Is there an order of loss of sounds in speakers with Parkinson's disease?

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Abstract

Influential reports on speech changes in people with Parkinson’s disease (Logemann et al, 1978, 1981) reported a posterior to anterior pattern of loss of speech sound accuracy. These claims have never been examined. In a partial replication of Logemann et al’s work we examined whether posterior lingual sounds are most affected in people with Parkinson’s disease, followed by anterior lingual sounds then labial sounds. Ninety-nine people with PD (age mean 70.7, SD 8.46; time since diagnosis mean 6.97, SD 6.2) with mild to severe overall motor symptoms (Hoehn and Yahr stages 1-5, median 2.5) completed a diagnostic intelligibility test. This was scored by 60 listeners unfamiliar with PD and dysarthric speech. We calculated the proportion of posterior vs anterior lingual vs labial sounds misrecognized by the listeners. We compared profiles of misperceived sounds within and across Hoehn and Yahr stages of severity, and in relation to Unified Parkinson’s Disease Rating Scale and speech intelligibility scores. Speech accuracy declined significantly in relation to overall motor impairment for labial and anterior lingual sounds but not for velar sounds. Speech sound accuracy was strongly associated with intelligibility outcomes ($p = <0.01$). Contrary to previous assertions, there was no evidence supporting the existence of a posterior to anterior order of ‘loss’ of oral speech sounds in people with PD, nor an interaction of anterior-posterior speech profile changes with Hoehn and Yahr stage. Findings support the notion that a common underlying impairment of movement downscaling affects all sounds similarly and simultaneously in PD from the start.

Keywords

Parkinson’s disease, speech, articulation, progression

Introduction

Parkinson's disease (PD) is a progressive neurological disorder, characterised by a range of motor and non-motor impairments that become more severe as the disease advances. Motor impairments include tremor, rigidity, bradykinesia all of which may be associated with the (hypokinetic) dysarthria and dysphonia experienced by people with PD (Miller 2017). Non-motor symptoms can include depressed mood, memory and attention changes, fatigue and cognitive slowing and decline, again with potential to negatively affect communication (Dupouy, Ory-Magne, Mekies, et al 2018).

Approximately 90% of PwP (People with Parkinson's) report changes to the intensity and quality of their voice and around 50% of PwP experience deterioration in their articulation that is sufficient to cause unfamiliar listeners difficulty understanding their speech (Ho et al, 1998; Miller et al, 2007). These changes often have a major impact on their lives, affecting aspects such as mood and activities of daily living (Miller et al, 2008). It is possible to detect the neuromuscular impairments underlying these changes instrumentally, on occasion even perceptually, before they significantly limit activity and/or result in restriction to participation, and they may be apparent already in the prodromal phase before a formal diagnosis of PD (Harel et al, 2004; Orozco-Arroyave et al, 2016).

Although some symptoms of PD progression can be ameliorated for a time through pharmacological or surgical interventions, the overall trajectory in PD is one of decline (Skodda et al, 2013). Within different domains of function, attempts have been made to grade and characterise the pattern of evolution, looking for consistencies in the nature and the rate of symptom progression. However, in PD different dysfunctions do not necessarily evolve at the same rate and individual dysfunctions do not always show a constant rate of progression

(Martínez-Fernández et al, 2016; Mollenhauer et al, 2016; Reinoso et al, 2015; Williams-Gray et al, 2013). Changes to speech have been examined to explore whether there is a predictable order in which changes to articulation occur over time and if so, what this might indicate regarding the progression of the underlying pathology in PD and implications for rehabilitation.

One such pair of studies was by Logemann et al (1978) and Logemann & Fisher (1981) who examined these questions in linked perceptual studies. These studies are extensively cited and their conclusion, that there is a posterior to anterior order or susceptibility of loss of speech sound accuracy in PD has entered textbooks and is quoted unquestioningly by many, right up to present day. However, there are several shortcomings to the Logemann et al studies, not least of which is that even they did not subject their results to statistical analysis. As such their findings have never been replicated.

In Logemann et al (1978; 1981) two speech pathology/ phonetician experts evaluated 200 PwP showing a range of overall motor and speech severities. It is unclear in the 1978 study how many of the 200 actually entered the analyses for articulation, but from the 1981 study it appears clear it was only 90. Participants read eleven sentences. Each sentence elicited words focused on a different place and manner of consonant articulation (e.g. bilabial plosives; alveolar fricatives; palatal-alveolar affricates), aiming to cover all phonemes of English across a variety of syllable and word positions. The 1978 study reported outcomes according to whether a target sound was heard by the speech pathologists as misarticulated or not; the 1981 study examined the same data employing phonetic transcription.

Findings suggested high consistency of error production - if a sound was in error in one context it was across all contexts. There was no clear clustering of misperceptions by manner of articulation. However, based on their data Logemann et al asserted that there existed a defined pattern of decline in articulatory precision. Phonemes requiring constriction were most susceptible to change, followed by those requiring close approximation to least approximation (e.g. stop to affricate to fricative) – though in actual fact their data did not strongly support this. Their results showed that /s/ and /z/ imprecision were next in frequency of occurrence after /k/ and /g/ misarticulation, whilst /t/ and /d/ were least affected of all. Voiced-voiceless pairs (e.g. /p~b/, /t~d/) were similarly affected. Hypernasality was not a prominent issue.

Logemann et al further maintained there existed a gradient of susceptibility to breakdown of sounds by place of articulation starting from posteriorly articulated sounds and proceeding to anterior place of articulation. They suggested such a picture is compatible with the order in which different cranial nerves might be affected, specifically XII (hypoglossal) and XI (accessory). Whilst the strong form of the posterior - anterior gradation assertion (posterior oral to anterior oral) is maintained in their results section, their discussion is more equivocal. There the contention is broadened to imply posterior in the sense of laryngeal then to anterior oral involvement, with the posterior – anterior articulation gradient restricted to lingual consonants only, since the most anterior place of articulation (labials) in their data actually evidenced greater breakdown than tongue tip/blade. Indeed, their results indicated that /t/ and /d/ phonemes were the least affected, even less so than affricates /tʃ/, /dʒ/ and fricatives /s/, /z/, /f/ and /v/. Another interpretation of their data is that they meant posterior – anterior in the sense of laryngeal involvement, then lingual involvement (based on the observation that /k/ and /g/ are affected before /p/ and /b/), then labial involvement.

In addition to this equivocation regarding what precisely they were asserting with the posterior - anterior prediction, there were other limitations to their studies. Comparing vocalisation subsystems (phonation) control with articulatory subsystem control in terms of speech motor control organisation is not directly valid. The soundness of their anatomical-physiological argumentation was questionable. Cranial nerve XI is little involved in speech motor control. The other key cranial nerves besides XII would be X (vagus), VII (facial) and V (trigeminal), which they failed to mention;

Furthermore, their cohort contained people with mixed aetiologies (e.g. idiopathic PD, post-encephalitic parkinsonism; some participants had undergone thalamic surgery, which may give added, different, effects on speech (Alomar et al, 2017). Crucially there were no statistical analyses to establish whether any of the raw score differences, on which claims were based, were significantly different – indeed they do not even report standard deviations or interquartile ranges. It is unclear whether all occurrences of a sound in the eleven sentences were totalled and it is not apparent from their reports whether comparisons across sounds related to straightforward raw totals, or whether totals were adjusted to reflect the different number of occurrences of different phonemes in their elicitation material. For instance sentence 1 (*Pete's job was to keep the baby happy*) is directed at bilabial plosives, sentence 3 is directed at velar plosives (The girls were baking the biggest cake for Mr Tag) but both contain other place and manner consonants. If these other sounds were misarticulated it appears from their examples that they were not counted, which potentially introduces more distortion into the calculations.

Re-examination of previous studies constitutes an important aspect of advancement in science, especially for research that has become influential (Shuster & Cottrill, 2015). The 1978 and 1981 assertions by Logemann et al continue to be reiterated in reports on voice and articulation changes in PwP, but without due regard to the reservations concerning their data and interpretations. We considered it important to re-examine the issue, employing a homogeneous group of people with idiopathic PD, with comparisons across sounds adjusted for relative frequency in the elicitation material and employing statistical analyses. Given that the nature of speech motor control for laryngeal-respiratory, phonatory control is different from lingual-labial control for articulation and that it is well attested that the two are well differentiated in PD, the focus of this study is oral articulation.

METHODOLOGY

Participants

Individuals were recruited from a hospital outpatient and community-based population of PwP. A neurologist confirmed the diagnosis of idiopathic PD, based on UK Parkinson's Brain Bank Criteria (Hughes et al, 1992). Participants were excluded if they: presented with a neurological illness in addition to or other than PD; had a history of speech-language disorder prior to PD onset; showed clinical depression (Geriatric Depression score >6 (Sheikh & Yesavage, 1986); were unable to cooperate in testing; were non-native speakers of English; made no perceived errors on the intelligibility test (below).

The study was conducted in accordance with XX (withheld for blind review) Ethics Committee approved procedures, which amongst other stipulations, ensured voluntary, informed, anonymous participation, with right to leave without reason at any stage in the research.

Assessments

A movement disorders neurologist assessed the overall severity of motor symptoms using the Unified Parkinson's Disease Rating Scale III (UPDRS (Goetz et al, 2003) and the Hoehn and Yahr stages. The Hoehn & Yahr Functional Rating Scale assigns patients to one of five stages depending on the severity of motor symptoms in PD Goetz, Poewe, Rascol, et al (2004). Stage 1 refers to unilateral motor symptoms with minimal impact on function; patients in stage 2 present with bilateral symptoms and posture becomes stooped. At stage 3, motor symptoms are deemed to be mild-moderate with some postural instability evident. Stages 4 and 5 encompass more severe motor symptoms, with significant rigidity and poor motor co-ordination at stage 4 and confinement to a wheelchair at stage 5.

Participants also completed an intelligibility test, administered by a research speech and language pathologist, which followed the format of the Assessment of Dysarthric Speech (Yorkston & Beukelman, 1981). Speakers read aloud sixty items selected at random from six matched lists of minimally differing words. Scoring employed a closed class method. In the scoring booklet for each speaker, for each item of the intelligibility test, listeners indicated from a written selection of twelve responses which word they believed they heard. The options consisted of six words that differed minimally from each other (e.g. fat, pat, tat, sat, chat, cat; bore, pour, tore, door, core, gore), one of which was randomly selected as the target, and six further foils which included more minimal pairs and/or assonantly similar words (e.g. vat, bat, mat, gnat, hat, rat; war, sore, lore, nor, roar). Twenty three items involved saying a single word; in the remainder the target word appeared in a carrier phrase (e.g. Can you see my {target word}; It's a {target word}) to elicit intelligibility in connected speech, whilst still maintaining a minimal pair context.

Procedures

Recording: Participants were audio-recorded in their own homes first thing in the morning in a practically defined 'off state', i.e. after withholding antiparkinsonian medication overnight. For all participants recording used a Marantz Professional recorder (PMD690; sampling frequency 48 kHz) with an AKG (C420) head mounted microphone to minimise background noise and maintain consistent mouth to microphone distance.

Speakers read aloud the 60-item intelligibility test. Words appeared on a computer screen one at a time, at a rate controlled by the participant. Recordings were transferred onto a computer. Tracks were 'cleaned' using Adobe Audition to remove extraneous noises and interference. These were copied to compact disc for listeners to audit and score.

To score the intelligibility recordings sixty listeners (mean age 40.5, SD 20.95, age range 18-83) with no training in phonetics or speech pathology or experience of listening to people with speech impairment, but familiar with the regional accent of the speakers, were recruited from the local community. Listeners stated that they had no or corrected hearing or visual impairment, and no self-reported reading difficulties. They were blind to all details of the speakers and aims of the study. The listening sessions took place in a quiet room in a university building or the listener's private residence. The samples were played through loudspeakers (either Ferguson HF 05/7 or Creative Model SBS20 DC 9V). The listeners were seated 1.5 meters from the loudspeakers, which were set at volume setting 5 (scale 1-10) and were able to take a break when they requested. This methods preserved differences in voice intensity between speakers rather than attempting to normalise intensity across all speakers. However, since comparisons for articulation were within rather than between individual speakers this was not considered to represent a major drawback.

To minimize listener variability effects in word recognition scoring and overestimation of scores through familiarity with word lists, three listeners scored each speaker independently (Hustad et al, 2015; Miller, 2013). Each listener heard only five speakers. Grouping of listeners was systematically varied to avoid the same trio evaluating the same tracks. Listeners received a £5 (approximately Euros 5.60; US$ 6.50) store voucher for taking part.

Data processing

Sounds involved in the contrasts examined by the intelligibility test were categorised according to place and manner of articulation in the vocal tract. The matrices included three broad consonant categories: labial consonants /p, b, m, f, v, w/; posterior lingual consonants (/k, g/); and anterior lingual consonants /n, t, d, l, r, s, z, ʃ, ʒ, tʃ, dʒ/. Though /ʃ, ʒ, tʃ, dʒ/ in English strictly speaking are palatal-alveolar sounds they were included in the general analyses which compared labial – anterior lingual – posterior lingual positions, as was done by Logemann et al (1978). More specific examinations focused on proportions of /p + b/ versus /t + d/ versus /k + g/ correctly perceived. As words from the minimal pair sets were randomly selected speakers did not produce exactly the same list of words, hence the total possible tokens of each sound per speaker differed slightly. Median tokens per speaker for all lip sounds was 35 (interquartile range, IQR, 34-38); for all tongue tip/blade sounds median 93 (IQR 88-95) and for /k+g/ median 13 (IQR 12-14). For lip sounds /p+b/ only, median token total was 21 (IQR 20-22) and for /t+d/ median 25 (IQR 24-28). Total tokens across all speakers for /p+b/ was 2093, for /t+d/ 2512, and for /k+g/ 1322. From this data the frequency with which each sound was (mis)perceived by the listeners was calculated, expressed as a proportion of the possible times it could be correct.

Statistical Analysis

Analyses were conducted in SPSS (version 22). Associations between variables were examined using correlational analyses. Analyses of variance (parametric and non-parametric depending on the parametricity of the data), with post hoc adjustments for multiple comparisons, were conducted to test for differences in proportions of misperceived sounds by place of articulation and Hoehn and Yahr stage. For some analyses the group of PwP was separated into more vs less affected motorically and according to more vs less affected in intelligibility score (total words recognised by listeners). The split was made by taking the median UPDRS III score for motoric status and median intelligibility score. Mann Whitney tests were used to examine for between-group differences between more versus less affected speakers divided according to median UPDRS III score and median intelligibility score. Significance was set at $p = \leq 0.05$.

RESULTS

Ninety-nine people with PD met the inclusion criteria. Summary data appear in table 1. Thirty-four were female. There were no statistically significant differences between men and women in age, time since diagnosis, UPDRS III score nor overall intelligibility. .

Table 1 about here

Participants ranged from Hoehn and Yahr stage 1 to 5. For analyses purposes stages 1+1.5 and stages 4+5 were merged due to limited subgroup numbers. The number of participants by Hoehn & Yahr stage appears in table 2, alongside summary statistics for the proportion of correctly perceived sound group productions overall and by Hoehn and Yahr stage.

Table 2 about here

The first analyses compared proportions of sounds correctly recognised across different places of articulation. Taking the whole cohort (n 99) together irrespective of Hoehn and Yahr stage, there were significant differences by place of articulation when all labial, all anterior lingual and posterior lingual places were compared ($F(2,294) = 3.296$, $p = 0.038$). Post hoc testing showed the main factor was a difference between labial and all anterior lingual sounds ($p = 0.037$) but there were no statistically significant differences between all labial and velar or all alveolar and velar sounds. This difference disappeared when plosives only were compared (/p+b/ with /t+d/ with /k+g/) across place ($F (2,294) = 1.474$, $p = 0.231$).

Examining profiles of error frequency between places of articulation within the individual Hoehn and Yahr stages revealed no statistically significant differences between labial – anterior lingual – posterior lingual at any stage. Analyses of variance gave no indication of interaction between place of articulation and Hoehn and Yahr stage ($p = 0.26$), indicating that the gradient of misperceptions by place of articulation did not alter significantly according to overall motor severity for participants in this group.

The second set of analyses investigated the different articulatory positions independently to examine the gradation in the proportion of correctly perceived sounds across groups defined by Hoehn and Yahr stages (summary data table 2) and by UPDRS III scores.

Labial Sounds: Spearman's rank correlation showed that the proportion of all labial sounds (/p, b, m, f, v, w/) correctly perceived by the listeners for the groups of speakers at each Hoehn and Yahr stage was significantly but weakly correlated with their Hoehn & Yahr stage (r -0.214, p = < 0.05, two-tailed). Similarly, a significant correlation between proportion of correct labial sounds and UPDRS III score was identified (r -0.381, p = < 0.001, two-tailed). Analysis of variance with post hoc adjustments showed no significant differences between any stages for /p+b/ except between stage 1+1.5 vs stages 4+5 (p = 0.036). Looking at all labial sounds the difference between stages 1+1.5 vs 4+5 only approached significance (p = 0.055).

Anterior lingual sounds: Spearman's rank correlation showed that the proportion of lingual sounds correctly perceived by the naïve listeners across the groups defined by Hoehn and Yahr stage was significantly but weakly correlated with the Hoehn & Yahr stage: all tongue tip, r .222, p = 0.03, two-tailed; /t + d/, r .305, p = 0.002. There was a similarly significant correlation between proportion of correct anterior lingual sounds and UPDRS III score: all tongue tip, r .308, p = <0.01; /t + d/, r .355, p = <0.01. For anterior lingual sounds (all alveolar and alveolar palatal and /t+d/), post hoc comparisons showed a difference approaching significance (p = 0.06) between proportions for stages 2.5 (where mean correct was marginally above stage 1+1.5) and 4+5, but no other significant differences.

Posterior lingual sounds: There were no significant correlations between correct posterior lingual perceptions across Hoehn and Yahr stage defined groups (r .046) nor UPDRS III (r .111). Neither were there any significant differences when comparing between Hoehn and Yahr stages.

Relation of proportion of (mis)perceived consonants to intelligibility: Given that Hoehn and Yahr and UPDRS III measures relate to overall motor impairment, and speech decline may not correlate significantly with this, analyses were conducted in relation to how severely intelligibility was affected, based on dividing the group by median intelligibility test score (raw score 50). Unsurprisingly there were strong correlations ($p = <0.01$) between proportion of plosives (mis)perceived and intelligibility scores (/p + b/, r .534; /t + d/, r .548; /k + g/, r .497). Equally unsurprisingly there were significant differences ($p = <0.01$, two tailed) in proportion of sounds correctly perceived between milder and more severely impaired groups for all places of articulation, both for all sounds at each place of articulation and when restricted to bilabial, alveolar and velar plosives only.

More affected speakers. The above analyses included all participants. Comparison of maximum and minimum scores across Hoehn and Yahr stages and standard deviations suggest the presence of participants who were relatively less affected in their speech whilst others experienced a more marked decline. The possibility existed that a potential gradation of loss was masked by including scores from participants who performed near to ceiling and who showed less prominent speech evolution. A further set of analyses therefore focused on those speakers who fell below median scores for correctly perceived sounds at each Hoehn and Yahr stage and for each place of articulation. Table 3 provides a summary of scores.

Table 3 about here

Comparison of total correctly perceived sounds for those below the median score showed a significant difference between places of articulation (Kruskal Wallis, chi 12.46, df2, p =

<0.002). Follow-up testing showed a significant difference (z 3.66, p = <0.001) between bilabial and alveolar plosives (/p+b/ more affected), a difference approaching significance (p = 0.061) between alveolar and velar sounds (velar lower than alveolar), but no significant difference between bilabial and velar plosives.

Within places of articulation and across Hoehn and Yahr stages there was a significant trend downwards for /p+b/ (chi 14.69, df4, p = <0.005), but not for /t+d/, nor /k+g/. Analysis of variance (place x Hoehn and Yahr) showed effects of place (F(1,2) = 3.628, p = 0.03, partial eta squared 0.05) and motor severity (F(1,4) = 3.30, p = 0.01, partial eta squared 0.87). However, there was no significant (p = 0.78) interaction between them to suggest place profiles altered systematically in relation to Hoehn and Yahr stage. Indeed, inspection of the associations between patterns of change across places of articulation indicated that they were very highly correlated: /p+b/ with /t+d/, r .997, p = <0.001; /p+b/ with /k+g/ r .995, p = <0.001; /t+d/ with /k+g/ r .996, p = <0.001.

A further possibility that might have obscured potential differences concerned the use of percent correctly perceived tokens per place of articulation in order to correct for the unequal total tokens across speakers, especially given the lower number of /k+g/ tokens. A further analysis therefore examined the proportions of correct/incorrectly perceived tokens across places of articulation based on raw scores. Chi square (3x2, place of articulation x right, wrong) indicated a significant difference in proportion correctly perceived across place of articulation (chi 9.42, df 2, p = <0.01). Pairwise testing with post hoc corrections revealed no significant difference in proportions between /p+b/ vs /k+g/ (chi, df 1, p = 0.47) or /t+d/ vs /k+g/ (Chi 3.13, df1, p = 0.07). There was a significant difference between /p+b/ vs /t+d/ (Chi 8.83, df1, p = <0.01), with /t+d/ proportionately less affected than /p+b/.

DISCUSSION

The present data do not support the contention of an order of loss of misperceived sounds in words according to posterior-anterior place of articulation, neither for all misperceived words irrespective of stage of PD, nor when confined to individual Hoehn and Yahr stages. Neither was there any interaction detected suggesting systematic changes in order of susceptibility to misperception as overall severity of PD progressed. Whilst inspection of scores confined to those performing below the median for each place of articulation gave a sharper focus to differences in some respects (in particular the steeper fall-off in bilabial sounds at Hoehn and Yahr stages 4+5), there still did not emerge any evidence for a systematic order of susceptibility for breakdown of contrasts in a posterior – anterior direction, nor any other configuration.

In this sense, the data fail to confirm the assertions of a posterior-anterior gradation made by Logemann et al and accepted by others. Like Logemann et al we did observe differences in mean scores between different places of articulation, overall and at different stages of motor decline, but once these were subjected to statistical analyses (which Logemann et al failed to do) the differences were nonsignificant.

Arguably what is notable about the current data is the consistency in profiles and the highly correlated nature of change across different places of oral articulation. This shifts interpretation away from places of articulation being differentially affected in association with the anatomical spread of pathology in PD, towards all places of articulation being similarly implicated from the start and evolving in parallel. A more likely explanation then for the observed variation would be that articulation at different places is differentially challenged by sensory-motor factors in articulatory control (e.g. velocity, timing, range, force (Brabenec et al, 2017; McAuliffe et al, 2006; Walsh & Smith, 2012; Wong et al, 2010). This is what leads to an apparent divergence by place of articulation, not that the underlying pathology affects one position before another.

This is in keeping with the notion that the underlying speech deficit in PD relates to down- or underscaling of articulatory (speech) motor dynamics (Ho et al, 2008; Rusz et al, 2016; Walsh & Smith, 2012). This leads to hypokinesia, decreased amplitude and/or velocity of movements and consequent reduced pressure of articulatory contacts, with undershooting of targets, especially in connected speech – the long attested notion of spirantisation in PD speech. The picture in this study is also compatible with the claim that speech accuracy in PwP is affected by a sensory component, whereby PwP do not (fully) utilise sensory feedback to guide accuracy or monitor their own speech (Arnold et al, 2014; Clark et al, 2014; De Keyser et al, 2016; Mollaei et al, 2016). This would be expected to impact on all manners and places of articulation simultaneously, not selectively.

Examination of labial sounds suggested they may behave differently or are more affected than other positions, particularly in more advanced stages of PD. Explanations for imprecision based on the larger movement amplitude required, as for velar consonants, or greater demands of fine motor place distinctions as might be forwarded for alveolar-(palatal) positions would not seem to apply here. The outcome may relate to the hypomimia found in PwP, associated with rigidity of facial musculature (Bologna et al, 2013; Chu et al, 2017; Marneweck & Hammond, 2014).This was not systematically closely measured in this study so requires further investigation to confirm.

A further account of why labial sounds should be more susceptible to disruption, or seen from another angle, why anterior lingual sounds appear relatively accurate despite the claimed finer motor control demands of placement, concerns patterns seen in phonological development and in proneness of sound (contrasts) to disruption in healthy speakers. Several researchers have noted relative accuracy or earlier stability of coronal or anterior tongue production, as well as ‘fronting’ being a common process in phonological development (Beckman and Edwards, 2010; Melo, Mota and Berti, 2017; Kehoe, 2017). Such arguments have maintained that coronal position represents a more default articulatory locus. The typically developing speaker hence achieves greater stability earlier in development, and correspondingly less susceptibility to disruption than velar or labial positions from neighbouring sounds or other perturbation. Especially in English coronal sounds may carry more salience in terms of intelligibility and this may confer stronger cognitive representation and drive for maintenance of accuracy.

If one accepts the argument for alveolar position representing a default placement (Fowler and Saltzman 1993) one might predict that labial sounds, given they are organized on a separate gestural tier, behave differently to lingual sounds independently of any posterior-anterior order of fragility. By the same token, although there would be closer interaction between velar and alveolar gestures given their tight coupling, as the non-default setting velar sounds might evidence more vulnerability to any disruption to articulatory control. This could suggest that a future study might gainfully compare lingual place accuracy in PwP in relation to phonetic environment (alveolar vs velar upcoming or preceding vowels and consonants).

Another factor that may influence profiles relates to the scope and extent of compensatory mechanisms. Compensatory improvement may arise from spontaneous reorganization of neural networks and from conscious strategies employed by the speaker (e.g. rate-accuracy tradeoffs, stressed-unstressed syllable tradeoffs, increased attention to effort), especially those who are aware of their speech imprecision. This has been observed in other areas of motor control in PD, such as swallowing (Noble et al, 2015; Suntrup et al, 2013). The phenomenon has been linked to apparently sudden rapid decline when spontaneous neural reorganization reaches its limits, as well as paradoxical improvement for a period once individuals become aware of their impairment and employ compensatory techniques. Evidence points to the possible operation of similar processes in speech (Arnold et al, 2014; Clark et al, 2014). A period of early decline, followed by seeming improvement or lengthy stability has also been attributed to medication effects in longitudinal studies of limb motor progression in PD (Reinoso et al, 2015). Even though the current study was cross-sectional and not a longitudinal investigation, we cannot exclude the possibility that this factor contributes to the slightly less severe or non-rapid falls between Hoehn and Yahr stages 2 to 2.5 after initial decline between stages 1 and 2. Against this is the finding that medication may not significantly influence speech accuracy and intelligibility (Ho et al, 2008; Parveen & Goberman, 2014; Skodda et al, 2010). However, given that this study was not specifically designed to address this issue, the discussion here remains speculative.

As intimated in the introduction, the anatomical explanations of Logemann et al for their thesis were weak, both in terms of which pathways are involved in speech motor control and more specifically the pattern of spread of pathology in PD. Nevertheless, more recent hypotheses regarding progression of PD pathology from prodromal phases until late on could potentially predict a posterior-anterior progression of speech deterioration if one accepts that pathology commences in the brain stem, with gradual spread to mid brain and eventual effects on cortical pathways (Braak et al, 2004). However, this would predict simultaneous lingual and laryngeal impairment from XII cranial nerve and brain stem respiratory control centres, with facial impairment emerging only much later. This was not the pattern in Logemann's data nor the present study. The present study was not constructed, though, to address in a fine-grained manner the pattern of progression across and within respiratory, phonatory and articulatory subsystems in relation to possible Braak staging, thus the final answer to this question remains open.

There are various points which warrant attention regarding the comparability of the Logemann et al studies and this one, and factors in interpretation of the current data arising from the methodology. The current study was not a precise replication of Logemann et al, particularly in relation to ascertainment of raw scores. However, the fact that the raw score profiles were very similar across the studies suggests ascertainment method did not exercise a great impact on the basic data. The profile across places of articulation also concurs with findings of others for people with PD and healthy controls (Parveen & Goberman, 2014).

Logemann et al (1978) counted derailments simply by whether the two listeners thought the sound was unclear, regardless of whether this affected intelligibility or whether the perceived change was minimal or marked; their 1981 study was based on phonetic transcription, again without heed to functional changes or consequences. The current study derived raw totals from whether distortions were sufficient to cause intelligibility confusions for unfamiliar listeners in a minimal pair paradigm, arguably giving the measure of change a more ecologically valid perspective. The raw scores in the Logemann et al studies were further potentially biased by the listeners being highly familiar with the target words/ sounds and the aims of their project. A further examination of the overall question may benefit from utilising both a functional assessment, similar to the intelligibility assessment employed here, but complemented by instrumental evaluation of lingual and labial movement in a variety of tasks – e.g. controlled words lists and comparison of diadochokinetic performance across articulatory positions.

The chief comparison measure for PD severity in this investigation (and Logemann et al) was Hoehn and Yahr staging, as employed in countless studies (Goetz et al, 2004). A criticism of its use here is that it is based on coarse limb and postural motor evaluation. The relationship of this to speech changes is weak. This in turn may derive from the fact that in PD, control of appendicular movement appears to be different to axial control, with speech behaving more like the latter. Additionally speech is noted to be dependent on non-dopaminergic pathways, in contrast to limb control that is heavily dopamine pathway dependent (Miller et al, 2007; Rusz et al, 2016; Skodda et al, 2013). An attempt was made in the present study to circumvent some of these potential shortcomings by conducting some analyses in relation to the more sensitive UPDRS scales and to the speech intelligibility results. These showed that outcomes differed little from when employing only the Hoehn and Yahr stages. Nevertheless, a future study could gainfully employ more specific measures of motor evolution and a variety of instrumental and perceptual speech measures to gauge extent of speech changes.

One final point concerns a finding typical of many studies of PwP (Feenaughty et al, 2014). The current data are characterised by appreciable individual variability, as evidenced by the wide standard deviations, even when focusing on those performing in the lower quartiles. To overcome this drawback a future study may take a closer case based longitudinal perspective, with multiple points of assessment across time to capture variability and better discern longer term trends.

Conclusion

This study sought to re-examine the long propagated assumption that there is a posterior-anterior progression in articulatory breakdown in PD. The current data failed to uphold the assertion. Findings were more compatible with an underlying pathology that affects all places of articulation equally from the start, with any apparent differences attributable to differing place demands on motor performance and/or variables in perceived accuracy, and/or simply reflect performance found in unaffected speakers. Further studies may benefit from additional data based on instrumental assessments of speech and speech-like stimuli to complement perceptual analyses. Clinically the findings are compatible with an approach to rehabilitation that emphasises attention to effort, online monitoring of scaling and production of speech movements. Outcomes do not support an approach to remediation that focuses on isolated strategies for individual places of articulation.

Declaration of interest

The authors have no conflicts of interest to declare.

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	Mean	SD	Range
Age (years)	71.7	8.46	45-91
Time since diagnosis (years)	6.97	6.2	1-37
UPDRS III (max 108, higher more severe)	35.5	15.3	8-73
Intelligibility score (max 60 higher less severe)	49.1	6.8	14-59

Table 1: Summary demographic statistics for people with Parkinson's disease

Articulatory position	Total %	Hoehn & Yahr stage				
		1+1.5	2	2.5	3	4+5
	n 99	n12	n30	n17	n24	n16
All labial	88.37 (SD 9.63)	92.73 (SD 5.45)	89.47 (SD 10.38)	86.41 (SD 6.39)	90.06 (SD 7.83)	82.61 (SD 13.28)
All tongue tip	91.92 (SD 7.70)	94.61 (SD 4.05)	92.96 (SD 6.45)	92.14 (SD 5.67)	91.82 (SD 5.33)	87.88 (SD 13.85)
/p/ and /b/	88.93 (SD 10.73)	93.59 (SD 7.46)	90.55 (SD 8.65)	88.81 (SD 9.05)	89.49 (SD 10.03)	81.75 (SD 15.70)
/t/ and /d/	91.47 (SD 9.82)	94.37 (SD 5.95)	92.64 (SD 10.29)	94.49 (SD 4.48)	90.59 (SD 6.91)	85.21 (SD 15.54)
/k/ and /g/	89.53 (SD 11.96)	92.07 (SD 4.81)	87.16 (SD 14.33)	89.29 (SD 11.47)	92.44 (SD 10.16)	87.96 (SD 13.75)

Table 2. Mean and standard deviations for percentage of correctly perceived sounds across Hoehn and Yahr stages.

Articulatory position	Total %	Hoehn & Yahr stage				
		1+1.5	2	2.5	3	4+5
/p/ and /b/ n50	n50 80.87 (SD9.37)	n4 84.46 (SD4.72)	n17 84.69 (SD6.87)	n9 82.05 (SD7.10)	n12 81.95 (SD8.45)	n8 68.01 (SD9.55)
/t/ and /d/ n52	n52 85.69 (SD10.46)	n4 86.88 (SD2.86)	n12 84.45 (SD12.25)	n9 90.92 (SD2.45)	n14 86.31 (SD5.91)	n13 82.17 (SD15.73)
/k/ and /g/ n51	n51 81.56 (SD11.75)	n7 89.12 (SD3.13)	n10 77.62 (SD13.44)	n10 83.21 (SD11.25)	n8 80.87 (SD9.67)	n10 81.44 (SD13.60)

Table 3. Mean and standard deviations for percentage of correctly perceived sounds across Hoehn and Yahr stages for PwP scoring below median scores for labial, alveolar and velar plosives.