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Hesitations in Primary Progressive Aphasia

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Abstract: Hesitations are often used by speakers in spontaneous speech not only to organise and prepare their speech but also to address any obstacles that may arise during delivery. Given the relationship between hesitation phenomena and motor and/or cognitive–linguistic control deficits, characterising the form of hesitation could be potentially useful in diagnosing specific speech and language disorders, such as primary progressive aphasia (PPA). This work aims to analyse the features of hesitations in patients with PPA compared to healthy speakers, with hesitations understood here as those related to speech planning, that is, silent or empty pauses, filled pauses, and lengthened syllables. Forty-three adults took part in this experiment, of whom thirty-two suffered from some form of PPA: thirteen from logopenic PPA (lvPPA), ten from nonfluent PPA (nfvPPA), and nine from semantic PPA (svPPA). The remaining 11 were healthy speakers who served as a control group. An analysis of audio data recorded when participants produced spontaneous speech for a picture description task showed that the frequency of silent pauses, especially those classified as long (>1000 ms) was particularly useful to distinguish PPA participants from healthy controls and also to differentiate among PPA types. This was also true, albeit to a lesser extent, of the frequency of filled pauses and lengthened syllables.

Keywords: fillers; hesitations; pauses; primary progressive aphasia (PPA)

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1. Introduction

When speakers take part in spontaneous oral communication, they rarely prepare what they intend to say in advance but instead attempt to organise their speech while in the process of producing it. This organisation process is manifested in the frequent pausing that occurs in spontaneous speech, in all languages. However, pausing gives speakers time not only to organise but also to cope with the challenges involved with language processing, such as lexical retrieval, grammatical and phonological encoding, and control and correction of what they are saying or have just said.

While hesitation phenomena vary among individuals and are thus one way in which individual styles of spontaneous speech can be distinguished (Maclay and Osgood 1959; McDougall and Duckworth 2017; Llisterri et al. 2022), they are also linked to motor control and/or cognitive–linguistic deficits and therefore could potentially be useful in differentiating among specific speech and language disorders (Yunusova et al. 2016). This study aims to analyse pausing in the spontaneous speech of patients with primary progressive aphasia (PPA), a degenerative disease that is characterised by progressive difficulty in speech and language functions due to frontotemporal lobar degeneration (Mesulam 2001; Gorno-Tempini et al. 2011).

1.1. Hesitations

The term ‘hesitations’ refers to a set of phenomena that disrupt the flow of spoken language and are assumed not to be semantically relevant to the message conveyed, such as:

- Repeats, which are meaningless repetitions of a syllable, word, or sequence of words;
- False starts, which are incomplete or self-interrupted utterances;
- Self-corrections, which consist of a word or a sequence of words intended to serve as a replacement for the immediately preceding utterance, which has been identified as an error by the speaker;
- Lexical fillers, which are fixed expressions essentially devoid of real semantic content;
- Hesitation pauses, which are pauses not due to articulatory or grammatical constraints (i.e., they are not juncture pauses).

In this study, we will focus on the latter. Hesitation pauses include:

- Silent pauses (also called 'empty pauses', 'unfilled pauses', or 'silences'), which can be defined as a segment of time without speech but possibly with an inhalation noise;
- Filled pauses (also known as 'sound-filled vocalisations' or 'fillers'), which are vocalisations that are not part of a lexical unit and that take some conventionalised form in a specific language (e.g., English: 'um'/'uh'; Spanish: 'e');
- Lengthenings, which consist of a sizeable non-phonemic prolongation of a phoneme or syllable of a word.

As we have noted, hesitations—especially hesitation pauses—are assumed to appear when the speaker needs time to plan or encode his/her speech and can also be linked to difficulties in syntactic processing or lexical retrieval, as well as articulatory impairments (e.g., Maclay and Osgood 1959; Shriberg 1994; Ballard et al. 2014; Galluzzi et al. 2015). Hesitations also occur when speakers are monitoring their own inner or overt speech (Postma 2000) and in the process detect an error. That is why hesitations, in particular filled pauses and repetitions, not only appear during post-articulatory self-corrections but also signal pre-articulatory repairs. Finally, hesitations have been suggested to play a role in the management of verbal interaction. Thus, pauses—whether silent, filled, or consisting of lengthened syllables—indicate to an interlocutor that the speaker is relinquishing the floor (Cestero 2000). However, interaction is not necessary for hesitations to appear since these phenomena also occur when the speakers know they will not be interrupted (Machuca et al. 2015).

Research on hesitations has raised methodological issues. The first issue is related to the classification of hesitation phenomena, which has been considered according to different criteria, leading to a certain amount of confusion over terminology. For instance, in the earliest attempt to classify hesitations, Maclay and Osgood (1959) identified four main types of hesitations, namely 'repeats', 'false starts' (which also include 'self-corrections'), 'filled pauses', and 'unfilled pauses' (which include silent pauses and lengthenings). By contrast, Rose (2013) came up with seven categories, not four: 'silent pauses', 'filled pauses', 'repairs' (which correspond to the abovementioned 'self-corrections'), 'repeats', 'false starts', 'lengthenings', and 'lexical fillers'. Other researchers have regarded lengthenings and filled pauses as a single category, arguing that they perform the same function in oral discourse (Rebollo 1997). The counterargument is that these two phenomena should be analysed separately because the sound produced during filled pauses is unrelated to any specific lexical unit, while the elongated sound in lengthenings is the phoneme of a word (Blondet 2001; Machuca et al. 2015). Attempts have also been made to classify hesitations according to their duration. For example, Vasilescu and Adda-Decker (2007) compared the duration of intra-lexical lengthened vowels and filled pauses in three languages and found that while the mean duration of lengthened vowels was around 60 ms, with nearly 90% of them shorter than 150 ms, filled pauses ranged from 150 to 250 ms, and only 15% lasted less than 150 ms. With regard to silent pauses, Campione and Véronis (2002) analysed 6000 silent pauses in spontaneous speech in five different languages and concluded that they could be categorised as either short (<200 ms), medium (200–1000 ms), or long (>1000 ms) pauses. Most medium silences were associated with demarcative prosodic functions, whereas short silences were not linked to prosodic–syntactic boundaries, and long silences were only observed in spontaneous speech.

A second methodological issue (already pointed out by Maclay and Osgood in 1959) concerns the fact that the labelling of hesitation phenomena is often an 'after-the-fact interpretation' based on the listener's judgement, since no discriminating threshold has been identified to distinguish, for example, between hesitation pauses on the one hand and silent pauses associated with other linguistic and expressive functions (Rodríguez Bravo 2022) on the other, or between lengthened syllables indicating hesitation and lengthened syllables attributable to other factors. Similarly, in spontaneous speech, the function being performed by a particular hesitation—whether it is allowing time for the speaker to plan, encode, or retrieve, or to monitor their inner speech, and so on—can only be hypothesised on an intuitive basis, allowing only tenuous conclusions to be drawn.

Therefore, it is important to clarify that although in the title of this study we refer to 'hesitation', we will be focusing specifically on silent pauses, filled pauses, and lengthened syllables, though we will refer to all three phenomena as 'pausing', regardless of their length or function.

1.2. Primary Progressive Aphasia

Primary progressive aphasia (PPA) is a degenerative neurological disease that causes speech and language dysfunction (Botha et al. 2015). Any examination of pausing patterns in patients with PPA requires first an understanding of the different types of PPA and their consequences with regard to language. It must first be emphasised that these different types or syndromes are characterised by clusters of features that do not necessarily constitute cleanly separated categories. In other words, a patient may be classified as having one type on the basis of a single feature pertaining to that type, whereas another patient may simultaneously show features of several types (Gorno-Tempini et al. 2011). That said, the three variants of PPA syndromes that have been distinguished are semantic PPA (svPPA), logopenic PPA (lvPPA), and nonfluent (or agrammatic) PPA (nfvPPA).

People with svPPA differ very little from healthy speakers except in their lexical deficits. Their speech usually seems vague, with frequent word substitutions and other semantic paraphasias (Mesulam et al. 2014). Because sufferers of svPPA have difficulty accessing the words they need, they often resort to silent or filled pauses (Botha et al. 2015). They do not present phonological difficulties; rather, they exhibit a specific lexical–semantic deficit, which results in low values on the semantic depth index (SDI) (Quaranta et al. 2022). The SDI value corresponds to the degree of generality vs. specificity of a word and is calculated on the basis of a hierarchical semantic taxonomy of the complete lexicon of a language. For example, a very general term, such as 'animal', is relatively low on this hierarchy and a more specific term, such as 'cat' (a subcategory of 'animal'), is higher. The SDI is a number indicating the degrees that separate a word from the most general root term that encompasses it. Thus 'entity' has an SDI of 1, 'organism' has an SDI of 2, 'animal' an SDI of 3, and so on, until we reach 'cat', with an SDI of 10. Therefore, lower SDI values are observed in speakers who have difficulty expressing themselves with precision, such as individuals with svPPA.

As for lvPPA, its main feature is difficulty in lexical retrieval both in spontaneous speech and in naming tasks, as well as in repeating sentences (Gorno-Tempini et al. 2011; Giannini et al. 2017). Although their fluency is often considered normal and people with lvPPA can produce words with higher SDI values than people with svPPA, their speech rate is slow, and they often pause as they grasp for words. Phonological paraphasias related to phonemic confusion often occur due to the effort they expend in finding the words they need (Pérez Lancho and García Bercianos 2020). Contrary to what happens in apraxia of speech (see below), such phonological confusions are not due to a motor deficit. Some researchers have also shown that the language dysfunction involved in lvPPA is not limited to impairments in word retrieval and verbal working memory but also affects syntactic production, phonological encoding, and semantic representations (Teichmann et al. 2013; Staiger et al. 2021).

Finally, nfvPPA presents motor speech disorders as its main characteristic. Patients may show pronounced agrammatism. They usually suffer from apraxia of speech and present a slower speech rate than patients with the other two PPA variants. They use more hesitations and false starts, probably due to motor problems (Gorno-Tempini et al. 2011; Wilson et al. 2010). In addition, they show phonological problems such as elisions, substitutions, and additions of phonemes. Overall, they find it very challenging to produce spontaneous speech.

Considering the abovementioned differences between the three main variants of PPA, it has been suggested that hesitation patterns in spontaneous speech might be of use in distinguishing among the three when it comes to diagnosis (Ash et al. 2013; Ballard et al. 2014; Poole et al. 2017; Potagas et al. 2022).

1.3. Hesitations in PPA

Most research in aphasiology has focused on single-word production. Nevertheless, it has been suggested that spontaneous speech—in other words, speech that is neither pre-planned nor read nor limited to single words, also known as 'continuous' or 'connected' speech—offers novel possibilities for the diagnosis of PPA (Quaranta et al. 2022). In fact, research on spontaneous speech is particularly relevant for our purpose given that some hesitation phenomena appear only in this type of speech (Boschi et al. 2017). It is worth noting, however, that some of these studies do not specify what kinds of hesitations were included (see the methodological issues noted above). In addition, only a few studies have focused on hesitations in connection with PPA, mostly concluding that atypical hesitation patterns in general are common in PPA patients compared to control speakers. For example, Sajjadi et al. (2012) analysed spontaneous speech elicited in two different tasks and found that the frequency of hesitations was one of the parameters that differentiated nfvPPA participants (more than 10% of utterances), healthy speakers (less than 5%), and a group of PPA participants whose characteristics did not neatly fit into any of the three PPA subclasses ('mixed PPA group', less than 10% but more than 5%).

Silent pauses are also useful for differentiating PPA types, though consensus has yet to be reached on which parameter—pause duration, frequency, or both—best distinguishes these patients. For example, Thomas (2021) indicated that the highest proportion of pauses were longer than 1000 ms for nonfluent aphasic speakers, while it was below 250 ms for fluent aphasic speakers. By contrast, after analysing 21 parameters associated with speech and pausing in Spanish, Baqué et al. (2022) concluded that the number of silences best discriminates among the different variants of PPA, rather than their duration. Similar results were found for Alzheimer's disease, a pathology that is commonly associated with some PPA variants, especially lvPPA (Rohrer et al. 2012). Patients with Alzheimer's also have difficulty recalling words or finding the right vocabulary to express themselves, and in one study it was again the frequency of pauses, not their duration, that distinguished healthy controls from Alzheimer's patients (Lofgren and Hinzen 2022). By contrast, Potagas et al. (2022) found that both parameters, frequency and duration, could be used as complementary biomarkers to discriminate between PPA patients and healthy speakers and also to differentiate the three variants of the illness. Finally, it has also long been noted that pauses in conversation are more frequent and longer in patients with post-stroke aphasia—a set of disorders that share some commonalities with PPA (Budd et al. 2010)—than in healthy speakers (Schlenck et al. 1987).

Concerning filled pauses (or fillers), Christenfeld and Creager (1996) found them to be more frequent in nonfluent than in fluent post-stroke aphasia (0.9/min in Wernicke's aphasia vs. 6.7/min in Broca's aphasia). These authors also observed that the number of filled pauses per every hundred words rather than per minute better differentiates these two types of aphasia.

As for syllable lengthening, though a study looking at overall syllable length in spontaneous speech found no differences between PPA patients and healthy speakers

(Code et al. 2013), to the best of our knowledge, no research has specifically addressed the question of lengthening as a hesitation strategy per se.

In an attempt to shed further light on the relationship between silent pauses, filled pauses, and lengthened syllables and aphasia, we will analyse a wide range of parameters related to the duration and frequency of these three types of hesitation pauses in spontaneous speech obtained from participants with PPA and matching controls.

1.4. Aims of the Current Study

The aim of this study is to determine if three sorts of hesitation pauses—silent pauses, filled pauses, and lengthened syllables—can serve in any way to differentiate the main variants of PPA, namely lvPPA, nfvPPA, and svPPA, in terms of atypicality and (dis)similarity. Thus, the main objective of this study is to answer the following questions:

1. Atypicality:
   - 1.1 Are the pausing patterns of the three main variants of PPA atypical as compared to control speakers of a similar age?
   - 1.2 If so, what are the parameters related to pausing that characterise the atypicality of each variant?
   - 1.3 How does all that contribute to a better understanding of the underlying deficits and allow us to characterise each variant in terms of (dys)fluency?
2. (Dis)similarity:
   - 2.1 To what extent are the observed abnormal pausing patterns (dis)similar in the three main variants of PPA?
   - 2.2 If so, what are the parameters related to pausing that differentiate each group from the other two?
   - 2.3 How does all that contribute to a better understanding of the deficit-specific vs. transversal nature of the impairment in each variant?
3. Parameter relevance:
   - 3.1 What are the parameters related to pausing that best explain the atypicality of each variant and the (dis)similarity between them?

2. Materials and Methods

2.1. Participants

Participants were recruited from a cohort of patients with PPA in the Memory Unit of Sant Pau Hospital in Barcelona between September 2019 and March 2022. The diagnosis of PPA was established following international criteria (Gorno-Tempini et al. 2011). Patients were administered a standardised speech assessment (Table 1) as well as neuropsychological and neurological evaluations, neuroimaging (magnetic resonance imaging or computed tomography), and neurodegeneration biomarkers in cerebrospinal fluid in accordance with the Memory Unit's usual procedures (Alcolea et al. 2019). Based on the results, 32 participants were classified as suffering from one of the following variants: logopenic (lvPPA, n = 13), nonfluent (nfvPPA, n = 10), and semantic (svPPA, n = 9). The severity of their disease was estimated by means of their scores on the Spanish-language versions of two tests, the *Mini-Mental State Examination* (MMSE, Blesa et al. 2001) and the *Clinical Dementia Rating–FTLD scale modified* (CDR-FTLD, Knopman et al. 2008). No significant differences were found between the three groups (MMSE scores: lvPPA = 25.92 ± 3.35, nfvPPA = 25.80 ± 3.76, svPPA = 23.22 ± 4.05, $p = 0.206$; CDR-FTLD scores: lvPPA = 0.53 ± 3.3, nfvPPA = 0.50 ± 3.7, svPPA = 0.77 ± 4.0, $p = 0.154$). The average age of participants was similar in the three groups (71.78 ± 4.6, 72.81 ± 10.2 and 74.88 ± 3.3). Eleven healthy individuals with no neurological conditions or disorders were recruited at the Memory Unit of the same hospital to serve as a control group. Their average age was 73.18 (±3.8). No significant differences were found for age ($p = 0.7$). All the participants were native speakers of Spanish or native Catalan–Spanish bilinguals.[1]

Demographic information about the participants for each PPA variant and controls is provided in Table 1.

Table 1. Demographic information of the participants. [1]

			Controls (n = 11)	lvPPA (n = 13)	nfvPPA (n = 10)	svPPA (n = 9)
Demographic data	Sex	Female	6 (54.5%)	6 (46.2%)	6 (60%)	5 (55.6%)
		Male	5 (45.5%)	7 (53.8%)	4 (40%)	4 (44.4%)
	Dominant hand	Right	11 (100%)	10 (76.9%)	10 (100%)	8 (88.90%)
		Left		1 (7.7%)		
		Both		2 (15.4%)		1 (11.10%)
	Age		73.18 (3.8)	71.78 (4.6)	72.81 (10.2)	74.88 (3.3)
Neurological test results	CDR-FTLD (0–21, lower scores = less impairment)		0.00 (0.00)	4.96 (2.14)	3.35 (2.19)	5.50 (3.28)
	MMSE (/30)		29.18 (0.40)	25.92 (3.35)	25.80 (3.76)	23.22 (4.05)
Language (BDAE)	Spontaneous BNT (/60)		51.27 (3.87)	30.76 (10.31)	44.10 (11.44)	44.10 (13.16)
	Sentence comprehension (/15)		14.90 (0.3)	13.53 (2.5)	13.40 (2.0)	13.44 (2.2)
	Phonetic fluency (in 60 s)		16.81 (1.47)	8.76 (4.76)	5.4 (3.83)	8.55 (5.43)
	Semantic fluency (in 60 s)		16.9 (2.77)	8.61 (3.37)	10.3 (4.76)	7.77 (3.41)
Executive Functions	WAIS Digit Span forward (/9)		6.54 (1.0)	4.69 (1.3)	4.40 (0.8)	5.22 (1.2)
	WAIS Digit Span backwards (/9)		5.36 (0.9)	3.30 (1.0)	3.10 (0.8)	3.77 (0.9)
	TMT-A		42.54 (9.2)	123.07 (177.47)	77.20 (51.39)	71.44 (48.9)
	TMT-B		85.00 (28.5)	426.23 (399.3)	328.00 (260.6)	388.22 (323.3)
Visual space recognition tasks	Poppelreuter Test × 2 (/5)		5 (0)	4.53 (0.77)	4.9 (0.31)	4.33 (0.70)
	CERAD, copy (/11)		7.36 (1.62)	6.38 (1.5)	5.40 (1.17)	4.44 (1.13)
Memory	FCSRT immediate recall (/48)		39.36 (4.4)	21.46 (11.3)	36.50 (10.6)	13.44 (11.0)
	FCSRT delayed recall (/16)		14.36 (1.6)	8.3 (5.0)	12.70 (4.4)	4.55 (4.1)
	CERAD, recall (/11)		5.36 (2.24)	2.0 (2.27)	2.70 (1.33)	1.55 (1.87)

[1] BDAE: Boston Diagnostic Aphasia Examination Test (Spanish-language version, García-Albea et al. 1996a); BNT: Boston Naming Test (Spanish-language version, García-Albea et al. 1996b); CDR-FTLD: Clinical Dementia Rating–FTLD scale-modified (Knopman et al. 2008); CERAD: Consortium to Establish a Registry for Alzheimer's Disease (Morris et al. 1988); FCSRT: Free and Cued Selective Reminding Test (Grober and Buschke 1987); lvPPA: logopenic variant of primary progressive aphasia; MMSE: Mini-Mental State Examination (Blesa et al. 2001); nfvPPA: nonfluent variant of primary progressive aphasia; Poppelreuter Test: Poppelreuter-Ghent Overlapping Figures Test (Ghent 1956; Poppelreuter 1917); svPPA: semantic variant of primary progressive aphasia; TMT: Trail-Making Test (Reitan 1955); WAIS Digit Span: Wechsler Adult Intelligence Scale Digit Span (Wechsler 2008).

2.2. Speech Assessment

For speech evaluation, a Spanish-language version of the SpeechFTLD protocol was used (Vogel 2018). Designed to sample speech, the protocol consists of various tasks (a balanced text, repetition of sentences and words, counting numbers, and so on), which have different levels of complexity. These tasks were administered to participants as part of a clinical trial during initial evaluation sessions. In the task intended to elicit spontaneous speech for analysis in this study, participants were asked to describe what they saw in a picture showing a picnic scene based on Kertesz (2006). The examiner did not intervene unless the participant's description was too short to provide a language sample adequate for analysis. In such cases, the examiner attempted to prompt the participant to elaborate with questions such as 'What else can you see in the picture?'.

2.3. Speech Samples

A health professional audio-recorded each participant performing the picnic scene description in a single session in an office at the Sant Pau Hospital using an application designed by Redenlab for the iPad (https://redenlab.com, accessed on 1 September 2022), with a Lavalier microphone designed for iPhone and iPad (https://apogeedigital.com/products/clipmic-digital, accessed on 1 September 2022).

Recordings were automatically segmented and annotated into speech and silence segments using Praat's Sound: To TextGrid (silences) command (Boersma and Weenink 2020). Speech samples were then manually transcribed orthographically. The intervention of the health professional was neither transcribed nor further analysed, and pauses preceding and following the intervention were removed from any further analysis, as they could not be attributed with any certainty to the participant's speech organisation. Based on the orthographic transcription, each recording was automatically transcribed phonetically and aligned with sound using EasyAlign (Goldman and Schwab 2014). The resulting alignment in phones, syllables, and words was manually corrected. Finally, filled pauses and lengthened syllables were also manually labelled.

From the annotated speech samples, we extracted 48 parameters related to hesitation. For each type of pause (silent pauses, filled pauses, and lengthened syllables), we computed 9 parameters: (1) mean duration; (2) median duration; (3) standard deviation of the duration; (4) number of each type of pause and all pauses together per (a) second of speech, (b) second of total duration (speech + pauses), (c) total number of syllables, and (d) total number of words; and (5) proportion of pause time over (a) the total duration of speech, and (b) the total duration (speech + pauses). Additionally, we classified every silent pause as long, medium, or short, according to Campione and Véronis (2002) criteria and calculated the percentage of each type of pause (long, medium, and short) over the total number of silent pauses. Then, for each of these three silent pause length categories, we also computed the number of pauses per (a) second of speech, (b) second of total duration (speech + pauses), (c) total number of syllables, and (d) total number of words. Table 2 lists these variables in the order in which they have been described here. A detailed list of the 48 variables, ordered orthographically, can be found in Appendix A, Table A1.

Table 2. Description of acoustic parameters.

Type of Parameters	Description	Parameters
Pause duration	Mean (Mn_), median (Mdn_), and standard deviation (SD_) of the duration (Dur) of: - Silent pauses (Psil); - Filled pauses (Pfill); - Lengthened syllables (SlbLONG).	Mn_DurPsil Mn_DurPfill Mn_DurSlbLONG Mdn_DurPsil Mdn_DurPfill Mdn_DurSlbLONG SD_DurPsil SD_DurPfill SD_DurSlbLONG
Distribution of long, medium, and short silent pauses	Ratio of the number (R_Num_) of: - Long silent pauses (LongPsil); - Medium silent pauses (MediumPsil); - Short silent pauses (ShortPsil); relative to the total number of silent pauses (_NumTotPsil)	R_NumLongPsil_NumTotPsil R_NumMediumPSil_NumTotPsil R_NumShortPsil_NumTotPsil
Pause frequency per time unit	Number (Num) of - Silent pauses: ○ Long silent pauses (LongPsil); ○ Medium silent pauses (MediumPsil); ○ Short silent pauses (ShortPsil); ○ All silent pauses: long + medium + short (Psil). - Filled pauses (Pfill); - Lengthened syllables (SlbLONG); - All pauses: silent + filled + lengthened syllables (PausesALL); per: - Second of speech (_DurSpeech); - Total duration (_DurTot).	NumLongPsil_DurSpeech NumMediumPsil_DurSpeech NumShortPsil_DurSpeech NumPsil_DurSpeech NumPfill_DurSpeech NumSlbLONG_DurSpeech NumPausesALL_DurSpeech NumLongPsil_DurTot NumMediumPsil_DurTot NumShortPsil_DurTot NumPsil_DurTot NumPfill_DurTot NumSlbLONG_DurTot NumPausesALL_DurTot

Table 2. *Cont.*

Type of Parameters	Description	Parameters
Pause frequency per linguistic unit	Number (Num) of - Silent pauses: ○ Long silent pauses (LongPsil); ○ Medium silent pauses (MediumPsil); ○ Short silent pauses (ShortPsil); ○ All silent pauses: long + medium + short (Psil). - Filled pauses (Pfill); - Lengthened syllables (SlbLONG); - All pauses: silent + filled + lengthened syllables (PausesALL); per: - Syllable (_NumTotSlb); - Word (_NumTotWords).	NumLongPsil_NumTotSlb NumMediumPsil_NumTotSlb NumShortPsil_NumTotSlb NumPsil_NumTotSlb NumPfill_NumTotSlb NumSlbLONG_NumTotSlb NumPausesALL_NumTotSlb NumLongPsil_NumTotWords NumMediumPsil_NumTotWords NumShortPsil_NumTotWords NumPsil_NumTotWords NumPfill_ NumTotWords NumSlbLONG_NumTotWords NumPausesALL_NumTotWords
Pause duration ratio	Ratio of the duration (R_Dur) of - Silent pauses (Psil); - Filled pauses (Pfill); - Lengthened syllables (SlbLONG); - All pauses: silent + filled + lengthened syllables (PausesALL); per: - Second of speech (_DurSpeech); - Second of total duration (_DurTot);	R_DurPsil_DurSpeech R_DurPfill_DurSpeech R_DurSlbLONG_DurSpeech R_DurPausesALL_DurSpeech R_DurPsil_DurTot R_DurPfill_DurTot R_DurSlbLONG_DurTot R_DurPausesALL_DurTot

Such a wide range of parameters should make it possible to account for the use of different types of pauses by each group of participants. Pause duration, variability, and frequency are assumed to reflect specific difficulties in speech processing (see above, Section 1), related to both speech–motor and cognitive–linguistic levels. Distinguishing between the frequency of pauses per word and per syllable should allow us to infer whether such difficulties arise from articulatory planning or execution deficits (increased frequency of pauses both per syllable and per word) or from lexical retrieval impairments (increased frequency per word, but not per syllable). Although pause–speech and pause–total duration ratios co-vary, we decided to include both parameters to allow comparisons with previous studies (see below, Discussion).

2.4. Statistical Analysis

Different statistical analyses were carried out to observe which parameters would vary as a function of the group and discern patterns and trends in the behaviour of each PPA group compared to the healthy control group. First, linear mixed-effects models were used in order to check for effects within and between groups. The duration was analysed as a function of group (four levels: control, lvPPA, nfvPPA, svPPA) and pause type (three levels: silent pauses, filled pauses, lengthened syllables), with speaker entered as a random factor, in R (v. 4.2.0, R Core Team 2022). The reference group was the group of healthy speakers. Then, linear regression models were used to estimate how the dependent variables (all the parameters in Table 2) changed as a function of the groups considered. The atypicality of each group of participants with PPA was determined by comparing each patient group with the healthy group. An analysis of the (dis)similarity among groups of participants with PPA was achieved by contrasting these three groups after excluding data from the control group.

3. Results

The results of this study are structured in five subsections, depending on the type of parameters considered, namely:

1. Pause duration: mean (raw data), median, and standard deviation;
2. Distribution of long, medium, and short silent pauses;
3. Pause frequency: number of pauses per second of speech and per total duration;
4. Pause frequency: number of pauses per syllable and per word;
5. Pause–speech and pause–total duration ratios.

For every parameter, we carried out two different analyses corresponding to the following two goals:

1. Atypicality: to account for any atypicality found in PPA by means of linear regression models in which each group of participants with PPA was compared to the control group;
2. (Dis)similarity: to determine whether the parameter would serve to differentiate any one of the three PPA groups from the other two by means of linear regression models where data corresponding to controls were excluded.

3.1. Pause Duration: Mean (Raw Data), Standard Deviation, and Median

As can be seen in Table 3, overall, the mean duration of silent pauses was shorter in controls (0.604 s) than in each of the patient groups (svPPA = 0.769 s; lvPPA = 0.837 s, and especially nfvPPA = 1.377 s). As for filled pauses and lengthened syllables, lvPPA participants presented similar duration values to controls (filled pauses: 0.622 s vs. 0.606 s; lengthened syllables: 0.589 s vs. 0.585 s, respectively), whereas the mean duration was longer in the nfvPPA group (0.674 s and 0.656 s) and shorter in the svPPA group (0.489 s and 0.520 s, respectively).

Table 3. Mean and standard deviation values for the duration of each pause type (silent pause, filled pause, or lengthened syllable), by group.

Parameter	Control		lvPPA		nfvPPA		svPPA	
	N	Control	N	Mean (sd)	N	Mean (sd)	N	Mean (sd)
Dur_Psil	696	0.604 (0.735)	778	0.837 (0.890)	283	1.377 (2.626)	200	0.769 (0.839)
Dur_Pfill	126	0.606 (0.429)	161	0.622 (0.387)	41	0.674 (0.320)	20	0.489 (0.239)
Dur_SlbLONG	290	0.585 (0.179)	247	0.589 (0.259)	85	0.656 (0.285)	78	0.520 (0.156)

The standard deviation of the duration of silent pauses showed a lower variability in controls (0.735 s) than in each group of persons with PPA (in ascending order, svPPA = 0.839 s, lvPPA = 0.890, and nfvPPA = 2.626 s). On the other hand, controls were associated with the highest standard deviation values of filled pause duration (0.429 s vs. lvPPA = 0.387 s, nfvPPA = 0.320 s, and svPPA = 0.239 s). As for lengthened syllables, the lowest standard deviation value corresponded to the svPPA group (0.156 s), followed by controls (0.179 s), the lvPPA group (0.259 s), and the nfvPPA group (0.285 s).

Overall, the median duration (see Table 4) of silent pauses was shorter in controls (0.503 s) than in each of the PPA groups (svPPA = 0.663 s; lvPPA = 0.678 s, and nfvPPA = 794 s). As for filled pauses, the lowest value corresponded to the svPPA group (0.427 s), followed by controls (0.524 s), the nfvPPA group (0.535 s), and the lvPPA group (0.579 s). The median duration of lengthened syllables was shorter in the lvPPA group (0.502 s) than in the controls (0.537 s), the lvPPA group (0.559 s), or the nfvPPA group (0.616 s).

Table 4. Mean and standard deviation values for the median duration of each pause type, by group.

Parameter	Control		lvPPA		nfvPPA		svPPA	
	N	Control	N	Mean (sd)	N	Mean (sd)	N	Mean (sd)
Mdn_DurPsil	696	0.503 (0.169)	778	0.678 (0.193)	283	0.794 (0.472)	200	0.663 (0.432)
Mdn_DurPfill	126	0.524 (0.183)	161	0.579 (0.212)	41	0.535 (0.289)	20	0.427 (0.216)
Mdn_DurSlbLONG	290	0.537 (0.069)	247	0.559 (0.128)	85	0.616 (0.121)	78	0.502 (0.089)

3.1.1. Atypicality of Each PPA Group

In order to find out the extent to which pause duration was atypical in each of the PPA groups, we compared each patient group to the control group. Nine separate models were computed: one for each pause type (silent pauses, filled pauses, lengthened syllables) and PPA group (lvPPA vs. controls, nfvPPA vs. controls, and svPPA vs. controls). The estimates are reported in Appendix A, Table A2.

With regard to standard deviation and median values, linear regression models were carried out for each PPA group (lvPPA vs. controls, nfvPPA vs. controls, and svPPA vs. controls). The estimates are reported in Appendix A, Tables A3 and A4, respectively.

In lvPPA–controls comparisons, the results show no significant effect of group on the duration of any type of pause. Although the mean duration of silent pauses was longer in the lvPPA group than in controls (0.837 s vs. 0.604 s), this difference did not reach significance (p = 0.050).

Compared to controls, the nfvPPA group presented significantly longer silent pauses (1.377 s vs. 0.604 s; p = 0.047) and lengthened syllable duration (0.656 s vs. 0.585 s; p = 0.025).

Concerning the svPPA group, they presented shorter lengthened syllables than controls (0.520 s vs. 0.585 s; p = 0.033). No other significant effects were observed.

No significant differences in the duration of filled pauses were found for any of the PPA groups compared to controls.

The comparisons of the standard deviation of pause duration between the lvPPA group and controls showed no significant effect of group for any of the pause types considered.

By contrast, compared to controls, the nfvPPA group was associated with lower standard deviation values of filled pause duration (0.320 s vs. 0.429 s) but higher values in those of lengthened syllables (0.285 s vs. 0.179 s). The standard deviation of silent pause duration was greater in the nfvPPA group than in the control group (2.626 s vs. 0.735 s), but this difference did not reach significance (p = 0.082).

As for the svPPA group, they differed from controls only in their shorter standard deviation of lengthened syllables (0.156 s vs. 0.179 s).

Concerning the median duration, we observed a significant difference between the lvPPA group and controls for silent pauses, the former being associated with much higher values (0.678 s vs. 0.503 s). No significant effects were found for either filled pauses or lengthened syllables.

Neither in the nfvPPA group nor in the svPPA group was there any significant effect of group on the median duration of any of the pause types considered.

3.1.2. (Dis)Similarity among PPA Groups

To investigate whether pause duration served in any way to differentiate the three PPA groups, we excluded the data from the control group and computed mixed effects linear regression models. The estimates are reported in Appendix A, Table A5.

Linear regression models were also calculated with the standard deviation and median values of the duration of each type of pause (see Appendix A, Tables A6 and A7, respectively).

No significant effect of group was found on the duration of silent pauses, filled pauses, or lengthened syllables. Therefore, despite sizeable differences between the mean values observed (see Table 3), none of these parameters alone allowed us to distinguish among the three PPA groups.

Concerning standard deviation values of pause duration, the results reveal a single significant group effect, which was related to lengthened syllables (p = 0.006). The post hoc analyses showed that the only significant contrast was between the nfvPPA and svPPA groups, with the former being associated with much higher variability (0.285 s vs. 0.156 s).

As for median duration, no significant effect of group was found on silent pauses, filled pauses, or lengthened syllables.

3.2. Distribution of Short, Medium, and Long Silent Pauses

Pause duration is extremely varied in spontaneous speech, and often presents trimodal behaviour (Campione and Véronis 2002), making overall mean and median values of little interest. Therefore, we categorised silent pauses into three length types, following Campione and Véronis' criteria, namely short (<0.2 s), medium (0.2–1.0 s), and long (>1 s).

From the descriptive data for the proportion of short, medium, and long silent pauses shown in Table 5, one can see that the four groups used medium pauses more often than short or long ones. The mean proportion of long pauses was greater in the svPPA group (22.7%), the lvPPA group (28.1%), and especially the nfvPPA group (33.3%), than in controls (16.1%). On the other hand, the three PPA groups used short pauses less frequently than did controls (svPPA = 12.1%, nfvPPA = 12.6%, lvPPA = 13.4%, vs. controls = 22.0%).

Table 5. Mean and standard deviation values of the proportion of the total number of silent pauses which are long, medium, or short, by group.

Parameter	Control (N = 11)	lvPPA (N = 13)	nfvPPA (N = 10)	svPPA (N = 9)
R_NumLongPsil_NumTotPsil	0.161 (0.115)	0.281 (0.151)	0.333 (0.234)	0.227 (0.221)
R_NumMediumPsil_NumTotPsil	0.619 (0.111)	0.585 (0.146)	0.541 (0.175)	0.653 (0.178)
R_NumShortPsil_NumTotPsil	0.220 (0.116)	0.134 (0.086)	0.126 (0.081)	0.121 (0.101)

3.2.1. Atypicality of Each PPA Group

The 'atypicality' of each PPA group in the proportion of long, medium, and short silent pauses was assessed using linear regression models. The estimates of the results are reported in Appendix A, Table A8.

The results show that the lvPPA group differed significantly from controls in that they took long silent pauses more often (28.1% vs. 16.1%; F(1) = 4.676, p = 0.042) and used short pauses less frequently (13.4% vs. 22.0%; F(1) = 4.407, p = 0.047).

The effects observed in the nfvPPA group were similar (long: F(1) = 4.767, p = 0.042; short: F(1) = 4.604, p = 0.045), but even stronger: almost one-third of silent pauses exceeded 1 s, while only 12.6% were inferior to 0.2 s.

As for the svPPA group, no significant differences were observed for any of the parameters considered.

No significant differences were observed in the proportion of medium pauses for any of the PPA groups compared to controls.

3.2.2. (Dis)Similarity among PPA Groups

In order to see whether the proportion of short, medium, or long silent pauses would allow us to differentiate the three PPA groups from each other, we carried out linear regression models in which group was entered as the independent variable. The results are reported in Appendix A, Table A9.

No significant group effect was found for any of the proportions under consideration, showing that none of these parameters can be used alone to distinguish among the three variants of PPA.

3.3. Pause Frequency: Number of Pauses per Second

Pause frequency, computed as the number of pauses produced per second, is believed to be atypical in PPA (see Section 1). We computed the pause frequency (per second of speech and per second of total duration, including speech and pauses) for each participant in our study, separately for each pause type (silent pause, filled pause, and lengthened syllables), and together, adding the frequency of the three categories of pauses.

As can be seen in Table 6, in the control group, on average, there were 0.941 pauses per second of speech (0.658 per second of total duration), distributed as follows: 0.593 silent pauses, 0.100 filled pauses, and 0.249 lengthened syllables (0.411 silent pauses, 0.070 filled pauses and 0.178 lengthened syllables per second of total duration, respectively).

Table 6. Mean and standard deviation values of pause frequency (per second of speech/total duration), by pause type (Psil = silent pauses, Pfill = filled pauses, SlbLONG = lengthened syllables, PausesALL = all three together) and group.

Parameter	Control (N = 11)	lvPPA (N = 13)	nfvPPA (N = 10)	svPPA (N = 9)
NumPsil_DurSpeech	0.593 (0.152)	0.870 (0.235)	0.843 (0.258)	0.574 (0.141)
NumPsil_DurTot	0.411 (0.091)	0.476 (0.113)	0.407 (0.126)	0.382 (0.084)
NumPfill_DurSpeech	0.100 (0.047)	0.164 (0.149)	0.126 (0.143)	0.060 (0.053)
NumPfill_DurTot	0.070 (0.031)	0.088 (0.076)	0.052 (0.035)	0.042 (0.042)
NumSlbLONG_DurSpeech	0.249 (0.096)	0.280 (0.138)	0.242 (0.136)	0.209 (0.125)
NumSlbLONG_DurTot	0.178 (0.074)	0.162 (0.092)	0.129 (0.087)	0.142 (0.089)
NumPausesALL_DurSpeech	0.941 (0.194)	1.312 (0.329)	1.210 (0.388)	0.843 (0.224)
NumPausesALL_DurTot	0.658 (0.125)	0.727 (0.183)	0.585 (0.208)	0.567 (0.164)

For every parameter, the lvPPA group showed the highest mean values, with one exception, the number of lengthened syllables per second of total duration, which was slightly smaller than that of controls (0.162 vs. 0.178). On average, the lvPPA group produced 1.312 pauses per second of speech (0.727 per second of total duration): 0.870 silent pauses, 0.164 filled pauses, and 0.280 lengthened syllables (0.476, 0.088 and 0.162, respectively, per second of total duration).

On the other hand, the lowest number of pauses taking into account only speech or total duration was observed in the svPPA group, either separately for silent pauses (0.574 and 0.382, respectively), filled pauses (0.060 and 0.042), and lengthened syllables (0.209 and 0.142), or when the three types of pauses were considered together (0.843 and 0.567, respectively). The only exception concerns the number of lengthened syllables per second of total duration, which was slightly higher than for the nfvPPA group.

The results for the nfvPPA group are somewhere in between the two poles represented by the svPPA and lvPPA groups. The mean pause frequency observed in the nfvPPA group per second of speech was higher than that of all the other groups except lvPPA, either overall (1.210 pauses per second), or for silent (0.843) or filled (0.126) pauses. The number of lengthened syllables per second of speech (0.242) was similar to that recorded for controls. However, when pause frequency was computed on the total duration of speech and pauses, the values obtained were similar to or lower than those obtained for controls: the nfvPPA group produced fewer pauses overall (0.585/s), fewer filled pauses (0.052/s), fewer lengthened syllables (0.129/s, which was even lower than in the svPPA group) than controls, and almost the same number of silent pauses (0.407/s).

Further analysis of the frequency of silent pauses per second of speech or per second of total duration, in which we distinguished short (<0.2 s), medium (0.2–1.0 s), and long (>1.0 s) pauses (see Table 7), showed that control participants had fewer long silent pauses per second of speech (0.094 vs., in increasing order, svPPA: 0.133, lvPPA: 0.232, and nfvPPA: 0.311 pauses/s) and more short silent pauses (0.136 vs., in descending order, lvPPA: 0.126, nfvPPA: 0.098, and svPPA: 0.065 pauses/s). Similar results were obtained for frequencies computed per second of total duration.

Table 7. Mean and standard deviation values of silent pause frequency (per second of speech/total duration), by length category and group.

Parameter	Control (N = 11)	lvPPA (N = 13)	nfvPPA (N = 10)	svPPA (N = 9)
NumLongPsil_DurSpeech	0.094 (0.073)	0.232 (0.112)	0.311 (0.291)	0.133 (0.121)
NumLongPsil_DurTot	0.062 (0.041)	0.123 (0.053)	0.111 (0.052)	0.078 (0.056)
NumMediumPsil_DurSpeech	0.363 (0.096)	0.511 (0.183)	0.433 (0.142)	0.377 (0.139)
NumMediumPsil_DurTot	0.252 (0.061)	0.284 (0.110)	0.238 (0.133)	0.258 (0.096)
NumShortPsil_DurSpeech	0.136 (0.090)	0.126 (0.088)	0.098 (0.053)	0.065 (0.044)
NumShortPsil_DurTot	0.097 (0.065)	0.069 (0.052)	0.056 (0.043)	0.047 (0.035)

As for medium silent pauses, the highest frequency per second of speech was found in the lvPPA group (0.511/s), followed by the nfvPPA group (0.433/s), the lvPPA group (0.377/s), and, finally, by controls (0.363/s). When computed by second of total duration, the highest value corresponded to the lvPPA group (0.284/s), followed by the svPPA group and controls (0.258 and 0.252/s). The lowest frequency of medium silent pauses per second of total duration was seen in the nfvPPA group (0.238/s).

3.3.1. Atypicality of Each PPA Group

In order to describe the extent to which the abovementioned differences in the frequency of pauses between each PPA group and controls are attributable to specific 'atypicalities', we carried out linear regression models of the effect of group on each of the parameters. Separately models were computed for each parameter and group comparison (lvPPA vs. controls, nfvPPA vs. controls, and svPPA vs. controls). The obtained estimates are reported in Appendix A, Table A10.

No significant effect of group was found for any of the comparisons of a PPA group with controls in terms of pause frequency per second of total duration, either when silent pauses, filled pauses, and lengthened syllables were considered separately, or when the three pause types were taken together.

As for pause frequency per second of speech, the results show that the lvPPA group differed significantly from controls in the number of silent pauses (lvPPA = 0.870 vs. control = 0.593 pauses/s, $p = 0.003$), as well as in the number of overall pauses (lvPPA = 1.312 vs. control = 0.941 pauses/s, $p = 0.003$).

Concerning the nfvPPA group, the frequency of silent pauses was also significantly higher than that of controls (nfvPPA = 0.843 vs. control = 0.593 pauses/s, $p = 0.013$). The number of overall pauses per second of speech was also greater in the nfvPPA group (1.210 vs. 0.941 pauses/s, respectively), but the difference was not significant ($p = 0.055$).

No significant effect of group was found in lvPPA–controls comparisons for any of the parameters considered.

In addition, more fine-grained analyses were conducted on long, medium, and short silent pauses taken separately (see Appendix A, Table A11).

The results show that the lvPPA group differed significantly from controls only in the frequency of long silent pauses per second (of both speech and total duration) and of medium silent pauses per second of speech. In all these cases, the lvPPA group produced pauses more often than controls (0.232 vs. 0.094 long pauses/s of speech, $p = 0.002$; 0.123 vs. 0.062 long pauses/s of total duration, $p = 0.005$; 0.511 vs. 0.363 medium pauses/s of speech, $p = 0.025$). No significant effects were found for short pauses or for the number of medium pauses per second of total duration.

The number of long pauses was also significantly higher in the nfvPPA group than in controls, both per second of speech (0.311 vs. 0.094 pauses/s, $p = 0.027$) and per second of total duration (0.111 vs. 0.062 pauses/s, $p = 0.024$). No further significant differences were found between the nfvPPA and svPPA groups.

As for the svPPA participants, by contrast, they differed from controls only in the number of short silent pauses per second of speech, which was significantly lower (0.065 vs.

0.136/s, p = 0.046). The frequency of short silent pauses per second of total duration was also lower in the lvPPA group than in controls (0.047 vs. 0.097 pauses/s), but the difference did not reach significance (p = 0.056).

3.3.2. (Dis)Similarity among PPA Groups

We carried out linear regression models of the effect of group on the frequency of silent and filled pauses, lengthened syllables, and all pauses taken together in order to determine the extent to which the three PPA groups might differ one from another in terms of each of these parameters (see Appendix A, Table A12).

The results show no significant effects except for the number of silent pauses (p = 0.010) and of overall pauses (p = 0.008) per second of speech. In both cases, the post hoc analyses revealed a single significant contrast between the nfvPPA and svPPA groups (0.843 vs. 0.574 silent pauses/s, p = 0.0343; 1.210 vs. 0.843 overall pauses/s, p = 0.0512).

Similar analyses were carried out for long, medium, and short silent pauses taken separately (see Appendix A, Table A13), but no significant effects were found for any of the parameters considered. Therefore, the frequency of silent pauses, divided by length type, did not allow us to differentiate among the three PPA groups.

3.4. Pause Frequency: Number of Pauses per Syllable/Word

Pause frequency, computed as the number of pauses per syllable or word, has also been conjectured to be atypical in PPA. In our study (see Table 8), on average, there were 0.201 pauses per syllable (i.e., a pause every 4.8 syllables) and 0.345 pauses per word (i.e., a pause every 2.9 words) in the control group. These pauses were distributed as follows: 0.126 silent pauses, 0.022 filled pauses, and 0.053 lengthened syllables per syllable, and 0.216 silent pauses, 0.037 filled pauses, and 0.091 lengthened syllables per word.

Table 8. Mean and standard deviation values of pause frequency (per syllable/word), by type and group.

Parameter	Control (N = 11)	lvPPA (N = 13)	nfvPPA (N = 10)	svPPA (N = 9)
NumPsil_NumTotSlb	0.126 (0.034)	0.193 (0.066)	0.210 (0.067)	0.108 (0.029)
NumPsil_NumTotWords	0.216 (0.057)	0.298 (0.099)	0.357 (0.129)	0.172 (0.050)
NumPfill_NumTotSlb	0.022 (0.011)	0.039 (0.042)	0.031 (0.031)	0.011 (0.010)
NumPfill_NumTotWords	0.037 (0.018)	0.059 (0.061)	0.054 (0.056)	0.018 (0.016)
NumSlbLONG_NumTotSlb	0.053 (0.021)	0.061 (0.030)	0.060 (0.037)	0.040 (0.023)
NumSlbLONG_NumTotWords	0.091 (0.037)	0.094 (0.044)	0.100 (0.062)	0.063 (0.038)
NumPausesALL_NumTotSlb	0.201 (0.048)	0.293 (0.106)	0.301 (0.102)	0.159 (0.044)
NumPausesALL_NumTotWords	0.345 (0.080)	0.451 (0.151)	0.511 (0.191)	0.253 (0.076)

The lowest values for frequency of pauses per syllable and per word were found in the svPPA group, for every type of pauses, and when all types were considered together. On average, the svPPA group produced 0.159 pauses/syllable or 0.253 pauses/word, which means a pause every 6.3 syllables or 4.0 words.

On the other hand, the lvPPA and nfvPPA groups presented higher values than controls in each parameter considered. Overall, the lvPPA group produced 0.293 pauses/syllable and 0.451 pauses per word, that is, a pause every 3.4 syllables or 2.2 words. As for the nfvPPA group, there was a pause about every 3.3 syllables or 2.0 words.

An exploration of the frequency of silent pauses per syllable and word, grouped by length type (see Table 9), showed that controls produced 0.020 long pauses per syllable (0.033 per word), which means a long pause every 50.0 syllables or 30.3 words. The frequency of long silent pauses was slightly higher in the svPPA group (a pause every 38.5 syllables or 24.4 words), and much higher in both the lvPPA group (a pause every 19.2 syllables or 12.5 words) and the nfvPPA group (one every 13.3 syllables and 7.7 words).

Table 9. Mean and standard deviation values of silent pause frequency (per syllable/word), by length category and group.

Parameter	Control (N = 11)	lvPPA (N = 13)	nfvPPA (N = 10)	svPPA (N =9)
NumLongPsil_NumTotSlb	0.020 (0.014)	0.052 (0.027)	0.075 (0.066)	0.026 (0.026)
NumLongPsil_NumTotWords	0.033 (0.024)	0.080 (0.042)	0.130 (0.118)	0.041 (0.039)
NumMediumPsil_NumTotSlb	0.077 (0.023)	0.112 (0.042)	0.111 (0.049)	0.070 (0.025)
NumMediumPsil_NumTotWords	0.133 (0.038)	0.173 (0.066)	0.187 (0.085)	0.112 (0.043)
NumShortPsil_NumTotSlb	0.029 (0.020)	0.029 (0.021)	0.025 (0.014)	0.012 (0.008)
NumShortPsil_NumTotWords	0.050 (0.033)	0.044 (0.031)	0.041 (0.023)	0.020 (0.014)

On the other hand, the highest frequency of short silent pauses was found in controls (one every 34.5 syllables or 20 words), followed by the lvPPA (a short pause every 34.5 syllables and 22.7 words) and nfvPPA groups (one every 40 syllables or 24.4 words). The lowest values corresponded to the svPPA group (a short silent pause every 83.3 syllables or 50 words).

As for medium silent pauses, they were much more frequent in the nfvPPA (one every 9.0 syllables or 5.3 words) and lvPPA groups (1/9.0 syllables or 1/5.8 words) than in controls (1/13.0 syllables or 1/7.5 words) or the svPPA group (1/14.3 syllables or 1/8.9 words).

3.4.1. Atypicality of Each PPA Group

We compared each PPA group with controls using linear regression models, separately for each parameter. The estimates are reported in Appendix A, Table A14.

The results show that lvPPA differed from controls in the number of silent pauses per syllable ($p = 0.006$) and word ($p = 0.004$), as well as in the frequency of overall pauses (per syllable: $p = 0.015$; per word: $p = 0.048$). In all cases, the lvPPA group produced pauses more frequently than controls (silent pauses: 0.193 vs. 0.126/syllable and 0.298 vs. 0.216/word; overall pauses: 0.293 vs. 0.201/syllable and 0.451 vs. 0.345/word). No other significant effects were found.

The same parameters significantly distinguished the nfvPPA group and controls: the number of silent pauses and overall pauses per syllable (silent: $p = 0.002$; overall: $p = 0.009$) and words (silent: $p = 0.004$; overall: $p = 0.016$). As with the lvPPA group, the frequency of silent pauses and overall pauses per syllable and word were much more frequent in the nfvPPA group than in controls (silent pauses: 0.210 vs. 0.126/syllable and 0.357 vs. 0.216/word; overall pauses: 0.301 vs. 0.201/syllable and 0.511 vs. 0.345/word). Again, no other significant effects were found.

Regarding the svPPA group, the only significant effects were observed in the number of filled pauses per syllable ($p = 0.036$) and word ($p = 0.022$) and in the overall pause frequency per word ($p = 0.018$). In all cases, the svPPA group produced fewer pauses than controls (0.011 vs. 0.022 filled pauses/syllable, 0.018 vs. 0.037 filled pauses/word, 0.253 vs. 0.345 overall pauses/word).

The estimates yielded by further comparisons of each PPA group with controls in terms of the number of long, medium, and short silent pauses are reported in Appendix A, Table A15.

We reported above a higher frequency of overall silent pauses in the lvPPA group than in controls, but these supplementary analyses showed that such differences appeared only for long silent pauses (0.052 vs. 0.020/syllable, $p = 0.002$; and 0.080 vs. 0.033/word, $p = 0.003$) and for medium silent pauses per syllable (0.112 vs. 0.077 pauses/syllable, $p = 0.025$). In addition, the lvPPA group produced more medium silent pauses per word than did controls (0.173 vs. 0.133 pauses/word), but this contrast did not reach significance ($p = 0.086$). No significant effects were shown in short pause frequency, either per syllable or per word.

Similarly, the nfvPPA group only differed from controls in the number of long silent pauses per syllable (0.075 vs. 0.020 pauses/syllable, p = 0.014) and per word (0.130 vs. 0.033 pauses/word, p = 0.016).

As for the svPPA group, which did not differ from controls in overall silent pause frequency, these results show that no difference was significant in the frequency of long or medium pauses, but that the svPPA group produced significantly fewer short silent pauses than controls, both per syllable (0.012 vs. 0.029 pauses/syllable, p = 0.025) and per word (0.020 and 0.050 pauses/word, p = 0.020).

3.4.2. (Dis)Similarity among PPA Groups

We investigated whether pause frequency per syllable and word could be used to distinguish the three variants of PPA by means of linear regression models of each parameter considered as a function of group (lvPPA, nfvPPA, and svPPA). The estimates are reported in Appendix A, Table A16.

Significant effects of group were found on only two pause parameters: the frequency of silent pauses (per syllable: p = 0.002; per word: p = 0.001) and the frequency of overall pauses (per syllable: p = 0.003; per word: p = 0.002). The post hoc analyses showed that the svPPA group produced significantly fewer silent pauses than the other two groups per syllable (0.108 vs. lvPPA = 0.193 and nfvPPA = 0.210 pauses/syllable) and word (0.172 vs. lvPPA = 0.298 and nfvPPA = 0.357 pauses/word). Similar contrasts were observed in the number of overall pauses per syllable (0.159 vs. lvPPA = 0.293 and nfvPPA = 0.301 pauses/syllable) and word (0.253 vs. lvPPA = 0.451 and nfvPPA = 0.511 pauses/syllable). No significant differences between the lvPPA and nfvPPA groups were found for any of the parameters under consideration.

The results of supplementary analyses carried out on the effects of group on the frequency of long, medium, and short silent pauses are reported in Appendix A, Table A17.

The results show a significant effect of group on the number of long silent pauses per word (p = 0.045). The post hoc analyses revealed a single significant contrast between the nfvPPA and svPPA groups (p = 0.0364): the nfvPPA group produced twice as many long silent pauses per word (0.511) than the svPPA group (0.253). No other significant contrasts were found. In addition, the effect of group on the other parameters considered did not reach significance.

3.5. Pause–Speech and Pause–Total Duration Ratios

The proportion of pause time in relation to the duration of speech or the total duration of both speech and pauses has also been suggested to be atypical in some variants of PPA.

In our study (see Table 10), the lowest overall pause–speech and pause–total duration ratio corresponded, as expected, to controls (58.15% and 39.95%, respectively) and followed by the svPPA group (63.18% and 39.80%, respectively). The highest values were observed in the lvPPA (98.64% and 53.26%) and nfvPPA groups (157.40% and 55.66%).

Table 10. Mean and standard deviation values of pause–speech and pause–total duration ratios, by type and group.

Parameter	Control (N = 11)	lvPPA (N = 13)	nfvPPA (N = 10)	svPPA (N = 9)
R_DurPsil_DurSpeech	37.268 (16.706)	72.598 (24.272)	133.141 (149.431)	49.590 (31.506)
R_DurPsil_DurTot	25.095 (8.238)	38.868 (8.565)	43.969 (20.406)	30.353 (12.832)
R_DurPfill_DurSpeech	6.436 (3.330)	9.854 (10.483)	8.739 (13.139)	2.742 (2.377)
R_DurPfill_DurTot	4.509 (2.144)	5.202 (4.974)	3.328 (2.664)	2.006 (1.851)
R_DurSlbLONG_DurSpeech	14.441 (5.919)	16.183 (7.316)	15.519 (8.204)	10.851 (6.527)
R_DurSlbLONG_DurTot	10.345 (4.568)	9.195 (4.697)	8.364 (5.733)	7.436 (4.827)
R_DurPausesALL_DurSpeech	58.145 (14.790)	98.635 (25.851)	157.398 (155.686)	63.183 (29.295)
R_DurPausesALL_DurTot	39.949 (6.205)	53.262 (7.239)	55.661 (17.683)	39.797 (11.042)

The proportion of time devoted to silent pauses over speech duration and total duration followed the same pattern: it was lower in controls (32.27% of speech duration and 25.10% of total duration), followed by the svPPA group (49.59% and 30.35%), and much higher in the lvPPA (72.60% and 38.87%) and nfvPPA groups (133.14% and 43.97%, respectively).

On average, the filled pause–speech ratio varied from 2.74% in the svPPA group to 9.85% in the lvPPA group; controls and the nfvPPA group presented intermediate values (6.44% and 8.74%, respectively). Similarly, the lengthened syllables–speech ratio varied from 10.85% in the svPPA group to 16.18% in the lvPPA group, with intermediate values observed in controls (14.44%) and the nfvPPA group (15.52%).

As for the percentage of total duration devoted to filled pauses and lengthened syllables, the lowest mean values corresponded to the svPPA (2.01% and 7.44%, respectively) and nfvPPA groups (3.33% and 8.36%, respectively), and the highest ones were observed in controls (4.51% and 10.35%) and the lvPPA group (5.20% and 9.20%, respectively).

3.5.1. Atypicality of Each PPA Group

Each group of participants with PPA was compared with controls by means of linear regression models of the effect of group on different parameters related to pause–speech and pause–total duration ratios (see Appendix A, Table A18).

The results show that the lvPPA group differed significantly from controls in the percentage of silent pause time over speech (p = 0.001) and total duration (p = 0.001), as well as in the proportion of overall pause time, in relation to both speech (p = 0.000) and total duration (p = 0.000). Compared to controls, lvPPA was associated with a higher silent pause–speech ratio (72.60% vs. 37.27%) and silent pause–total duration ratio (38.87% vs. 25.10%, respectively). Similarly, the proportion of time devoted to overall pauses was much greater in the lvPPA group than in controls (98.64% vs. 58.15% of speech time, and 53.26% vs. 39.95% of total duration, respectively). No significant effects were found in pause–speech or pause–total duration ratio for either filled pauses or lengthened syllables.

A significant effect was found for the nfvPPA group on the same parameters: silent pause–speech ratio (p = 0.048), silent pause–total duration ratio (p = 0.01), overall pause–speech ratio (p = 0.048), and overall pause–total duration ratio (p = 0.000). In this group, silent pause duration equalled on average 133.14% of speech duration (vs. 37.27% in controls) and 43.97% of total duration (vs. 25.10% in controls). The percentage of time devoted to pauses overall was also much higher in the nfvPPA group than in controls, in relation to both speech (157.40% vs. 58.15%) and total duration (55.66% vs. 39.95%, respectively). Again, no significant effects were found for filled pauses or lengthened syllables.

With regard to the svPPA group, the results show significant effects only on the percentage of time of filled pauses over both speech time (p = 0.012) and total duration (p = 0.013). Compared to controls, svPPA participants allowed a proportionally smaller amount of time for filled pauses than did controls (pause–speech ratio: 2.74% vs. 6.44%; pause–total duration ratio: 2.01% vs. 4.51%).

3.5.2. (Dis)Similarity among PPA Groups

We report in Appendix A, Table A19, the results of the linear regression models carried out in order to investigate whether any of the parameters related to pause–speech or pause–total duration ratio could be used to differentiate the three PPA groups from each other.

No significant group effect was found on any of the parameters considered, with only one exception: the proportion of total duration devoted to pauses overall (p = 0.019). The post hoc analyses showed that the svPPA group differed from the other two PPA groups by showing lower values for the pause–total duration ratio (38.80% vs. lvPPA = 53.26%, p = 0.0452; and vs. nfvPPA = 55.66%, p = 0.0239).

4. Discussion

The goal of this study was to determine whether measures related to pausing could be used to distinguish the three main variants of primary progressive aphasia from healthy controls and also to differentiate the three variants of PPA from each other. We will examine the light that our findings shed on these two questions and then address certain methodological issues that bear on our results.

4.1. Atypicalities in PPA

For several of the parameters examined, our results reveal no significant differences between controls and each of the variants of PPA. However, other parameters did differ significantly across groups. Most notably, the frequency of total pauses per word was much higher in the lvPPA and nfvPPA groups (every 2.22 and 1.9 words, respectively) than in the control group (every 2.9 words) and significantly lower in the svPPA group (every 3.95 words). This frequency seems to be the most reliable index of different pausing patterns in PPA types (Ash et al. 2013; Fraser et al. 2014; Potagas et al. 2022; Wilson et al. 2010) and apparently can also help to distinguish variants of vascular aphasia (Angelopoulou et al. 2018). This reliability may be due to the fact that this parameter does not depend on speech and articulatory rates, which are highly variable as a result of both individual personality traits (Goldman-Eisler 1968) and the particularities of speech and language impairments (Christenfeld and Creager 1996). Additionally, in the present study, each group with PPA presented atypical values in a different set of pause-related metrics, which we will now examine in detail.

4.1.1. lvPPA

Participants with lvPPA presented higher values than controls in a set of dimensions, mostly related to the frequency of silent pauses per second of speech, per syllable, and per word. This difference seems to be related to an increased number of long silent pauses (>1 s) and to a significantly greater duration of silent pauses and overall pauses relative to speech and total speech duration. The median duration of silent pauses was also longer in participants with lvPPA, albeit not significantly. These results are congruent with previous studies (Ash et al. 2013; Ballard et al. 2014; Boschi et al. 2017; Cordella et al. 2017; Nevler et al. 2019; Poole et al. 2017; Potagas et al. 2022; Yunusova et al. 2016), and they may explain why lvPPA, where diagnostic features do not include dysfluency (Gorno-Tempini et al. 2011), has been categorised as fluent by some researchers but nonfluent by others (Gorno-Tempini et al. 2008; Hilger et al. 2014; Wilson et al. 2010).

4.1.2. nfvPPA

Like the lvPPA group, participants with nfvPPA differed from controls in their higher frequency and proportion of time of silent (and overall) pauses, especially long silent pauses. However, the difference in the number of overall pauses per second of speech was not significant. In addition, compared to controls, nfvPPA participants produced longer silent pauses (1.377 s vs. 0.604 s) and longer (0.656 s vs. 0.585 s) and more variable (SD = 0.285 s vs. 0.179 s) lengthened syllables. By contrast, the standard deviation of the duration of filled pauses was lower than in controls (SD = 0.320 s vs. 0.429 s).

Our results are similar to those of previous studies (Ballard et al. 2014; Cordella et al. 2017; Nevler et al. 2019; Poole et al. 2017; Potagas et al. 2022; Rohrer et al. 2010; Wilson et al. 2010; Yunusova et al. 2016), despite some inconsistencies (which could be due to methodological discrepancies, see below), to wit:

- The mean duration of silent pauses is systematically reported as longer in nfvPPA than in controls, but not always significantly so (Nevler et al. 2019; Yunusova et al. 2016);
- Significantly higher median and standard values of the duration of silent pauses (Ballard et al. 2014) and a higher frequency of filled pauses per word (Wilson et al. 2010) in nfvPPA than in controls have been reported, while such differences have been found to be non-significant in other studies (including this one).

4.1.3. svPPA

Several parameters distinguished svPPA participants from controls, primarily lower frequencies of filled pauses (per syllable and word) and short silent pauses (per second of speech, syllable, and word), as well as a low filled pauses–speech ratio. Additionally, lengthened syllables were shorter (0.520 s vs. 0.585 s) and less variable (SD: 0.156 s vs. 0.179 s) in svPPA participants compared to healthy controls.

As individuals with svPPA are generally regarded as being fluent, research on the temporal characteristics of their speech is far less common and frequently focuses only on silent pauses. Similar to our results, most studies have found no significant differences between people with svPPA and healthy speakers in the mean duration of silent pauses (Cordella et al. 2017; Nevler et al. 2019) or in the proportion of time that they occupy (Cordella et al. 2017). However, Nevler et al. (2019) found a significantly increased frequency of silent pauses per minute of speech in svPPA participants compared to controls.

Research on filled pauses in svPPA (Fraser et al. 2014; Wilson et al. 2010) has not looked at their duration or the proportion of speech they occupy but has reported their frequency per word to be similar in participants with svPPA and healthy speakers. Our results have led to a different conclusion in that we found no difference between the two groups in duration in terms of mean, median, or standard deviation, but the frequency of filled pauses per word was significantly lower in svPPA participants than in controls (this study, 0.018 vs. 0.037 pauses per second; Fraser et al. (2014), 0.053 vs. 0.054; Wilson et al. (2010), 0.04 for both groups). Moreover, similar differences were observed in the speech time (or total duration) devoted to filled pauses, with svPPA participants demonstrating less than half that of controls. Our findings may be interpreted as a consequence of individuals with svPPA not self-monitoring their speech, resulting in a lower number of pauses (Oomen et al. 2001, 2005; Postma 2000). Similar effects have been reported in Wernicke's aphasia (Christenfeld and Creager 1996).

4.1.4. Dysfluency in the Three Variants of PPA

Overall, groups with PPA showed atypical values in several temporal variables; they can therefore be considered dysfluent in the sense that they present some 'abnormality of fluency' (Wingate 1984). For lvPPA and nfvPPA participants, dysfluency was characterised by significantly more frequent pauses overall (particularly long silent ones), both per unit of time and per syllable or word, as well as by a higher proportion of (speech and total) time devoted to these pauses. The mean (nfvPPA) and median (lvPPA) duration of silent pauses were also significantly higher. Such observations suggest that these two PPA variants may be regarded as hypo-fluent; that is, they show reduced fluency, albeit to varying degrees. This dysfluency may arise from impaired phono-lexical access and difficulties in syntactic processing. Additionally, unlike lvPPA, nfvPPA was associated with longer lengthened syllables, probably due to a specific impairment in articulatory planning (apraxia of speech), resulting in a decreased articulation rate.

svPPA participants presented a lower (atypical) frequency of overall pauses per word, especially in both filled pauses and short silent pauses per syllable and word, and the proportion of (speech and total) time devoted to filled pauses. Shorter lengthened syllables, commonly related to a faster articulation rate, were also observed. Their fluency was therefore greater than that of controls, which suggests that hyper-fluency can be regarded as a feature of svPPA (Kirsner et al. 2005).

These results highlight the fact that (dys)fluency is a multifaceted concept (Götz 2013) that involves both production and perception and depends on both articulatory and prosodic abilities, and can impact various things, such as accuracy, lexical diversity, and sentence structure. Even though the three variants of PPA can be regarded as dysfluent, as manifested by the differences observed between each of them and the control group in several pause-related values, at least two dimensions should be distinguished.

Firstly, motoric-related phenomena include the duration of lengthened syllables, which depends on the articulatory rate and, consequently, on motoric deficits, allowing us to classify svPPA as hyper-fluent, nfvPPA as hypo-fluent, and lvPPA as not atypical. Secondly, pausing phenomena attributable to higher-level speech processing include the overuse in lvPPA and nfvPPA of pauses (in particular, long silent ones), which have often been attributed to specific difficulties in phono-lexical retrieval and grammatical encoding. However, in our study, atypical pausing behaviour was also observed in svPPA participants, who produced much fewer pauses per word than controls (especially filled and short silent pauses). Since this PPA variant is characterised by naming difficulties related to their semantic deficit and paragrammatisms, such dysfluent characteristics cannot be attributed to preserved speech production.

An overall interpretation of these two opposite behaviours is that they may form part of more general processes, such as the degree of attention speakers pay to their speech (Christenfeld and Creager 1996). We hypothesised above that the hyper-fluency in individuals with svPPA may be due to the reduced attention they pay to their speech, because of either strategic decisions (Postma 2000; Sahraoui et al. 2015) or higher levels of anosognosia (Tondelli et al. 2021), leading to decreased self-monitoring. It has already been reported that people with svPPA tend not to grasp for 'lost' words in a conversation (Marshall et al. 2018), contrary to what is observed in the other two variants of PPA. Therefore, hypo-fluency in lvPPA and nfvPPA, and hyper-fluency in svPPA, could result from over-monitoring and under-monitoring the speech output, respectively.

4.2. (Dis)Similarity among the Three Variants of PPA

Like in previous studies, none of the parameters analysed here by itself sufficed to differentiate the three variants of PPA. The group effect was significant only for a few parameters, mostly related to silent pauses and overall pause frequency. Post hoc analyses showed that most of these metrics differentiated svPPA from both lvPPA and nfvPPA: svPPA presented lower values of (a) the frequency of silent pauses and overall pauses per second of speech, per syllable and word, (b) the overall pause–total duration ratio, and (c) variability in lengthened syllable duration. The contrasts between svPPA and lvPPA and nfvPPA were significant for almost all the metrics mentioned above, except for the number of overall pauses per second of speech, in which only the contrast with lvPPA was significant, along with the number of long silent pauses per word and the standard deviation of lengthened pause duration, in which svPPA differed significantly only from nfvPPA.

Consistent with our results, no significant contrasts between lvPPA and nfvPPA in any of the temporal measures related to pausing have been reported when considered separately, except in a few studies. In Ballard et al. (2014), nfvPPA was associated with higher median and standard deviation values of the duration of silent pauses. Our data also showed such differences, albeit not significant, which may be explained by the task type (reading vs. picture description). Another exception is the number of silent pauses per word, which was higher in nfvPPA than in lvPPA patients in the study by Potagas et al. (2022). In our study, on the other hand, this contrast did not reach significance, possibly due to differences in the number of participants between the two studies.

Furthermore, consistent with our results, several parameters, among them the number of silent pauses per second of speech time (Nevler et al. 2019) and per word (Potagas et al. 2022), have been previously reported as making it possible to distinguish svPPA from the other two main variants of PPA. It is worth noting, however, that in Potagas et al. (2022), the svPPA groups significantly differed from the other two PPA groups in the frequency of silent pauses in the personal story task but only from nfvPPA in the picture description task. Additionally, Cordella et al. (2017) found a longer mean silent pause duration in nfvPPA than in svPPA patients, while no significant differences were found either in our study or in others, such as Nevler et al. (2019).

Taken together, these results show that indices related to the frequency of pauses (overall and silent ones, but not filled pauses or lengthened syllables, per unit of time and per syllable or word) are more suitable than duration values for differentiating the variants of PPA, mostly svPPA from the other two. However, despite characteristic differences in pausing behaviour among the three groups, no single pause-related parameter differentiated them. Further multi-parametric analyses should be conducted to determine what combination of parameters might permit the differentiation of each main variant of PPA from the other two.

4.3. Methodological Considerations

As previously mentioned, some differences between our results and previous studies may be due to methodological decisions related to task types, speech sample processing, or the parameters and languages analysed.

Task-dependent differences may account for some discrepancies. For instance, picture description is more demanding in terms of lexical retrieval than reading tasks and therefore results in more word-finding pauses. This may explain why, unlike the findings of our study, no mean duration differences were found between nfvPPA participants and healthy controls in Yunusova et al. (2016). Moreover, picture description requires more attention to grammatical encoding or text planning, which increases the number and variability of long pauses, not only in persons with PPA but also in healthy speakers, diminishing the contrast among different groups. Hence, it is not surprising that the reported increase in the median values of silent pause duration in nfvPPA patients (Yunusova et al. 2016) and the standard deviation of the duration of silent pauses in lvPPA patients (Ballard et al. 2014; Poole et al. 2017) was not significant in our study.

Other discrepancies may be due to speech sampling and quantitative measurements. In our study, the labelling of both pause events and syllables was corrected manually, allowing us to include all kinds of pauses (silent, filled, or lengthened syllables), regardless of their length. This time-consuming procedure was replaced in other studies by fully automatic silence detection algorithms (Nevler et al. 2019), which are highly prone to alignment errors (Brognaux and Drugman 2016). In addition, speech samples were sometimes pre-processed and filled pauses and non-speech vocalisations were zeroed in the waveform (Cordella et al. 2017), which may affect the reporting of pause frequency and duration. Thus, even if most of the research above supports our results, methodological issues may explain differences such as the lower frequency of silent pauses per second found in nfvPPA (Cordella et al. 2017) and svPPA patients (Nevler et al. 2019).

Filled pauses have received less scholarly attention and led to partly inconsistent results. Our study confirmed prior results finding that no significant differences between controls and lvPPA or nfvPPA participants were found in frequency or proportion of speech time for filled pauses and lengthened syllables, nor in mean pause duration. Other studies have found no difference in the number of filled pauses per syllable or word between lvPPA patients and healthy speakers (Poole et al. 2017; Wilson et al. 2010). Most studies also found that nfvPPA patients produced more such pauses than controls, but their values often fell into the normal range (this study, Fraser et al. 2014), the exception being Wilson et al. (2010). Concerning svPPA, only a few studies have reported data on filled pauses (Fraser et al. 2014; Wilson et al. 2010). They mainly conclude that svPPA participants did not differ from controls in the frequency of filled pauses per word, but that they produced fewer filled pauses than lvPPA (only in Wilson et al. 2010) and nfvPPA. By contrast, our results show that svPPA produced significantly fewer filled pauses per word than both controls and nfvPPA patients and the proportion of time of speech devoted to filled pauses was also lower. Such inconsistencies may be due to the elicitation task used (Fraser et al. 2014), since, relative to describing a picture, telling the Cinderella story requires more memory resources, which can induce more filled pauses in svPPA patients, and to potential differences across languages and cultures (Wilson et al. 2010), as pointed out by several authors (Crible et al. 2017; Endrass et al. 2008; Rose and Watanabe 2019).

The variables under analysis also distinguish our study from previous work. Although most researchers have focused on silent pauses, to the best of our knowledge, the grouping of silent pauses into three categories as a function of their length has not yet been analysed in

PPA, even if their bi- or tri-modal distribution has repeatedly been reported, in both typical and disordered speech (Angelopoulou et al. 2018; Baditzné Pálvölgyi 2020; Campione and Véronis 2002; Goldman-Eisler 1968; Hird and Kirsner 2010; Kirsner et al. 2005; Parjane et al. 2021; Thomas 2021; Trouvain and Werner 2022). In normal speech, short pauses are often associated with breathing or articulatory phenomena, while medium pauses are linked to demarcative functions that are assumed to aid listeners to parse utterances correctly. In contrast, longer pauses appear only in spontaneous speech and seem to be related to higher cognitive functions, such as word seeking or sentence planning. Pre- and post-articulatory monitoring processes might also lead to a specific distribution of pause duration (Pillai 2006). For example, people with post-stroke aphasia differ from healthy speakers solely in indices related to long pauses, reflecting impaired lexical access or deficits in sentence planning, while short pauses are irrelevant (e.g., Angelopoulou et al. 2018; Hird and Kirsner 2010; Kirsner et al. 2005; Oomen et al. 2001, 2005). Therefore, in our study we decided to include a more fine-grained analysis, and distinguished between short, medium, and long pauses, following the thresholds established in Campione and Véronis (2002). Our study revealed that pausing atypicality did not affect short, medium, and long silent pauses in the same way. In nfvPPA and lvPPA, only long (and medium, in lvPPA) silent pauses presented a higher frequency and proportion of time than controls. The opposite pattern was observed in svPPA, in which atypical values were found only for short pauses, which were less frequent and corresponded to a lower proportion of the time. It may be assumed, therefore, that thresholds based on the distribution of pauses for a specific participant and task can lead to a fuller understanding of individual pausing behaviour.

To our knowledge, no previous research has focused on the frequency, duration, or proportion of time of lengthened syllables, considered a hesitation phenomenon, in the spontaneous speech of persons with PPA. It should be emphasised that 'syllable lengthening' refers to different concepts, as syllables that are longer than normal can be due to an overall decrease in articulatory rate, prosodic effects (e.g., utterance-final lengthening), or hesitation phenomena (see above, Sections 1 and 2). In our study, this type of hesitation was included and led to some interesting results since specific—and opposite—atypicalities were found in nfvPPA and svPPA, in both duration and variability. They also allowed us to compute holistic parameters that include the three types of hesitation phenomena, namely silent pauses, filled pauses, and lengthened syllables, thereby enabling us to obtain an overall picture of pausing behaviour.

5. Conclusions

PPA is a multifaceted condition, and differentiating its variants may be difficult. In addition to biological and neuropathological measurements, the degree of language impairment must be determined for accurate diagnosis. It has been shown that hesitancy phenomena are important indicators of speech processing dysfunction. In this research, a wide number of factors related to silent and filled pauses and syllable lengthening were studied and compared among patients with variants of PPA (lvPPA, nfvPPA, and svPPA) and healthy controls via a picture description task. According to the results, the frequency of pauses per word, especially lengthy pauses, seems to be the measure that best distinguishes between healthy speakers and each of the three major variants of PPA. However, less researched hesitation phenomena, such as filled pauses and lengthened syllables, can also contribute to a better understanding of varied types of dysfluency present in each phenotype. Therefore, we argue that analysing pausing behaviour in detail, as we have done here, might aid in diagnosis and speech treatment. Another point to mention is that, since no single measure distinguishes among the three variants of PPA, new multi-parametric techniques that can capture the complexity of hesitation phenomena are required. For a fuller picture of dysfluency in each variant of PPA, further in-depth study is necessary on the relationship between pausing behaviour and other speech features, such as articulatory mechanisms and speech rate, the length of speech chunks, and the proportion of semantic information provided.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of Hospital of Hospital de la Santa Creu i Sant Pau (protocol code IIBSP-REH-2020-88, 13 October 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Description of acoustic parameters (in alphabetical order).

Parameters	Definition
Mdn_DurPfill	Median of duration of filled pauses
Mdn_DurPsil	Median of duration of empty pauses
Mdn_SlbLONG	Median of duration of lengthened syllables
Mn_DurPfill	Mean duration of filled pauses
Mn_DurPsil	Mean duration of empty pauses
Mn_DurSlbLONG	Mean duration of lengthened syllables
NumLongPsil_DurSpeech	Total number of long empty pauses relative to speech duration
NumLongPsil_DurTot	Total number of long empty pauses relative to total sample (speech + pauses) duration
NumLongPsil_NumTotSlb	Total number of long empty pauses relative to total number of syllables
NumLongPsil_NumTotWords	Total number of long empty pauses relative to total number of words
NumMediumPsil_DurSpeech	Total number of medium empty pauses relative to speech duration
NumMediumPsil_DurTot	Total number of medium empty pauses relative to total sample (speech + pauses duration)
NumMediumPsil_NumTotSlb	Total number of medium empty pauses relative to total number of syllables
NumMediumPsil_NumTotWords	Total number of medium empty pauses relative to total number of words
NumPausesALL_DurSpeech	Total number of pauses relative to speech
NumPausesALL_DurTot	Total number of pauses relative to total sample (speech + pauses duration)
NumPausesALL_NumTotSlb	Total number of pauses relative to total number of syllables
NumPausesALL_NumTotWords	Total number of pauses relative to total number of words
NumPfill_DurSpeech	Total number of filled pauses relative to speech duration
NumPfill_DurTot	Total number of filled pauses relative to total sample (speech + pauses duration)
NumPfill_NumTotSlb	Total number of filled pauses relative to total number of syllables
NumPfill_NumTotWords	Total number of filled pauses relative to total number of words
NumPsil_DurSpeech	Total number of empty pauses relative to speech duration
NumPsil_DurTot	Total number of empty pauses relative to total sample (speech + pauses duration)
NumPsil_NumTotSlb	Total number of empty pauses relative to total number of syllables
NumPsil_NumTotWords	Total number of empty pauses relative to total number of words
NumShortPsil_DurSpeech	Total number of short empty pauses relative to speech duration
NumShortPsil_DurTot	Total number of short empty pauses relative to total sample (speech + pauses duration)
NumShortPsil_NumTotSlb	Total number of short empty pauses relative to total number of syllables
NumShortPsil_NumTotWords	Total number of short empty pauses relative to total number of words
NumSlbLONG_DurSpeech	Total number of lengthened syllables relative to speech duration
NumSlbLONG_DurTot	Total number of lengthened syllables relative to total sample (speech + pauses duration)
NumSlbLONG_NumTotSlb	Total number of lengthened syllables relative to total number of syllables

Table A1. *Cont.*

Parameters	Definition
NumSlbLONG_NumTotWords	Total number of lengthened syllables relative to total number of words
R_DurPausesALL_DurSpeech	Ratio of duration of pausing relative to speech
R_DurPausesALL_DurTot	Ratio of duration of pausing to total duration of speech (speech + pauses)
R_DurPfill_DurSpeech	Ratio of duration of filled pauses relative to speech
R_DurPfill_DurTot	Ratio of duration of filled pauses relative to total duration of speech (speech + pauses)
R_DurPsil_DurSpeech	Ratio of duration of empty pauses relative to speech
R_DurPsil_DurTot	Ratio of duration of empty pauses relative to total duration of speech (speech + pauses)
R_DurSlbLONG_DurSpeech	Ratio of duration of lengthened syllables relative to speech
R_DurSlbLONG_DurTot	Ratio of duration of lengthened syllables relative to total duration of speech (speech + pauses)
R_NumLongPsil_NumTotPsil	Ratio of the number of long empty pauses relative to total number of empty pauses
R_NumMediumPsil_NumTotPsil	Ratio of the number of medium empty pauses relative to total number of empty pauses
R_NumShortPsil_NumTotPsil	Ratio of the number of short empty pauses relative to total number of empty pauses
SD_DurPfill	Standard deviation of duration of filled pauses
SD_DurPsil	Standard deviation of duration of empty pauses
SD_DurSlbLONG	Standard deviation of duration of lengthened syllables

Table A2. Mixed-effects linear regression models of pause duration, by group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	df	*t*	*p*
Dur_Psil	control–lvPPA	Intercept (=control)	0.62809	0.08233	21.37626	7.629	1.56×10^{-7} ***
		lvPPA	0.23301	0.11223	21.5892	2.076	0.05
		$F(1, 21.589) = 4.310, p = 0.050$					
	control–nfvPPA	Intercept (=control)	0.6305	0.2339	17.4693	2.696	0.0151 *
		nfvPPA	0.7314	0.3445	18.6156	2.123	0.0474 *
		$F(1, 18.616) = 4.508, p = 0.047$					
	control–svPPA	Intercept (=control)	0.63	0.1029	11.37	6.12	6.53×10^{-5} ***
		svPPA	0.2015	0.1595	13.1578	1.263	0.228
		$F(1, 13.158) = 1.596, p = 0.228$					
Dur_Pfill	control–lvPPA	Intercept (=control)	0.63038	0.05021	19.59174	12.554	8.03×10^{-11} ***
		lvPPA	−0.04567	0.07037	19.75771	−0.649	0.524
		$F(1, 19.758) = 0.421, p = 0.524$					
	control–nfvPPA	Intercept (=control)	0.637425	0.057696	13.336115	11.048	4.35×10^{-8} ***
		nfvPPA	0.001624	0.098047	22.391093	0.017	0.987
		$F(1, 22.391) = 0.000, p = 0.987$					
	control–svPPA	Intercept (=control)	0.63295	0.05282	12.41269	11.983	3.46×10^{-8} ***
		svPPA	−0.14479	0.11353	37.97495	−1.275	0.21
		$F(1, 37.975) = 1.626, p = 0.210$					
Dur_SlbLONG	control–lvPPA	Intercept (=control)	0.57837	0.0327	18.95185	17.689	3.07×10^{-13} ***
		lvPPA	0.0134	0.04511	20.13137	0.297	0.77
		$F(1, 20.131) = 0.088, p = 0.770$					
	control–nfvPPA	Intercept (=control)	0.58405	0.01574	7.35739	37.108	1.22×10^{-9} ***
		nfvPPA	0.07254	0.02955	17.64642	2.455	0.0247 *
		$F(1, 17.646) = 6.026, p = 0.025$					
	control–svPPA	Intercept (=control)	0.58325	0.01482	9.03557	39.343	2.04×10^{-11} ***
		svPPA	−0.06468	0.02792	17.46701	−2.317	0.0329 *
		$F(1, 17.467) = 5.368, p = 0.033$					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A3. Mixed-effects linear regression models of the standard deviation of pause duration, by group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	*t*	*p*
SD_DurPsil	control–lvPPA	Intercept (=control)	0.5936	0.1249	4.752	9.63×10^{-5} ***
		lvPPA	0.1733	0.1697	1.021	0.318
		F(1) = 1.042, p = 0.318				
	control–nfvPPA	Intercept (=control)	0.5936	0.3722	1.595	1.27×10^{-1}
		nfvPPA	0.9894	0.5394	1.834	0.0823
		F(1) = 3.364, p = 0.082				
	control–svPPA	Intercept (=control)	0.5936	0.1586	3.744	1.49×10^{-3} **
		svPPA	0.1819	0.2364	0.77	0.45149
		F(1) = 0.592, p = 0.451				
SD_DurPfill	control–lvPPA	Intercept (=control)	0.413	0.05915	6.982	8.92×10^{-7} ***
		lvPPA	−0.13717	0.08009	−1.713	0.102
		F(1) = 2.933, p = 0.102				
	control–nfvPPA	Intercept (=control)	0.413	0.06607	6.251	6.76×10^{-6} ***
		nfvPPA	−0.219	0.09343	−2.344	0.0308 *
		F(1) = 5.494, p = 0.031				
	control–svPPA	Intercept (=control)	0.413	0.07802	5.294	1.13×10^{-4} ***
		svPPA	−0.18967	0.1274	−1.489	0.158738
		F(1) = 2.216, p = 0.159				
SD_DurSlbLONG	control–lvPPA	Intercept (=control)	0.16909	0.02024	8.355	2.85×10^{-8} ***
		lvPPA	0.02322	0.0275	0.844	0.408
		F(1) = 0.713, p = 0.408				
	control–nfvPPA	Intercept (=control)	0.16909	0.02897	5.836	1.27×10^{-5} ***
		nfvPPA	0.09891	0.04199	2.356	0.0294 *
		F(1) = 5.549, p = 0.029				
	control–svPPA	Intercept (=control)	0.16909	0.01594	10.61	3.56×10^{-9} ***
		svPPA	−0.05576	0.02376	−2.347	0.0306 *
		F(1) = 5.508, p = 0.031				

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A4. Mixed-effects linear regression models of median pause duration, by group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	*t*	*p*
Mdn_DurPsil	control–lvPPA	Intercept (=control)	0.50318	0.05498	9.152	5.90×10^{-9} ***
		lvPPA	0.1752	0.0747	2.345	0.0284 *
		F(1) = 5.501, p = 0.028				
	control–nfvPPA	Intercept (=control)	0.5032	0.1047	4.806	1.23×10^{-4}
		nfvPPA	0.2909	0.1517	1.917	0.070353
		F(1) = 3.676, p = 0.070				
	control–svPPA	Intercept (=control)	0.50318	0.09477	5.309	4.78×10^{-5} ***
		svPPA	0.15982	0.14128	1.131	0.273
		F(1) = 1.280, p = 0.273				

Table A4. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
Mdn_DurPfill	control–lvPPA	Intercept (=control)	0.52445	0.06006	8.732	1.34×10^{-8} ***
		lvPPA	0.05416	0.08161	0.664	0.514
		F(1) = 0.440, *p* = 0.514				
	control–nfvPPA	Intercept (=control)	0.52445	0.07198	7.286	6.52×10^{-7} ***
		nfvPPA	0.01065	0.10431	0.102	0.92
		F(1) = 0.010, *p* = 0.920				
	control–svPPA	Intercept (=control)	0.52445	0.0598	8.77	6.46×10^{-8} ***
		svPPA	−0.09734	0.08914	−1.092	0.289
		F(1) = 1.192, *p* = 0.289				
Mdn_DurSlbLONG	control–lvPPA	Intercept (=control)	0.53664	0.03176	16.895	4.38×10^{-14} ***
		lvPPA	0.0219	0.04316	0.508	0.617
		F(1) = 0.258, *p* = 0.617				
	control–nfvPPA	Intercept (=control)	0.53664	0.0293	18.316	1.57×10^{-13} ***
		nfvPPA	0.07936	0.04246	1.869	0.0771
		F(1) = 3.494, *p* = 0.077				
	control–svPPA	Intercept (=control)	0.53664	0.02344	22.89	3.26×10^{-14} ***
		svPPA	−0.03489	0.03613	−0.966	0.348
		F(1) = 0.932, *p* = 0.348				

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A5. Linear regression models of pause duration, by group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
Dur_Psil	lvPPA–nfvPPA	−0.499585971	0.296278111	28.17736763	−1.686206144	0.2280
	lvPPA–svPPA	0.027988754	0.310520944	29.88620046	0.090134836	0.9955
	nfvPPA–svPPA	0.527574725	0.332519936	31.18010197	1.586595774	0.2663
	F(2, 28.582) = 1.771, *p* = 0.188					
Dur_Pfill	lvPPA–nfvPPA	−0.064391969	0.079882149	21.28827929	−0.806087088	0.703
	lvPPA–svPPA	0.098126945	0.099215587	40.08238697	0.98902751	0.588
	nfvPPA–svPPA	0.162518914	0.110399422	49.95845659	1.472099323	0.313
	F(2, 42.376) = 1.112, *p* = 0.338					
Dur_SlbLONG	lvPPA–nfvPPA	−0.069768127	0.054240504	27.22960508	−1.286273581	0.415
	lvPPA–svPPA	0.070984397	0.057110031	26.42537252	1.242940962	0.439
	nfvPPA–svPPA	0.140752524	0.063565198	30.49386627	2.21430169	0.085 .
	F(2, 31.008) = 2.478, *p* = 0.100					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A6. Linear regression models of standard deviation of pause duration, by group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
SD_DurPsil	lvPPA–nfvPPA	−0.816076923	0.45286852	29	−1.802017333	0.1867
	lvPPA–svPPA	−0.008632479	0.466872508	29	−0.018490013	0.9998
	nfvPPA–svPPA	0.807444444	0.494692626	29	1.632214433	0.2486
	F(2) = 1.958, *p* = 0.159					

Table A6. *Cont.*

Parameter	Contrast	B	SE(B)	df	*t*	*p*
SD_DurPfill	lvPPA–nfvPPA	0.081833333	0.067443384	25	1.2133634	0.4565
	lvPPA–svPPA	0.0525	0.078756904	25	0.666608221	0.7848
	nfvPPA–svPPA	−0.029333333	0.081339781	25	−0.360627148	0.9310
	F(2) = 0.758, p = 0.479					
SD_DurSlbLONG	lvPPA–nfvPPA	−0.075692308	0.040313716	29	−1.877582018	0.1633
	lvPPA–svPPA	0.078974359	0.041560331	29	1.900234125	0.1567
	nfvPPA–svPPA	0.154666667	0.044036839	29	3.512210954	0.0041 **
	F(2) = 6.170, p = 0.006					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A7. Linear regression models of median pause duration, by group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
Mdn_DurPsil	lvPPA–nfvPPA	−0.115715385	0.155176451	29	−0.745701967	0.7386
	lvPPA–svPPA	0.015384615	0.15997495	29	0.096168903	0.9949
	nfvPPA–svPPA	0.1311	0.169507578	29	0.77341675	0.7220
	F(2) = 0.381, p = 0.687					
Mdn_DurPfill	lvPPA–nfvPPA	0.043515385	0.100720181	29	0.432042359	0.9026
	lvPPA–svPPA	0.151504274	0.103834737	29	1.459090459	0.3250
	nfvPPA–svPPA	0.107988889	0.110022068	29	0.981520265	0.5942
	F(2) = 1.085, p = 0.351					
Mdn_DurSlbLONG	lvPPA–nfvPPA	−0.057461538	0.049163265	28	−1.168790129	0.4812
	lvPPA–svPPA	0.056788462	0.052522024	28	1.081231408	0.5333
	nfvPPA–svPPA	0.11425	0.055442108	28	2.060708094	0.1166
	F(2) = 2.136, p = 0.137					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A8. Linear regression models of the proportion of the total number of long, medium, and short silent pauses, by group. Estimates (B), standard errors (SE(B)), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	*t*	*p*
R_NumLongPsil_NumTotPsil	control–lvPPA	Intercept (=control)	0.16055	0.04092	3.924	0.000726 ***
		lvPPA	0.12022	0.0556	2.162	0.041723 *
		F(1) = 4.676, p = 0.042				
	control–nfvPPA	Intercept (=control)	0.16055	0.05463	2.939	0.00843 **
		nfvPPA	0.17285	0.07917	2.183	0.04177 *
		F(1) = 4.767, p = 0.042				
	control–svPPA	Intercept (=control)	0.16055	0.05139	3.124	0.00586 **
		svPPA	0.06601	0.0766	0.862	0.40018
		F(1) = 0.743, p = 0.400				
R_NumMediumPsil_NumTotPsil	control–lvPPA	Intercept (=control)	0.61927	0.03964	15.623	2.16×10^{-13} ***
		lvPPA	−0.03381	0.05386	−0.628	0.537
		F(1) = 0.394, p = 0.537				
	control–nfvPPA	Intercept (=control)	0.61927	0.04368	14.178	1.48×10^{-11} ***
		nfvPPA	−0.07857	0.06329	−1.241	0.23
		F(1) = 1.541, p = 0.230				
	control–svPPA	Intercept (=control)	0.61927	0.04362	14.198	3.22×10^{-11} ***
		svPPA	0.03351	0.06502	0.515	0.613
		F(1) = 0.266, p = 0.613				

Table A8. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
R_NumShortPsil_NumTotPsil	control–lvPPA	Intercept (=control)	0.22045	0.03036	7.261	2.84×10^{-7} ***
		lvPPA	−0.08661	0.04126	−2.099	0.0475 *
		F(1) = 4.407, *p* = 0.047				
	control–nfvPPA	Intercept (=control)	0.22045	0.03038	7.257	6.90×10^{-7} ***
		nfvPPA	−0.09445	0.04402	−2.146	0.045 *
		F(1) = 4.604, *p* = 0.045				
	control–svPPA	Intercept (=control)	0.22045	0.03304	6.672	2.93×10^{-6} ***
		svPPA	−0.09979	0.04926	−2.026	0.0579
		F(1) = 4.104, *p* = 0.058				

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A9. Linear regression models of the proportion of the total number of long, medium, and short silent pauses, by group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
R_NumLongPsil_NumTotPsil	lvPPA–nfvPPA	−0.052630769	0.083958973	29	−0.626862948	0.8067
	lvPPA–svPPA	0.054213675	0.086555224	29	0.626347813	0.8069
	nfvPPA–svPPA	0.106844444	0.091712899	29	1.164988195	0.4831
	F(2) = 0.679, *p* = 0.515					
R_NumMediumPsil_NumTotPsil	lvPPA–nfvPPA	0.044761538	0.069316202	29	0.645758667	0.7962
	lvPPA–svPPA	−0.067316239	0.071459657	29	−0.942017383	0.6186
	nfvPPA–svPPA	−0.112077778	0.075717814	29	−1.480203567	0.3150
	F(2) = 1.105, *p* = 0.345					
R_NumShortPsil_NumTotPsil	lvPPA–nfvPPA	0.007846154	0.037484946	29	0.209314795	0.9762
	lvPPA–svPPA	0.013179487	0.038644088	29	0.341047956	0.9380
	nfvPPA–svPPA	0.005333333	0.040946822	29	0.13025024	0.9907
	F(2) = 0.061, *p* = 0.941					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A10. Linear regression models of pause frequency (per second of speech/total duration), by type and group. Estimates (B), standard errors (SE(B)), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	*t*	*p*
NumPsil_DurSpeech	control–lvPPA	Intercept (=control)	0.59273	0.06077	9.753	0.0000 ***
		lvPPA	0.27727	0.08258	3.358	0.0028 **
		F(1) = 11.275, *p* = 0.003				
	control–nfvPPA	Intercept (=control)	0.59273	0.06316	9.385	0.0000 ***
		nfvPPA	0.25027	0.09152	2.735	0.0132 *
		F(1) = 7.478, *p* = 0.013				
	control–svPPA	Intercept (=control)	0.59273	0.04446	13.331	0.0000 ***
		svPPA	−0.01828	0.06628	−0.276	0.7860
		F(1) = 0.076, *p* = 0.786				

Table A10. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
NumPsil_DurTot	control–lvPPA	Intercept (=control)	0.41091	0.0312	13.169	0.0000 ***
		lvPPA	0.06524	0.04239	1.539	0.1380
			F(1) = 2.368, *p* = 0.138			
	control–nfvPPA	Intercept (=control)	0.410909	0.032833	12.515	0.0000 ***
		nfvPPA	−0.003909	0.047579	−0.082	0.9350
			F(1) = 0.007, *p* = 0.935			
	control–svPPA	Intercept (=control)	0.41091	0.02644	15.54	0.0000 ***
		svPPA	−0.02869	0.03942	−0.728	0.4760
			F(1) = 0.530, *p* = 0.476			
NumPfill_DurSpeech	control–lvPPA	Intercept (=control)	0.1	0.03459	2.891	0.0085 **
		lvPPA	0.06385	0.047	1.359	0.1881
			F(1) = 1.846, *p* = 0.188			
	control–nfvPPA	Intercept (=control)	0.1	0.03135	3.19	0.0048 **
		nfvPPA	0.026	0.04543	0.572	0.5739
			F(1) = 0.327, *p* = 0.574			
	control–svPPA	Intercept (=control)	0.1	0.01504	6.648	0.0000 ***
		svPPA	−0.04	0.02242	−1.784	0.0913 .
			F(1) = 3.182, *p* = 0.091			
NumPfill_DurTot	control–lvPPA	Intercept (=control)	0.07	0.01811	3.866	0.0008 ***
		lvPPA	0.01838	0.0246	0.747	0.4628
			F(1) = 0.559, *p* = 0.463			
	control–nfvPPA	Intercept (=control)	0.07	0.009966	7.024	0.0000 ***
		nfvPPA	−0.018	0.014443	−1.246	0.2280
			F(1) = 1.553, *p* = 0.228			
	control–svPPA	Intercept (=control)	0.07	0.01095	6.391	0.0000 ***
		svPPA	−0.02778	0.01633	−1.701	0.1060
			F(1) = 2.894, *p* = 0.106			
NumSlbLONG_DurSpeech	control–lvPPA	Intercept (=control)	0.24909	0.03643	6.838	0.0000 ***
		lvPPA	0.03091	0.04949	0.625	0.5390
			F(1) = 0.390, *p* = 0.539			
	control–nfvPPA	Intercept (=control)	0.249091	0.035233	7.07	0.0000 ***
		nfvPPA	−0.007091	0.051058	−0.139	0.8910
			F(1) = 0.019, *p* = 0.891			
	control–svPPA	Intercept (=control)	0.24909	0.03313	7.518	0.0000 ***
		svPPA	−0.0402	0.04939	−0.814	0.4260
			F(1) = 0.662, *p* = 0.426			
NumSlbLONG_DurTot	control–lvPPA	Intercept (=control)	0.17818	0.02552	6.982	0.0000 ***
		lvPPA	−0.01587	0.03467	−0.458	0.6520
			F(1) = 0.210, *p* = 0.652			
	control–nfvPPA	Intercept (=control)	0.17818	0.02426	7.343	0.0000 ***
		nfvPPA	−0.04918	0.03516	−1.399	0.1780
			F(1) = 1.956, *p* = 0.178			
	control–svPPA	Intercept (=control)	0.17818	0.02449	7.277	0.0000 ***
		svPPA	−0.03596	0.0365	−0.985	0.3380
			F(1) = 0.970, *p* = 0.338			

Table A10. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
NumPausesALL_DurSpeech	control–lvPPA	Intercept (=control)	0.94091	0.08327	11.299	0.0000 ***
		lvPPA	0.3714	0.11315	3.282	0.0034 **
		F(1) = 10.775, p = 0.003				
	control–nfvPPA	Intercept (=control)	0.94091	0.09101	10.34	0.0000 ***
		nfvPPA	0.26909	0.13189	2.04	0.0555 .
		F(1) = 4.163, p = 0.055				
	control–svPPA	Intercept (=control)	0.94091	0.06267	15.013	0.0000 ***
		svPPA	−0.09758	0.09343	−1.044	0.3100
		F(1) = 1.091, p = 0.310				
NumPausesALL_DurTot	control–lvPPA	Intercept (=control)	0.65818	0.048	13.711	0.0000 ***
		lvPPA	0.06874	0.06522	1.054	0.3030
		F(1) = 1.111, p = 0.303				
	control–nfvPPA	Intercept (=control)	0.65818	0.05106	12.891	0.0000 ***
		nfvPPA	−0.07318	0.07399	−0.989	0.3350
		F(1) = 0.978, p = 0.335				
	control–svPPA	Intercept (=control)	0.65818	0.04325	15.218	0.0000 ***
		svPPA	−0.09152	0.06447	−1.419	0.1730
		F(1) = 2.015, p = 0.173				

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A11. Linear regression models of silent pause frequency (per second of speech/total duration), by length category and group. Estimates (B), standard errors (SE(B)), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	*t*	*p*
NumLongPsil_DurSpeech	control–lvPPA	Intercept (=control)	0.09355	0.02908	3.217	0.0040 **
		lvPPA	0.13807	0.03951	3.495	0.0021 **
		F(1) = 12.215, p = 0.002				
	control–nfvPPA	Intercept (=control)	0.09355	0.06247	1.497	0.1507
		nfvPPA	0.21775	0.09053	2.405	0.0265 *
		F(1) = 5.786, p = 0.027				
	control–svPPA	Intercept (=control)	0.09355	0.02936	3.187	0.0051 **
		svPPA	0.03945	0.04376	0.902	0.3792
		F(1) = 0.813, p = 0.379				
NumLongPsil_DurTot	control–lvPPA	Intercept (=control)	0.06182	0.01442	4.286	0.0003 ***
		lvPPA	0.06149	0.0196	3.138	0.0048 **
		F(1) = 9.847, p = 0.005				
	control–nfvPPA	Intercept (=control)	0.06182	0.01394	4.436	0.0003 ***
		nfvPPA	0.04948	0.02019	2.45	0.0241 *
		F(1) = 6.004, p = 0.024				
	control–svPPA	Intercept (=control)	0.06182	0.01453	4.253	0.0005 ***
		svPPA	0.01618	0.02167	0.747	0.4648
		F(1) = 0.558, p = 0.465				

Table A11. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
NumMediumPsil_DurSpeech	control–lvPPA	Intercept (=control)	0.36255	0.04524	8.013	0.0000 ***
		lvPPA	0.14822	0.06147	2.411	0.0247 *
			F(1) = 5.814, p = 0.025			
	control–nfvPPA	Intercept (=control)	0.36255	0.03624	10.01	0.0000 ***
		nfvPPA	0.07035	0.05251	1.34	0.1960
			F(1) = 1.795, p = 0.196			
	control–svPPA	Intercept (=control)	0.36255	0.03524	10.288	0.0000 ***
		svPPA	0.01445	0.05253	0.275	0.7860
			F(1) = 0.076, p = 0.786			
NumMediumPsil_DurTot	control–lvPPA	Intercept (=control)	0.25236	0.02743	9.201	0.0000 ***
		lvPPA	0.03187	0.03727	0.855	0.4020
			F(1) = 0.731, p = 0.402			
	control–nfvPPA	Intercept (=control)	0.25236	0.03074	8.21	0.0000 ***
		nfvPPA	−0.01466	0.04455	−0.329	0.7460
			F(1) = 0.108, p = 0.746			
	control–svPPA	Intercept (=control)	0.252364	0.023692	10.652	0.0000 ***
		svPPA	0.005192	0.035318	0.147	0.8850
			F(1) = 0.022, p = 0.885			
NumShortPsil_DurSpeech	control–lvPPA	Intercept (=control)	0.135909	0.026888	5.055	0.0000 ***
		lvPPA	−0.009986	0.036534	−0.273	0.7870
			F(1) = 0.075, p = 0.787			
	control–nfvPPA	Intercept (=control)	0.13591	0.02263	6.006	0.0000 ***
		nfvPPA	−0.03761	0.03279	−1.147	0.2660
			F(1) = 1.315, p = 0.266			
	control–svPPA	Intercept (=control)	0.13591	0.02211	6.148	0.0000 ***
		svPPA	−0.07069	0.03296	−2.145	0.0459 *
			F(1) = 4.600, p = 0.046			
NumShortPsil_DurTot	control–lvPPA	Intercept (=control)	0.09664	0.01759	5.495	0.0000 ***
		lvPPA	−0.02794	0.02389	−1.169	0.2550
			F(1) = 1.368, p = 0.255			
	control–nfvPPA	Intercept (=control)	0.09664	0.01688	5.724	0.0000 ***
		nfvPPA	−0.04054	0.02446	−1.657	0.1140
			F(1) = 2.746, p = 0.114			
	control–svPPA	Intercept (=control)	0.09664	0.01631	5.927	0.0000 ***
		svPPA	−0.04975	0.02431	−2.047	0.0556 .
			F(1) = 4.189, p = 0.056			

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A12. Linear regression models of pause frequency (per second of speech/total duration), by type and group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
NumPsil_DurSpeech	lvPPA–nfvPPA	0.027	0.093129414	29	0.289919143	0.9548
	lvPPA–svPPA	0.295555556	0.096009242	29	3.078407351	0.0122 *
	nfvPPA–svPPA	0.268555556	0.101730265	29	2.639878658	0.0343 *
	F(2) = 5.357, $p = 0.010$					
NumPsil_DurTot	lvPPA–nfvPPA	0.069153846	0.046411505	29	1.490015171	0.3104
	lvPPA–svPPA	0.093931624	0.047846681	29	1.963179515	0.1395
	nfvPPA–svPPA	0.024777778	0.050697781	29	0.488734954	0.8772
	F(2) = 2.194, $p = 0.130$					
NumPfill_DurSpeech	lvPPA–nfvPPA	0.037846154	0.053692802	29	0.704864575	0.7626
	lvPPA–svPPA	0.103846154	0.055353136	29	1.8760663	0.1637
	nfvPPA–svPPA	0.066	0.058651533	29	1.125290274	0.5066
	F(2) = 1.764, $p = 0.189$					
NumPfill_DurTot	lvPPA–nfvPPA	0.036384615	0.024079778	29	1.511002967	0.3007
	lvPPA–svPPA	0.046162393	0.024824393	29	1.859557777	0.1686
	nfvPPA–svPPA	0.009777778	0.026303635	29	0.37172724	0.9269
	F(2) = 2.050, $p = 0.147$					
NumSlbLONG_DurSpeech	lvPPA–nfvPPA	0.038	0.056380962	29	0.673986374	0.7803
	lvPPA–svPPA	0.071111111	0.058124422	29	1.22342913	0.4493
	nfvPPA–svPPA	0.033111111	0.061587955	29	0.537623162	0.8535
	F(2) = 0.764, $p = 0.475$					
NumSlbLONG_DurTot	lvPPA–nfvPPA	0.033307692	0.037724942	29	0.882909051	0.6552
	lvPPA–svPPA	0.02008547	0.038891504	29	0.516448782	0.8640
	nfvPPA–svPPA	−0.013222222	0.041208981	29	−0.320857779	0.9449
	F(2) = 0.402, $p = 0.672$					
NumPausesALL_DurSpeech	lvPPA–nfvPPA	0.102307692	0.136534901	29	0.749315314	0.7364
	lvPPA–svPPA	0.468974359	0.14075695	29	3.331802506	0.0065 **
	nfvPPA–svPPA	0.366666667	0.149144411	29	2.458467358	0.0512 .
	F(2) = 5.812, $p = 0.008$					
NumPausesALL_DurTot	lvPPA–nfvPPA	0.141923077	0.078276391	29	1.813101941	0.1831
	lvPPA–svPPA	0.16025641	0.080696921	29	1.985904899	0.1337
	nfvPPA–svPPA	0.018333333	0.08550551	29	0.214411135	0.9750
	F(2) = 2.551, $p = 0.095$					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A13. Linear regression models of silent pause frequency (per second of speech/total duration), by length category and group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
NumLongPsil_DurSpeech	lvPPA–nfvPPA	−0.079684615	0.079263358	29	−1.00531466	0.5795
	lvPPA–svPPA	0.098615385	0.081714407	29	1.20682984	0.4588
	nfvPPA–svPPA	0.1783	0.086583626	29	2.059280818	0.1163
	F(2) = 2.123, $p = 0.138$					

Table A13. *Cont.*

Parameter	Contrast	B	SE(B)	df	*t*	*p*
NumLongPsil_DurTot	lvPPA–nfvPPA	0.012007692	0.022543868	29	0.532636733	0.8560
	lvPPA–svPPA	0.045307692	0.023240989	29	1.949473511	0.1431
	nfvPPA–svPPA	0.0333	0.024625879	29	1.352235998	0.3787
		F(2) = 1.951, *p* = 0.160				
NumMediumPsil_DurSpeech	lvPPA–nfvPPA	0.077869231	0.067193469	29	1.158880944	0.4867
	lvPPA–svPPA	0.133769231	0.069271283	29	1.931092153	0.1481
	nfvPPA–svPPA	0.0559	0.073399038	29	0.761590365	0.7291
		F(2) = 1.937, *p* = 0.162				
NumMediumPsil_DurTot	lvPPA–nfvPPA	0.046530769	0.048033097	29	0.968723077	0.6021
	lvPPA–svPPA	0.026675214	0.049518417	29	0.538692777	0.8530
	nfvPPA–svPPA	−0.019855556	0.052469133	29	−0.378423547	0.9243
		F(2) = 0.480, *p* = 0.624				
NumShortPsil_DurSpeech	lvPPA–nfvPPA	0.027623077	0.028662036	29	0.9637514	0.6052
	lvPPA–svPPA	0.060700855	0.029548348	29	2.054289318	0.1174
	nfvPPA–svPPA	0.033077778	0.031309082	29	1.056491459	0.5481
		F(2) = 2.116, *p* = 0.139				
NumShortPsil_DurTot	lvPPA–nfvPPA	0.012592308	0.019018285	29	0.662115821	0.7870
	lvPPA–svPPA	0.021803419	0.019606385	29	1.112057049	0.5145
	nfvPPA–svPPA	0.009211111	0.020774695	29	0.443381282	0.8977
		F(2) = 0.641, *p* = 0.534				

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A14. Linear regression models of pause frequency (per syllable/word), by type and group. Estimates (B), standard errors (SE(B)), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	*t*	*p*
NumPsil_NumTotSlb	control–lvPPA	Intercept (=control)	0.1259	0.01624	7.752	0.0000 ***
		lvPPA	0.06675	0.02207	3.025	0.0062 **
			F(1) = 9.150, *p* = 0.006			
	control–nfvPPA	Intercept (=control)	0.1259	0.01583	7.952	0.0000 ***
		nfvPPA	0.08394	0.02294	3.658	0.0017 **
			F(1) = 13.384, *p* = 0.002			
	control–svPPA	Intercept (=control)	0.1259	0.009674	13.01	0.0000 ***
		svPPA	−0.017445	0.014421	−1.21	0.2420
			F(1) = 1.463, *p* = 0.242			
NumPsil_NumTotWords	control–lvPPA	Intercept (=control)	0.21585	0.02503	8.625	0.0000 ***
		lvPPA	0.08217	0.034	2.417	0.0244 *
			F(1) = 5.840, *p* = 0.024			
	control–nfvPPA	Intercept (=control)	0.21585	0.02955	7.305	0.0000 ***
		nfvPPA	0.14141	0.04282	3.303	0.0037 **
			F(1) = 10.908, *p* = 0.004			
	control–svPPA	Intercept (=control)	0.21585	0.01634	13.209	0.0000 ***
		svPPA	−0.04357	0.02436	−1.788	0.0906 .
			F(1) = 3.198, *p* = 0.091			

Table A14. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
NumPfill_NumTotSlb	control–lvPPA	Intercept (=control)	0.021845	0.009658	2.262	0.0339 *
		lvPPA	0.016889	0.013123	1.287	0.2115
				F(1) = 1.656, *p* = 0.212		
	control–nfvPPA	Intercept (=control)	0.021845	0.006858	3.185	0.0049 **
		nfvPPA	0.009272	0.009938	0.933	0.3625
				F(1) = 0.870, *p* = 0.363		
	control–svPPA	Intercept (=control)	0.021845	0.003225	6.775	0.0000 ***
		svPPA	−0.010893	0.004807	−2.266	0.0360 *
				F(1) = 5.135, *p* = 0.036		
NumPfill_NumTotWords	control–lvPPA	Intercept (=control)	0.03732	0.01407	2.653	0.0145 *
		lvPPA	0.02144	0.01911	1.122	0.2741
				F(1) = 1.258, *p* = 0.274		
	control–nfvPPA	Intercept (=control)	0.03732	0.01226	3.043	0.0067 **
		nfvPPA	0.01651	0.01777	0.929	0.3647
				F(1) = 0.863, *p* = 0.365		
	control–svPPA	Intercept (=control)	0.037317	0.005274	7.076	0.0000 ***
		svPPA	−0.019681	0.007862	−2.503	0.0222 *
				F(1) = 6.267, *p* = 0.022		
NumSlbLONG_NumTotSlb	control–lvPPA	Intercept (=control)	0.053205	0.007982	6.665	0.0000 ***
		lvPPA	0.008105	0.010846	0.747	0.4630
				F(1) = 0.558, *p* = 0.463		
	control–nfvPPA	Intercept (=control)	0.053205	0.008898	5.979	0.0000 ***
		nfvPPA	0.006629	0.012894	0.514	0.6130
				F(1) = 0.264, *p* = 0.613		
	control–svPPA	Intercept (=control)	0.053205	0.006557	8.115	0.0000 ***
		svPPA	−0.013464	0.009774	−1.378	0.1850
				F(1) = 1.898, *p* = 0.185		
NumSlbLONG_NumTotWords	control–lvPPA	Intercept (=control)	0.091492	0.012298	7.44	0.0000 ***
		lvPPA	0.002664	0.016709	0.159	0.8750
				F(1) = 0.025, *p* = 0.875		
	control–nfvPPA	Intercept (=control)	0.091492	0.01513	6.047	0.0000 ***
		nfvPPA	0.008633	0.021925	0.394	0.6980
				F(1) = 0.155, *p* = 0.698		
	control–svPPA	Intercept (=control)	0.09149	0.01124	8.137	0.0000 ***
		svPPA	−0.02835	0.01676	−1.691	0.1080
				F(1) = 2.860, *p* = 0.108		
NumPausesALL_NumTotSlb	control–lvPPA	Intercept (=control)	0.20095	0.02555	7.863	0.0000 ***
		lvPPA	0.09175	0.03472	2.642	0.0149 *
				F(1) = 6.982, *p* = 0.015		
	control–nfvPPA	Intercept (=control)	0.20095	0.02365	8.496	0.0000 ***
		nfvPPA	0.09984	0.03427	2.913	0.0089 **
				F(1) = 8.486, *p* = 0.009		
	control–svPPA	Intercept (=control)	0.20095	0.01383	14.529	0.0000 ***
		svPPA	−0.0418	0.02062	−2.027	0.0577 .
				F(1) = 4.111, *p* = 0.058		

Table A14. *Cont.*

Parameter	Contrast		B	SE(B)	t	p
NumPausesALL_NumTotWords	control–lvPPA	Intercept (=control)	0.34466	0.03732	9.234	0.0000 ***
		lvPPA	0.10628	0.05071	2.096	0.0478 *
			F(1) = 4.392, p = 0.048			
	control–nfvPPA	Intercept (=control)	0.34466	0.04327	7.966	0.0000 ***
		nfvPPA	0.16656	0.0627	2.656	0.0156 *
			F(1) = 7.057, p = 0.016			
	control–svPPA	Intercept (=control)	0.34466	0.02368	14.557	0.0000 ***
		svPPA	−0.09159	0.03529	−2.595	0.0183 *
			F(1) = 6.734, p = 0.018			

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A15. Linear regression models of silent pause frequency (per syllable/word), by length category and group. Estimates (B), standard errors (SE(B)), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	t	p
NumLongPsil_NumTotSlb	control–lvPPA	Intercept (=control)	0.019545	0.006627	2.949	0.0074 **
		lvPPA	0.032455	0.009005	3.604	0.0016 **
			F(1) = 12.990, p = 0.002			
	control–nfvPPA	Intercept (=control)	0.01955	0.01401	1.395	0.1792
		nfvPPA	0.05525	0.02031	2.721	0.0136 *
			F(1) = 7.402, p = 0.014			
	control–svPPA	Intercept (=control)	0.019545	0.006086	3.211	0.0048 **
		svPPA	0.006788	0.009073	0.748	0.4640
			F(1) = 0.560, p = 0.464			
NumLongPsil_NumTotWords	control–lvPPA	Intercept (=control)	0.03318	0.01052	3.154	0.0046 **
		lvPPA	0.04697	0.01429	3.286	0.0034 **
			F(1) = 10.799, p = 0.003			
	control–nfvPPA	Intercept (=control)	0.03318	0.02508	1.323	0.2015
		nfvPPA	0.09632	0.03634	2.651	0.0158 *
			F(1) = 7.026, p = 0.016			
	control–svPPA	Intercept (=control)	0.033182	0.009454	3.51	0.0025 **
		svPPA	0.007485	0.014093	0.531	0.6018
			F(1) = 0.282, p = 0.602			
NumMediumPsil_NumTotSlb	control–lvPPA	Intercept (=control)	0.07727	0.0105	7.362	0.0000 ***
		lvPPA	0.03442	0.01426	2.414	0.0246 *
			F(1) = 5.825, p = 0.025			
	control–nfvPPA	Intercept (=control)	0.07727	0.01133	6.821	0.0000 ***
		nfvPPA	0.03323	0.01642	2.024	0.0573 .
			F(1) = 4.097, p = 0.057			
	control–svPPA	Intercept (=control)	0.077273	0.007192	10.745	0.0000 ***
		svPPA	−0.006939	0.01072	−0.647	0.5260
			F(1) = 0.419, p = 0.526			

Table A15. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
NumMediumPsil_NumTotWords	control–lvPPA	Intercept (=control)	0.13264	0.01672	7.932	0.0000 ***
		lvPPA	0.04083	0.02272	1.797	0.0861 .
				F(1) = 3.229, p = 0.086		
	control–nfvPPA	Intercept (=control)	0.13264	0.01951	6.799	0.0000 ***
		nfvPPA	0.05386	0.02827	1.905	0.0720 .
				F(1) = 3.630, p = 0.072		
	control–svPPA	Intercept (=control)	0.13264	0.01223	10.845	0.0000 ***
		svPPA	−0.02064	0.01823	−1.132	0.2730
				F(1) = 1.281, p = 0.273		
NumShortPsil_NumTotSlb	control–lvPPA	Intercept (=control)	0.0291818	0.0061829	4.72	0.0001 ***
		lvPPA	−0.0003357	0.0084009	−0.04	0.9685
				F(1) = 0.002, p = 0.968		
	control–nfvPPA	Intercept (=control)	0.029182	0.00526	5.548	0.0000 ***
		nfvPPA	−0.004382	0.007623	−0.575	0.5720
				F(1) = 0.330, p = 0.572		
	control–svPPA	Intercept (=control)	0.029182	0.00473	6.17	0.0000 ***
		svPPA	−0.017182	0.007051	−2.437	0.0254 *
				F(1) = 5.938, p = 0.025		
NumShortPsil_NumTotWords	control–lvPPA	Intercept (=control)	0.050091	0.009665	5.182	0.0000 ***
		lvPPA	−0.006168	0.013133	−0.47	0.6430
				F(1) = 0.221, p = 0.643		
	control–nfvPPA	Intercept (=control)	0.050091	0.008759	5.719	0.0000 ***
		nfvPPA	−0.008791	0.012692	−0.693	0.4970
				F(1) = 0.480, p = 0.497		
	control–svPPA	Intercept (=control)	0.050091	0.007997	6.264	0.0000 ***
		svPPA	−0.030424	0.011921	−2.552	0.0200 *
				F(1) = 6.513, p = 0.020		

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A16. Linear regression models of pause frequency (per syllable/word), by type and group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
NumPsil_NumTotSlb	lvPPA–nfvPPA	−0.017188314	0.024675406	29	−0.696576766	0.7674
	lvPPA–svPPA	0.084197561	0.02543844	29	3.309855526	0.0069 **
	nfvPPA–svPPA	0.101385875	0.026954272	29	3.761402818	0.0021 **
			F(2) = 8.140, p = 0.002			
NumPsil_NumTotWords	lvPPA–nfvPPA	−0.059240685	0.041933904	29	−1.412715691	0.3477
	lvPPA–svPPA	0.12573904	0.04323062	29	2.90856432	0.0184 *
	nfvPPA–svPPA	0.184979724	0.045806658	29	4.038271597	0.0010 **
			F(2) = 8.467, p = 0.001			
NumPfill_NumTotSlb	lvPPA–nfvPPA	0.007616662	0.013685029	29	0.556568905	0.8439
	lvPPA–svPPA	0.027781261	0.014108209	29	1.969155704	0.1380
	nfvPPA–svPPA	0.020164599	0.014948893	29	1.348902509	0.3804
			F(2) = 1.984, p = 0.156			

Table A16. *Cont.*

Parameter	Contrast	B	SE(B)	df	*t*	*p*
NumPfill_NumTotWords	lvPPA–nfvPPA	0.00493464	0.021348837	29	0.231143252	0.9710
	lvPPA–svPPA	0.04112329	0.022009004	29	1.868475768	0.1660
	nfvPPA–svPPA	0.036188651	0.023320482	29	1.551796862	0.2824
	F(2) = 1.934, p = 0.163					
NumSlbLONG_NumTotSlb	lvPPA–nfvPPA	0.001475497	0.012940583	29	0.114020924	0.9929
	lvPPA–svPPA	0.021568754	0.013340743	29	1.616758051	0.2548
	nfvPPA–svPPA	0.020093256	0.014135695	29	1.421455185	0.3434
	F(2) = 1.503, p = 0.239					
NumSlbLONG_NumTotWords	lvPPA–nfvPPA	−0.0059695	0.020561471	29	−0.290324568	0.9547
	lvPPA–svPPA	0.031009914	0.02119729	29	1.462918756	0.3232
	nfvPPA–svPPA	0.036979414	0.0224604	29	1.646427221	0.2429
	F(2) = 1.571, p = 0.225					
NumPausesALL_NumTotSlb	lvPPA–nfvPPA	−0.008096155	0.038642381	29	−0.209514918	0.9761
	lvPPA–svPPA	0.133547575	0.039837314	29	3.352323788	0.0062 **
	nfvPPA–svPPA	0.141643731	0.04221115	29	3.355599894	0.0061 **
	F(2) = 7.222, p = 0.003					
NumPausesALL_NumTotWords	lvPPA–nfvPPA	−0.060275545	0.062779733	29	−0.960111523	0.6074
	lvPPA–svPPA	0.197872244	0.064721062	29	3.057308376	0.0128 *
	nfvPPA–svPPA	0.258147789	0.068577677	29	3.764312249	0.0021 **
	F(2) = 7.751, p = 0.002					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A17. Linear regression models of silent pause frequency (per syllable/word), by length category and group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
NumLongPsil_NumTotSlb	lvPPA–nfvPPA	−0.0228	0.018015207	29	−1.26559743	0.4255
	lvPPA–svPPA	0.025666667	0.018572289	29	1.381987262	0.3633
	nfvPPA–svPPA	0.048466667	0.019678979	29	2.462864876	0.0507 .
	F(2) = 3.033, p = 0.064					
NumLongPsil_NumTotWords	lvPPA–nfvPPA	−0.049346154	0.031119401	29	−1.585703871	0.2678
	lvPPA–svPPA	0.039487179	0.032081701	29	1.230831845	0.4451
	nfvPPA–svPPA	0.088833333	0.033993394	29	2.613252849	0.0364 *
	F(2) = 3.452, p = 0.045					
NumMediumPsil_NumTotSlb	lvPPA–nfvPPA	0.001192308	0.017196672	29	0.069333631	0.9974
	lvPPA–svPPA	0.041358974	0.017728442	29	2.332916497	0.0670 .
	nfvPPA–svPPA	0.040166667	0.018784849	29	2.138248075	0.0996 .
	F(2) = 3.230, p = 0.054					
NumMediumPsil_NumTotWords	lvPPA–nfvPPA	−0.013038462	0.02842212	29	−0.45874345	0.8909
	lvPPA–svPPA	0.061461538	0.029301013	29	2.097590876	0.1079
	nfvPPA–svPPA	0.0745	0.03104701	29	2.399586969	0.0582 .
	F(2) = 3.298, p = 0.051					
NumShortPsil_NumTotSlb	lvPPA–nfvPPA	0.004046154	0.006866938	29	0.589222447	0.8269
	lvPPA–svPPA	0.016846154	0.007079283	29	2.379641236	0.0607 .
	nfvPPA–svPPA	0.0128	0.007501125	29	1.706410666	0.2200
	F(2) = 2.936, p = 0.069					

Table A17. *Cont.*

Parameter	Contrast	B	SE(B)	df	*t*	*p*
NumShortPsil_NumTotWords	lvPPA–nfvPPA	0.002623077	0.010439284	29	0.251269806	0.9658
	lvPPA–svPPA	0.02425641	0.010762097	29	2.253874028	0.0789 .
	nfvPPA–svPPA	0.021633333	0.011403391	29	1.897096469	0.1576
	F(2) = 2.837, p = 0.075					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A18. Linear regression models of pause–speech and pause–total duration ratios, by type and group. Estimates (B), standard errors (SE(B)), *t*-values, and *p*-values.

Parameter	Contrast		B	SE(B)	*t*	*p*
R_DurPsil_DurSpeech	control–lvPPA	Intercept (=control)	37.268	6.383	5.839	0.0000 ***
		lvPPA	35.33	8.673	4.074	0.0005 ***
		F(1) = 16.594, p = 0.001				
	control–nfvPPA	Intercept (=control)	37.27	31.22	1.194	0.2473
		nfvPPA	95.87	45.25	2.119	0.0475 *
		F(1) = 4.490, p = 0.048				
	control–svPPA	Intercept (=control)	37.268	7.362	5.062	0.0001 ***
		svPPA	12.322	10.975	1.123	0.2760
		F(1) = 1.261, p = 0.276				
R_DurPsil_DurTot	control–lvPPA	Intercept (=control)	25.095	2.538	9.887	0.0000 ***
		lvPPA	13.773	3.448	3.994	0.0006 ***
		F(1) = 15.952, p = 0.001				
	control–nfvPPA	Intercept (=control)	25.095	4.602	5.453	0.0000 ***
		nfvPPA	18.874	6.669	2.83	0.0107 *
		F(1) = 8.010, p = 0.011				
	control–svPPA	Intercept (=control)	25.095	3.175	7.904	0.0000 ***
		svPPA	5.259	4.733	1.111	0.2810
		F(1) = 1.235, p = 0.281				
R_DurPfill_DurSpeech	control–lvPPA	Intercept (=control)	6.436	2.431	2.648	0.0147 *
		lvPPA	3.417	3.302	1.035	0.3120
		F(1) = 1.071, p = 0.312				
	control–nfvPPA	Intercept (=control)	6.436	2.822	2.281	0.0343 *
		nfvPPA	2.303	4.09	0.563	0.5800
		F(1) = 0.317, p = 0.580				
	control–svPPA	Intercept (=control)	6.4364	0.8877	7.25	0.0000 ***
		svPPA	−3.6941	1.3234	−2.791	0.0121 *
		F(1) = 7.792, p = 0.012				
R_DurPfill_DurTot	control–lvPPA	Intercept (=control)	4.5091	1.1903	3.788	0.0010 **
		lvPPA	0.6932	1.6174	0.429	0.6724
		F(1) = 0.184, p = 0.672				
	control–nfvPPA	Intercept (=control)	4.5091	0.7249	6.22	0.0000 ***
		nfvPPA	−1.1811	1.0505	−1.124	0.2750
		F(1) = 1.264, p = 0.275				
	control–svPPA	Intercept (=control)	4.5091	0.6087	7.408	0.0000 ***
		svPPA	−2.5035	0.9074	−2.759	0.0129 *
		F(1) = 7.612, p = 0.013				

Table A18. *Cont.*

Parameter	Contrast		B	SE(B)	*t*	*p*
R_DurSlbLONG_DurSpeech	control–lvPPA	Intercept (=control)	14.441	2.025	7.131	0.0000 ***
		lvPPA	1.742	2.752	0.633	0.5330
		F(1) = 0.401, p = 0.533				
	control–nfvPPA	Intercept (=control)	14.441	2.139	6.752	0.0000 ***
		nfvPPA	1.078	3.099	0.348	0.7320
		F(1) = 0.121, p = 0.732				
	control–svPPA	Intercept (=control)	14.441	1.868	7.73	0.0000 ***
		svPPA	−3.591	2.785	−1.289	0.2140
		F(1) = 1.662, p = 0.214				
R_DurSlbLONG_DurTot	control–lvPPA	Intercept (=control)	10.345	1.399	7.397	0.0000 ***
		lvPPA	−1.151	1.9	−0.606	0.5510
		F(1) = 0.367, p = 0.551				
	control–nfvPPA	Intercept (=control)	10.345	1.554	6.659	0.0000 ***
		nfvPPA	−1.982	2.251	−0.88	0.3900
		F(1) = 0.775, p = 0.390				
	control–svPPA	Intercept (=control)	10.345	1.413	7.324	0.0000 ***
		svPPA	−2.909	2.106	−1.382	0.1840
		F(1) = 1.909, p = 0.184				
R_DurPausesALL_DurSpeech	control–lvPPA	Intercept (=control)	58.145	6.494	8.953	0.0000 ***
		lvPPA	40.49	8.824	4.589	0.0001 ***
		F(1) = 21.055, p = 0.000				
	control–nfvPPA	Intercept (=control)	58.14	32.47	1.791	0.0893 .
		nfvPPA	99.25	47.05	2.109	0.0484 *
		F(1) = 4.450, p = 0.048				
	control–svPPA	Intercept (=control)	58.145	6.762	8.599	0.0000 ***
		svPPA	5.039	10.08	0.5	0.6230
		F(1) = 0.250, p = 0.623				
R_DurPausesALL_DurTot	control–lvPPA	Intercept (=control)	39.949	2.047	19.518	0.0000 ***
		lvPPA	13.313	2.781	4.787	0.0001 ***
		F(1) = 22.917, p = 0.000				
	control–nfvPPA	Intercept (=control)	39.949	3.912	10.211	0.0000 ***
		nfvPPA	15.712	5.67	2.771	0.0122 *
		F(1) = 7.680, p = 0.012				
	control–svPPA	Intercept (=control)	39.9491	2.6212	15.241	0.0000 ***
		svPPA	−0.1524	3.9074	−0.039	0.9690
		F(1) = 0.002, p = 0.969				

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Table A19. Linear regression models of pause–speech and pause–total duration ratios, by type and group. Estimates (B), standard errors (SE(B)), degrees of freedom (df), *t*-values, and *p*-values of the pairwise contrasts between the three PPA groups.

Parameter	Contrast	B	SE(B)	df	*t*	*p*
R_DurPsil_DurSpeech	lvPPA–nfvPPA	−60.54253846	36.2992659	29	−1.667872255	0.2345
	lvPPA–svPPA	23.00846154	37.42174282	29	0.614842062	0.8132
	nfvPPA–svPPA	83.551	39.65163922	29	2.107126001	0.1059
	F(2) = 2.448, *p* = 0.104					
R_DurPsil_DurTot	lvPPA–nfvPPA	−5.101307692	6.0224746	29	−0.847045115	0.6773
	lvPPA–svPPA	8.514358974	6.208706707	29	1.371357897	0.3687
	nfvPPA–svPPA	13.61566667	6.578672714	29	2.069667737	0.1140
	F(2) = 2.176, *p* = 0.132					
R_DurPfill_DurSpeech	lvPPA–nfvPPA	1.114846154	4.218931148	29	0.264248483	0.9623
	lvPPA–svPPA	7.111623932	4.349392543	29	1.635084408	0.2474
	nfvPPA–svPPA	5.996777778	4.60856526	29	1.301224446	0.4059
	F(2) = 1.447, *p* = 0.252					
R_DurPfill_DurTot	lvPPA–nfvPPA	1.874307692	1.539023641	29	1.217855037	0.4524
	lvPPA–svPPA	3.196752137	1.586614645	29	2.01482581	0.1266
	nfvPPA–svPPA	1.322444444	1.681158245	29	0.786626987	0.7141
	F(2) = 2.112, *p* = 0.139					
R_DurSlbLONG_DurSpeech	lvPPA–nfvPPA	0.664361538	3.113531785	29	0.213378756	0.9752
	lvPPA–svPPA	5.332683761	3.209811076	29	1.661369979	0.2370
	nfvPPA–svPPA	4.668322222	3.401078121	29	1.372600704	0.3681
	F(2) = 1.524, *p* = 0.235					
R_DurSlbLONG_DurTot	lvPPA–nfvPPA	0.831038462	2.134732906	29	0.389293883	0.9201
	lvPPA–svPPA	1.75842735	2.200744941	29	0.799014605	0.7066
	nfvPPA–svPPA	0.927388889	2.331883495	29	0.397699495	0.9168
	F(2) = 0.321, *p* = 0.728					
R_DurPausesALL_DurSpeech	lvPPA–nfvPPA	−58.76338462	37.70476862	29	−1.558513333	0.2795
	lvPPA–svPPA	35.45128205	38.8707077	29	0.912030785	0.6372
	nfvPPA–svPPA	94.21466667	41.18694539	29	2.287488566	0.0736 .
	F(2) = 2.712, *p* = 0.083					
R_DurPausesALL_DurTot	lvPPA–nfvPPA	−2.398692308	5.191833083	29	−0.462012601	0.8894
	lvPPA–svPPA	13.46564103	5.352379383	29	2.515823349	0.0452 *
	nfvPPA–svPPA	15.86433333	5.671318337	29	2.797291986	0.0239 *
	F(2) = 4.575, *p* = 0.019					

Note: Significance codes: '***' refers to $p < 0.001$; '**' refers to $p < 0.01$; '*' refers to $p < 0.05$; '.' refers to $p < 0.1$; ' ' refers to $p < 1$.

Note

1 Note that the last available public report on language use in Catalonia (Direcció General de Política Lingüística de la Generalitat de Catalunya 2019) showed that 97% of the population over the age of 15 say that they are proficient in understanding, speaking, reading, and writing in Spanish (in Catalan: 94%, 81.2%, 85.5%, and 65.3%, respectively), and that 94.2% use Spanish on a daily basis. In addition, Catalan and Spanish have both been mandatory school subjects since 1992 (Departament d'Ensenyament de la Generalitat de Catalunya 2018); those who finished school before 1992 received all their schooling exclusively in Spanish. Therefore, in the context of Catalonia, bilingualism is not expected to be an intervening factor in word-finding difficulties in Spanish. Further information about Spanish–Catalan bilingualism in Catalonia can be found in Seoane et al. (2019).

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