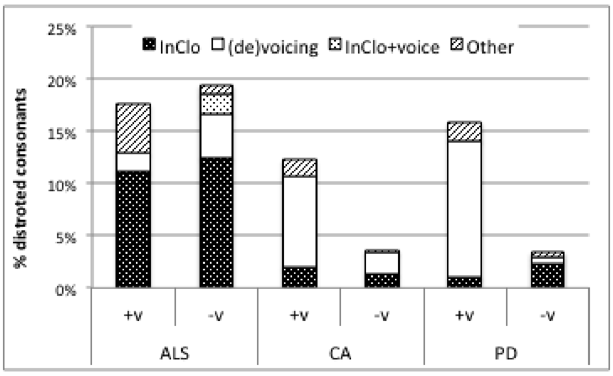

Figure 1: Distortion on voiced (+v) and voiceless (-v) consonants for the 3 groups. (InClo=incomplete closure; InClo+voice=incomplete closure and voicing; other=other distortions). % over the total number of voiced and voiceless consonants in each group.

(b) Distortions on alveolar vs. velar stops are illustrated on the left of Figure 2. Again, the ALS group does not show a preference depending on the place of articulation of the stops: 19% of the velar and 19% of the alveolar stops are distorted and most of them have incomplete closure. For the PD group there is a slight tendency for alveolar to be more resistant, but the small number of distortions for this group does not allow strong conclusions (as well as for the CA group).

(c) Distortions on fricatives (/s/) and stops (/t/) are illustrated on the right of Figure 2. In the ALS group, the distortions in the two categories differ more in types than in number: /s/ distortions involve the voicing of the voiceless fricative, while most distorted /t/s have an incomplete closure. The types of distortions on the fricatives seem also different in the groups: mostly voicing in ALS and more diverse in CA (with retraction, stopping, voicing).

In summary, distortions in the ALS group are found to be more uniformly distributed over consonant types: be they voiced or unvoiced, front or back, distortions of stops result mostly from a failure to achieve the lingo-palatal occlusion. This failure can be explained by muscle weakness, which is stable across segments. Another characteristic of the ALS group is the voicing of voiceless consonants, notable especially for fricatives but also for voiceless stops. For the PD and CA groups, asymmetries in the distortion profile, such as a greater resistance of voiceless stops, are found. Small trends like the resistance of alveolar over velars for PD or stops over fricative in PD and CA, need to be further studied on a larger set of consonants.

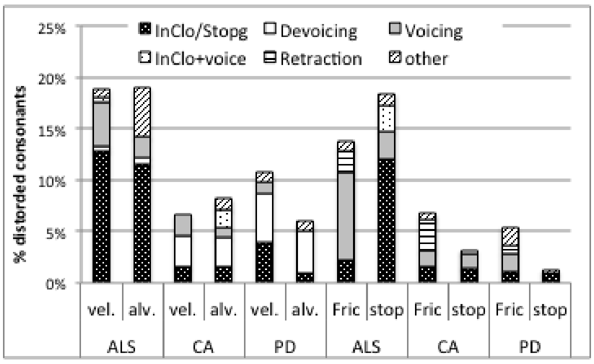

Figure 2: Distortion on velar (vel, /k,g/) vs. alveolar (alv, /t,d/) stops and on fricative (fric, /s/) vs. stop (/t/) for the 3 groups. Incomplete closure for stops and stopping for fricative are represented by 'InClo/stopg'. % over the total number of consonants category in each group.

3.3. Consonant distortions & perceived features

Table 5 shows the relationship between the rate of distortions observed on the consonants selected for this study and the perceptual evaluation made by 22 judges on 1 minute of speech extracted from text reading for each speaker, in terms of 'speech intelligibility' and global 'articulatory imprecision'.

The amount of consonant distortions is well correlated with the alteration scores for the ALS and PD groups. More distortions are found for the least intelligible patients and for patients perceived to have the most articulatory imprecisions. For these groups, articulatory imprecisions explain 60 (PD) to 70% (ALS) of the intelligibility scores. Interestingly, although only 18% of all analyzed consonants were distorted in the ALS group, this feature appears to be particularly salient. For the CA group on the contrary, the intelligibility of the speakers is not much affected by the rate of consonantal distortion, which was found to be quite low in this group. Other speech dimensions must be more prevalent in this group. The low correlation for the CA group and the high correlation for the PD group are in contradiction with [1]'s perceptual assessments, where consonant imprecision strongly contributed to intelligibility for ALS (.91) and CA (.77) while the relationship is not even mentioned for PD.

|r| & (r^2)	*Intell.*	*Art. Imp.*
ALS	*.83 (.7)*	*.76 (.6)*
CA	*.49 (.2)*	*.4 (.2)*
PD	*.77 (.6)*	*.72 (.5)*

Table 5: Correlation coefficient and (r^2) between distortion rate, intelligibility scores (Intell) and perceived articulatory imprecision (Art.Imp).

4. Conclusions

Although the total amount of consonants examined in the study was large (4990 consonants), the number of consonants per speaker was restricted (48 consonants) as was the number of consonant in each of the inspected categories. This data limitation is probably why the number of distortions was quite limited, with only 10% of the patient's consonants being distorted. Nonetheless, this study is the first examination of consonantal distortions on such a large cohort of French dysarthric speakers which has allowed us to obtain an overview of the main features of ALS, PD and CA profiles. It also gives us valuable information for future, more targeted, research which will include a larger set of consonants in specific categories (in IP initial position, voiced consonants, fricatives) and in which the distortion profiles will be quantified and the groups will be assessed on acoustic measurements.

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