BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-014642
Article Type:	Research
Date Submitted by the Author:	08-Oct-2016
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Primary Subject Heading:	Rehabilitation medicine
Secondary Subject Heading:	Communication, Neurology
Keywords:	Parkinson-s disease < NEUROLOGY, REHABILITATION MEDICINE, GERIATRIC MEDICINE

Speech and communication in Parkinson's disease: a cross-sectional perspective from the United Kingdom

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ABSTRACT

Objective: To assess associations at various stages along the potential pathway to reduced functional communication in PD.

Design: Cross-sectional study, into which we embedded a within-participants experimental psychology design for listener assessment

Setting: A major academic medical centre in the East of England, United Kingdom.

Participants: Questionnaire data were assessed for 45 people with Parkinson's disease (PD) who had self-reported speech or communication difficulties and who did not have clinical dementia. Acoustic and listener analyses were conducted for 20 people with PD and 20 familiar conversation partner controls without speech, language or cognitive difficulties.

Main outcome measures: Functional communication as assessed by the Communicative Participation Item Bank (CPIB) and Communicative Effectiveness Survey (CES).

Results: People with PD had lower intelligibility than controls for both the read (81% vs 88% correct, $p<0.01$) and conversational (56% vs 72% correct, $p<0.05$) sentences. Intensity and pause were statistically significant predictors of intelligibility in read sentences. Listeners were less accurate identifying the intended emotion in the speech of people with PD (15% point difference across conditions, $p<0.05$) and this was associated with worse cognitive status (17% point difference, $p<0.05$). Cognitive status was a significant predictor of functional communication using CPIB ($F=8.99$, $p=0.005$, $\eta^2 = 0.15$) but not CES. Intelligibility in conversation sentences was a statistically significant predictor of CPIB ($F=4.96$, $p=0.04$, $\eta^2 = 0.19$) and CES ($F=13.65$, p=0.002, $\eta^2 = 0.43$). Read sentence intelligibility was not a significant predictor of either outcome.

Conclusions: Cognitive status was an important predictor of functional communication – the role of intelligibility was modest and limited to conversational and not read speech. Our results highlight the importance of focusing on functional communication as well as physical speech impairment in Speech and Language Therapy (SLT) for PD. Our results could inform future trials of SLT techniques for PD.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- We provide the first same-study overview of associations at various stages along the potential pathway to reduced functional communication in Parkinson's disease (PD).
- Ours is the first study to consider the acoustic characteristics of the speech of British people with PD.
- Our study was cross-sectional and therefore cannot provide definitive insight into causality.
- Studies in this field, including ours, tend to have smaller sample sizes than many other fields in applied health science research, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population.

INTRODUCTION

Parkinson's disease (PD) affects around 1.5% of people aged over 65 in Europe.[1] Originally conceptualised predominantly in terms of its motor features,[2] PD is now recognised to be a multifaceted condition.[3] Indeed, non-motor symptoms, including cognitive impairment in over a quarter of people with PD,[4] are believed to exert a substantial effect on quality of life.[5] Speech and functional communication difficulties are also widespread.[6-7] The mainstay of medical treatment for PD is levodopa-based pharmacotherapy,[8] although non-adherence,[9] dyskinesia[10] and a lack of clear benefit on speech and cognition are problematic.[11-13] Therefore, a wide range of supplementary therapies can be used, including singing,[14] dance[15] and speech-and-language therapy (SLT). SLT is popular among people with PD and families alike,[16] but there is no definitive randomised controlled trial evidence for the effectiveness of currently tested SLT techniques.[17] Moreover, the content and focus of SLT provision can vary markedly between localities. In the UK, the focus has traditionally been on motor function. In a survey conducted in 2007, functional communication did not form a major part of many UK SLT's clinical practice for PD,[18] although clinical contacts suggest that the situation has improved in recent years. Recently, M.S.B. and S.M.C.H. published a clinical magazine feature article[19] to emphasise the importance of functional communication to SLT clinicians.

In order to consider what the optimal focus of SLT might be, it is important to know i) which speech features are most important for intelligibility in PD, ii) to what extent cognitive status may play a role in speech and communication in

PD, iii) how closely related difficulties speech (International Classification of Functioning (ICF)[20] ability level) and functional communication (ICF activity and participation levels) are in PD and iv) also how wider aspects of communication such as emotional conveyance may be affected.

Functional communication has been shown to be more important to people with PD than motoric speech impairment[21] and also be an important predictor of quality of life.[22] Nevertheless, functional communication has received relatively limited research attention compared to speech impairment. A systematic review of the literature up to July 2015[23] found that, while nine prior studies, besides our unpublished study, had assessed the association between cognitive status and functional communication in PD of which eight had found a positive association. None of the studies had used a cognitive assessment sensitive to mild cognitive impairment in PD and a validated outcome measure that assessed either communicative effectiveness or communicative participation as a concept, rather than specific sub-aspects such as turn taking or social inference. In addition, while three prior studies had found an association between intelligibility and communicative outcomes, only one study[24-25] used a standardised validated assessment tool – the Communicative Effectiveness Survey (CES)[24-25] – but this tool covers the ICF activity level, not the ICF participation level. Subsequent to our review, one further large study[22] has assessed functional communication outcomes in PD and found that people with PD with self-reported worse cognitive status and intelligibility had more difficulties in communicative participation. The size of this study is a major strength, but the practicalities of such a large sample size probably explain why the study relied entirely on self-report data, which is a substantial limitation with regard to assessing cognitive status and intelligibility accurately.

Taking a wider perspective on communication difficulties in PD and potentially associated risk factors, it is important to note that no study in the published literature has provided an overview of the potential pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. There has been no comparative overview of which acoustic features are most predictive of reduced intelligibility. However, the available literature suggests that increased articulatory phonological distinctiveness[26-27] and loudness[28-29] may be associated with better intelligibility, with the latter having beneficial effects on the distinctiveness of speech in PD besides loudness itself.[29] Additionally, no study of speech acoustics has used speech that we considered to be naturalistic conversational dialogue – for example, the ‘conversational’ speech in the study by Goberman and Elmer[30] was a standard passage read out in the style of conversational speech. Moreover, the ability to communicate emotions effectively is important in everyday life[31] and studies have shown that reduced pitch variation and facial expression can cause negative evaluations of the personality of people with PD.[32-35] Additionally, people with PD have been shown to have impaired perception of the intended emotion in the speech of others,[36-38] which might in part relate to impaired mesolimbic processing.[39] In the only study to assess normal listeners’ ability to identify specific emotions in the speech of people with PD, a conference presentation by Miller *et* al[40] showed that listeners were less likely to correctly identify the intended emotion in the speech of people with PD when auditory and visual information were both available It was suggested that this effect may result from a lack of temporal synchronization in the speech of people with PD.

In light of the limitations in the existing literature, we conducted a study to provide an overview of associations along the potential pathway from motor (e.g. acoustic) speech impairment and cognitive impairment through reduced intelligibility to reduced emotional conveyance and functional communication difficulties at both the ICF activity (communicative effectiveness) and participation (communicative participation) levels.

MATERIALS AND METHODS

We used a cross-sectional design, into which we embedded a within-participants experimental psychology design for listener assessment. Since our methods are largely based on clinical psychology and clinical linguistics and are not epidemiology, there is no suitable reporting guideline to follow. Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Participants

Our study recruited from the Neurology and Medicine for the Elderly outpatient clinics at a major academic medical centre in the East of England region in 2012-2013. Patients were eligible for the study if they i) were aged at least 18, ii) had idiopathic PD according to the United Kingdom Parkinson's

Disease Society Brain Bank criteria,[41] iii) had no clinical indication of dementia, iv) had no other serious medical conditions that would affect cognitive status or speech, v) were not considered by clinical staff to be unsuitable for the study, for example due to personal circumstances, vi) were native English speakers and vii) reported having some difficulty with their speech and/or communication. Participants with PD were asked to invite a familiar conversation partner control (CP) to join them in the study where possible. CPs had to i) be aged at least 18, ii) be a native English speaker, iii) not have PD and iv) not have any serious medical problems affecting cognition or speech. Written informed consent was obtained from all participants prior to the commencement of study procedures.

Measures and data collection

The study consisted of one appointment typically of around 45 minutes after consent, which could take place either at home or at the University of East Anglia. Initially, participants completed a demographic form, which for people with PD provided their medication information which allowed their Levodopa Equivalent Daily Dose (LEDD)[42] to be calculated. Validated assessments of cognitive status (Montreal Cognitive Assessment, MoCA[43-44]), mood (Hospital Anxiety and Depression Scale, HADS[45-47]), communicative effectiveness (CES[24-25,48]) and communicative participation (Communicative Participation Item Bank, CPIB[49-50]) were completed. Since CPIB was our primary measure of functional communication, we assessed test-retest reliability by sending out a second copy of CPIB by post two weeks after the study visit and assessed convergent validity using CES. As per the terms of our ethical approval, cognitive, mood and functional communication assessments were only administered to participants with PD and not to CPs.

Audiovisual recordings were obtained of all participants' (PD and CP) speech at a standardised distance of 1.5m using Panasonic NV-GS17 (Panasonic, Corporation, Osaka, Japan) video cameras. Video was encoded in high quality 48 kHz AVI format, from which high quality 44.1 kHz WAV audio files could be extracted. Participants first read a standardised set of sixteen sentences taken from the Assessment of Intelligibility of Dysarthric Speech (AssIDS) assessment tool.[51] Then, participants held a short conversation on a topic of their choice in an exercise that was intended to offer as naturalistic speech as possible. Besides offering support to people with PD in completing questionnaires where required, this was the main advantage of including familiar CPs in the study – King and Gallegos-Santellan have shown that people with dysarthria use different strategies with familiar and unfamiliar conversation partners.[52] Finally, participants read four standardised sentences (the three sentences from Miller *et al*[40] plus one additional sentence) in three ways: happy, sad and neutral. All sentences contained words of moderate to high frequency and did not have an intrinsic emotional connotation.

Data analysis

Speech sample analysis (acoustics, intelligibility and emotional conveyance) was conducted on a purposive sample of 20 people with PD and 20 CPs. As we used standardised read sentences in the intelligibility assessment, we designed this part of the study so that each script sentence would only be rated twice by each assessor in order to avoid stimulus exposure effects and learning bias.[53-54] Assessment of self-report measures could be conducted on the full sample of 45 people with PD, but could not be conducted on CPs as we did not gather this data for ethical reasons.

Acoustic (phonetic) analysis was conducted by M.S.B. using Praat software (P. Boersma & D. Weenink, University of Amsterdam) and a 10% reliability check was completed by Senior Lecturer in Phonetics Z.R.B. Acoustic measures covered four broad domains[55-57] – initiation (the production of airflow), prosody (rhythm and melody), phonation (voicing) and articulation (the modification of sound waves by the resonant properties arising from different vocal tract configurations). A list of measures with a brief description of each is provided in Table 1. Sentence-level parameters were calculated for conversational and mood sentences. Phoneme-level parameters were additionally calculated for the set of 16 standardised read sentences.

Sixty-four assessors (88% female, median age 22) served as members of the study team to conduct assessment of speech samples for intelligibility and emotional conveyance. Assessors had to be i) members of the University of East Anglia (UEA, for ethical reasons), ii) fluent English speakers and iii) not having significant expertise in listening to disordered speech (for example SLT staff, final year SLT students and those with a close member with PD or working with groups or individuals with PD as part of their course or extra-curricular activities. Twenty tracks (each comprising a different combination of utterances and speakers) were created in EditStudio software (MediaChance, Ottawa, Canada) with stimulus allocation based on a Latin Square design[58] and randomised presentation order. All tracks were rated three times and four tracks were rated an additional time, meaning that each token spoken by each participant was rated by at least three different assessors. The intelligibility task was transcription and following AssIDS protocol, the outcome measure was % words correctly identified. This was scored separately for read and conversational sentences and the transcript for the latter was agreed between authors M.S.B. and S.M.C.H. The emotional conveyance task was to circle which of three options (happy, neutral or sad) the speaker intended to convey and the outcome measure was % moods correctly identified following Miller *et al*.[40] In the intelligibility task, all stimuli were presented audiovisually, while in the emotional conveyance tasks, half were presented audiovisually and half in audio only.

Statistical aspects of the study were overseen by Senior Lecturer in Medical Statistics A.B.C. The headline sample size of 45 for the questionnaire-based relationships was based on a power calculation for observational designs[59] to calculate the number of people with PD required to have 80% power to detect an expected association equivalent to r=0.5 for our primary relationship between cognitive status (MoCA) and functional communication (CPIB), allowing for issues such as non-completion and technical failure. Stata (Stata Corp, College Station, Texas) and SPSS (IBM Inc, Armonk, New York) software was used for statistical analysis. Appropriate linear regression models were constructed to assess i) differences in speech acoustics between people with PD and CPs and the contribution of cognitive status to speech acoustics of people with PD, ii) differences in intelligibility and the contribution of cognitive status and particular acoustic characteristics, iii) differences in the acoustic correlates of happy, neutral and sad mood and the contribution of cognitive status, iv) differences in emotional conveyance and the contribution of cognitive status and particular acoustic characteristics, v) the contribution of cognitive status and intelligibility to functional communication as measured by CES and CPIB. The test-retest reliability of CPIB was assessed using interclass correlation and its convergent validity with CES using correlation. Due to the exploratory nature of the study and the fact that analysis was on a range of outcome measures rather than repeated analysis of the same outcome measure, it was decided a priori not to perform adjustment for multiple testing.[60] A p-value of $p<0.05$ was considered significant and variables associated at $p<0.1$ were retained in models as marginally significant. There were limited missing data, only one participant had missing data for the CPIB outcome measure and none for CES. Full case analysis was used.

RESULTS

Participants

Forty-five people with PD contributed to the questionnaire analysis. The mean age was 71.0 (SD 8.1), 28 (62%) were male and the most common educational category was to have no formal educational qualifications (n=17, 38%). With regard to smoking status, 25 (56%) were never smokers, 19 (42%) were past smokers and 1 (2%) were current smokers.

Among the 20 people with PD used for speech sample analysis, the mean age was 71.1 (SD 9.0), 23 (65%) were male and the most common educational category was shared between no formal educational qualifications and vocational qualifications (both n=7, 35%). Eleven (55%) were never smokers, 8 (40%) were past smokers and 1 (5%) was a current smoker. Table 2 presents the clinical characteristics of both the full (n=45) and purposive (n=20) samples of people with PD.

Among the 20 CPs used for speech sample analysis, the mean age was 70.0 (SD 10.4), 7 (35%) were male and the most common educational category was to have vocational qualifications (n=8, 40%). Nine (45%) were never smokers, 7 (35%) were past smokers, 2 (10%) were current smokers and 2 (10%) declined to state their smoking status.

Speech acoustics and intelligibility

Table 3 profiles the principal speech and communication measures in our study. The overall concordance rate was r=0.99 for inter-rater reliability of acoustic measures. In read sentences, people with PD had lower speech intensity and greater pause time than CPs. For other measures, there was either no significant difference, a marginally significant difference or an effect that applied only for one gender. MoCA was associated with intensity, although the effect was in opposite directions for men and women – men with PD with better cognitive status spoke more loudly, while women with PD with better cognitive status spoke more quietly. MoCA was not associated with pause. In conversational sentences, people with PD had higher within-word iteration than CPs. This was not associated with MoCA. Statistical details on the main effects and interactions can be found in Supplementary tables 1 (read sentences) and 2 (conversational sentences).

Assessors were significantly less accurate in transcribing both the read (mean difference = 13.7 percentage points, $p<0.01$) and conversational (mean difference = 16.2 percentage points, $p<0.05$) speech of people with PD compared to CPs. In neither case was there an association between MoCA and intelligibility. In read sentences, intensity (mean difference = 2.4 percentage points per dB SPL, $p<0.05$) and pause (mean difference = 3.6 percentage points per percentage unit change in pause, $p<0.05$) were identified as significant predictors of listener accuracy – assessors were more accurate in transcribing the read speech of people with PD who spoke more loudly and paused less. No significant acoustic predictors of conversational sentence intelligibility were identified.

Emotional conveyance

In the emotion sentences, men with PD spoke more quietly than CPs, women with PD had significantly reduced mean fundamental frequency compared to CPs, both men and women with PD had significantly reduced SD of fundamental frequency, men with PD had significantly reduced speech rate (but not adjusted speech rate) and both men and women with PD had significantly increased pause time. In the PD group, participants with MoCA below median had significantly lower speech rate and adjusted speech rate. Main effects of mood were found within the PD group for most measures, meaning that people with PD were on the whole able to distinguish emotions in their speech, although distinctions were reduced relative to CPs. Significant and marginally significant group by emotion interactions, for happy vs sad, suggest that people with PD were particularly impaired in the production of happy emotion. Statistical details on the main effects and interactions can be found in Supplementary table 3.

Listeners were significantly less accurate in identifying the intended emotion (happy, neutral or sad) in the speech of people with PD compared to CPs (mean difference = 14.8 percentage points, $p<0.05$). A significant interaction between group and emotion (mean difference for group * emotion (sad vs happy) = 17.8 percentage points, $p<0.001$) shows that the impact of PD on listener accuracy was greater for happy mood. There was no significant effect of presentation modality (audiovisual vs audio only) on listener accuracy. There was a significant effect of MoCA (mean difference = 16.7 percentage points between participants scoring above and below the median, $p<0.01$), showing that listeners had more difficulty in identifying emotion in the speech of people with PD with greater cognitive impairment. A significant interaction between MoCA and emotion (mean difference for MoCA (median split) * emotion (sad vs happy) = 23.2 percentage points, =<0.01), showing that the differential effect of PD on happy mood conveyance was less for those with more intact cognition.

CPIB showed satisfactory test-retest reliability ($r=0.85$, $p<0.001$) and validity ($r=0.74$, $p<0.001$) in our population, noting that CPIB and CES are measures of related but not identical constructs, so a higher concordance would have been unexpected. In the full sample, MoCA ($F=8.99$, $p=0.005$, $\eta^2 = 0.15$) and

HADS (F=8.73, p=0.005, η^2 = 0.15) were retained as significant predictors of CPIB, while HADS (F=20.18, p<0.001, η^2 = 0.32) was the only significant predictor of CES, but a marginally significant finding for LEDD (F=3.72, p=0.06, η^2=0.06). With regard to MoCA sub-domains, the Executive and Visuospatial (F=3.22, p=0.08, η^2=0.05) and Attention (F=3.05, p=0.09, η^2=0.05) sub-domains were both marginally significant predictors of CPIB. Among the purposive sample for whom intelligibility scores were available, MoCA (F=5.32, p=0.04, η^2=0.20) and intelligibility in conversational sentences (F=4.96, p=0.04, η^2 = 0.19), but not intelligibility in read sentences, were significant predictors of CPIB, while only intelligibility in conversational sentences (F=13.65, p=0.002, η^2 = 0.43) was a significant predictor of CES.

DISCUSSION

The study presented in this article is the first to provide an overview of associations along the potential pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. We also include a combination of self-reported and observed measures, which avoids one of the key limitations associated with larger studies that only include self-report measures, such as that by McAuliffe *et al*.[22] It is also the first to study the acoustics of the speech of British people with PD, noting that there are notable acoustic differences between British and American English.[61-62]

The first main finding was that intelligibility was reduced in both read and conversational speech for people with PD compared to controls, and the effect was greater on conversational sentences, potentially reflecting the greater cognitive and perceptual challenges of spontaneous speech. The second main finding was that acoustic differences between people with PD and CPs in our sample were modest and few were statistically significant, although many participants in our study had relatively mild motoric speech difficulties. The results of our study reflect the natural hierarchy that can emerge in clinical practice, starting initially with work on physical aspects of read speech due to the cognitive demands of altering one's speech and then progressing to less structured tasks that generalize more readily to everyday conversation (R.A. Atkinson, personal communications).

The third main finding was that emotional conveyance, especially of happy emotion, was impaired in people with PD compared to CPs. The fourth main finding was that, despite a relatively mild profile of motoric speech deficits, participants often had difficulties with functional communication. Intelligibility did not account for a large proportion of variance in functional outcomes, emphasising the need to include functional communication tasks in SLT for people with PD to overcome the challenge with generalization from the clinic to everyday life. Cognitive status predicted CPIB and emotional conveyance, but not intelligibility or CES. This may imply a greater role for cognitive status with regard to participation-level phenomena.

Our identification of reduced intelligibility in people with PD compared to CPs is in line with previous studies and in particular our identification of intensity as a key predictor of intelligibility (although only found for read sentences in our study) corroborates the prior findings of Tjaden and Sussman[28] and Neel,[29] while our identification of pause suggests a potentially novel acoustic correlate of intelligibility in PD. Our study is the first to compare conversational and read speech intelligibility in PD and found that intelligibility was lower in conversational sentences, which is explicable in terms of contextual effects and the lower distinctiveness of more spontaneous speech and therefore the potential for a lower ability on the behalf of listeners to adjust for phonetic alterations.

With regard to emotional conveyance, in keeping with Miller *et al*,[40] our findings support the view that people with PD were less successful in conveying emotion in their speech. Our findings show that the communication of happy emotion was particularly affected. Unlike Miller *et al*,[40] potentially due to lesser severity of speech impairment, we did not find that listeners were more accurate in the audio only condition compared to the audiovisual condition. Our identification that intelligibility contributes a relatively modest proportion of the variance in functional communication is consistent with Donovan *et al*,[24-25] although we advance this knowledge by demonstrating differences between conversational and read sentence intelligibility as well as communicative effectiveness and communicative participation. Previous studies in our review[9] and also McAuliffe *et al*[22] have generally found an association between cognitive status and functional communication. The prior study by Miller *et al*,[6,63] which did not find such as association used as a measure of cognitive status the Mini Mental State Examination,[64] which has been shown to be insensitive to mild cognitive impairment in PD.[65-68]

Communication is fundamental to humanity and in particular the development and maintenance of human relationships.[69] Although participation may mean different things to different people,[70] it is evident that participation aspects, including those of functional communication,[21] are of great importance to people with PD. Indeed, it is important than research and clinical priorities and perspectives match those of people with the condition as closely as possible.[71] The relatively modest contribution of intelligibility to functional communication outcomes shown by our study and others indicates that it is important for SLT for people with PD to focus on non-motoric issues affecting functional communication in addition to more traditionally recognised motoric issues. In environments where there has been a move to include a higher proportion of functional communication in therapy, this should be maintained. In environments where this has not yet happened, it is recommended that greater focus on functional communication be considered. Further research is required to investigate the effectiveness of SLT for PD. The pathway proposed by our study could be useful to inform future research into defining treatments to include in intervention trials.

There are some limitations of this study that should be taken into account. The PhD time scale did not allow for a longitudinal study, so we cannot be definitive about causality. Secondly, it was not possible to use the entire sample size for speech sample analysis due to the constraints that read sentences impose upon the sample size in the intelligibility assessment so as to avoid learning biases. Thirdly, the sample we recruited had on average relatively mild motoric speech deficits, potentially due to greater reluctance to take part in speech studies among those with more severe speech impairment or alternatively due to an overrepresentation of people with early PD and greater insight into research. Fourthly, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population, sample sizes in this field, tend to be lower than in many other areas of applied health research.

In conclusion, we present the first study that provides an overview of the potential pathway from cognitive status and motoric speech impairment through reduced intelligibility to difficulties with emotional conveyance difficulties and functional communication in PD. Our results support the idea that SLT for people with PD should focus on functional communication as well as motor deficits, and could also inform future trials to identify the optimal form of therapy.

FOOTNOTES

Acknowledgements

This study constituted M.S.B.'s PhD work at the University of East Anglia (UEA). We thank Dr Carolyn Baylor, Prof Kathryn Yorkston and colleagues (University of Washington, USA) for prior information about the CPIB tool. We thank our participants and assessors, our recruiting clinicians at the Neurology and Medicine for the Elderly Clinics at the Norfolk and Norwich University Hospital as well as Mr Mike Stevens, formerly of UEA, who provided guidance and training in relation to audio-visual technology used in the study.

Contributors

M.S.B. was the Chief Investigator and K.H.O.D. the primary academic supervisor. S.M.C.H. and R.A.A. are registered SLTs and are specialists in adult neurological disorders. The study was conceptualised and overseen by M.S.B., S.M.C.H., Z.R.B. and K.H.O.D. Data were collected by M.S.B. Acoustic analysis was conducted by M.S.B. and Z.R.B. Listener assessment was conducted by our panel of assessors supervised by M.S.B with advice from S.M.C.H, Z.R.B. and K.H.O.D.. Statistical analysis was overseen by A.B.C. and conducted by M.S.B. and A.B.C. The first draft of the manuscript was written by M.S.B. Data were initially interpreted by M.S.B. and further interpretation provided by S.M.C.H., Z.R.B., A.B.C., R.A.A. and K.H.O.D. All authors contributed academically and/or clinically valuable revisions to the manuscript. All authors approved the submission.

Funding

We acknowledge funding from a UEA PhD studentship to M.S.B.

Competing interests

The authors declare no conflicts of interest with regard to this work

Ethics approval

Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Data sharing statement

No additional data are available

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Table 1. List of acoustic measures with a brief explanation of each

Domain	Measure	Explanation
Initiation	Intensity	Objective correlate of loudness, measured in db SPL
	Intensity decay	% decay in intensity from first to last sentence
Prosody	Mean fundamental frequency (F_0)	Objective correlate of pitch, measured in Hz
	Standard deviation of F_0	Objective correlate of pitch variation
	Speech rate	Speaking speed, measured in syllables per second
	Adjusted speech rate	As per speech rate, but excluding dysfluencies and pause
	Acceleration	% increase in speech rate from first to last sentence
	Adjusted acceleration	As per acceleration, but excluding dysfluencies and pause
	Pause	A measure of hesitation, calculated in ms and expressed as % of utterance time, using a threshold of 50ms as the minimum significant pause duration
	Within-word pause	% of pause that occurred within rather than between words
	Iteration	Number of instances of linguistic unit repetition
	Within-word iteration	% of instances of linguistic unit repetition that occurred within rather than between words
Phonation	Jitter	Relative percentage variation in glottal cycle duration (indicative of voicing frequency consistency)
	Shimmer	Relative percentage variation in glottal cycle amplitude (indicative of voicing amplitude consistency)
	Harmonic-to-noise ratio (HNR)	A measure of cycle-to-cycle variation in waveform shape (indicative of voicing strength)
Articulation	Formant Centralization Ratio (FCR)	A measure of vowel distinctiveness
	Standard deviation of /s/ amplitude	A measure of consonant articulation strength
	Voice Onset Time (VOT) ratio	A measure of the ability to differentiate for example 'bark'

		and 'park'

Table 2. Key clinical characteristics of people with PD in the full and purposive samples

Measure	Full sample	Purposive sample
Disease duration (years)	6.5 (8.3)*	9.0 (9.5)*
MoCA	22.9 (3.6)	22.2 (3.3)
HADS	11.0 (8.5)*	9.6 (4.8)
LEDD	640.5 (656.5)*	691.5 (1027.3)*

Figures are mean (SD), unless when marked with * in which case they are median (IQR). MoCA = Montreal Cognitive Assessment, HADS = Hospital Anxiety and Depression Scale and LEDD = Levodopa Equivalent Daily Dose

Table 3. Descriptive profile of principal speech and communication measures

	People with Parkinson's disease	**Conversation partner controls**
Read sentence intelligibility	81.1 (15.0)	87.9 (3.6)
Conversational sentence intelligibility	55.8 (26.5)	71.9 (13.0)
Emotional conveyance (happy audio)	36.5 (20.5)	55.6 (20.8)
Emotional conveyance (happy audiovisual, %)	54.1 (20.5)	61.4 (13.9)
Emotional conveyance (neutral audio, %)	55.4 (18.0)	46.7 (18.6)
Emotional conveyance (neutral audiovisual,%)	38.5 (25.3)	53.6 (20.8)
Emotional conveyance (sad audio, %)	55.8 (21.3)	64.8 (18.7)
Emotional conveyance (sad audiovisual,%)	55.8 (23.1)	63.0 (25.2)
Communicative Participation Item Bank (CPIB, T score)	53.0 (9.6)	NA
Communicative Participation Item Bank (CPIB, overall rating of degree to which PD affects communication, n(%))	Not at all: 11 (24%) A little: 24 (53%) Quite a bit: 9 (20%) Very much: 1 (2%)	NA

Figures are mean (SD) unless stated. Intelligibility is scored as % words correctly identified. Emotional conveyance is scored as % tokens for which emotion was correctly identified.

Supplementary table 1. Statistical details for acoustic analysis of read sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA *Gender
Intensity	59.54 (4.73)	62.27 (4.81)	61.98 (8.22)a	63.49 (1.81)	62.90 (2.75)	63.13 (2.39)	4.13*	2.8[illegible]	-2.89	6.87**	-10.1*
Intensity decay	5.42 (4.72)	5.05 (3.87)	5.52 (4.60)	3.83 (3.34)	3.17 (5.67)	3.43 (4.79)	-1.73	-0.[illegible]9	0.04	1.55	1.04
Mean F_0	137.30 (18.46)	185.80 (25.32)	155.96 (30.83)	116.00 (11.41)	190.10 (27.78)	161.28 (43.38)	-19.80?	42.[illegible]0***	30.70*	28.70*	1.04
SD of F_0	21.36 (8.18)	26.60 (6.09)	23.32 (7.70)	20.73 (6.52)	38.13 (9.26)	31.36 (11.90)	0.95	7.0[illegible]*	9.63?	6.92?	-14.5*
Speech rate	3.73 (0.43)	3.83 (0.80)	3.77 (0.57)	4.18 (0.43)	3.54 (0.33)	3.79 (0.48)	0.57*	0.2[illegible]	-0.92**	0.64?	-0.34
Acceleration	40.28 (31.49)	55.63 (35.22)a	42.31 (30.06)	51.76 (8.80)	43.94 (14.50)	46.98 (12.90)	9.97	1.1[illegible]	-9.02	-15.9	-1.85
Adjusted speech rate	3.90 (0.39)	4.03 (0.69)	3.95 (0.50)	4.27 (0.37)	3.63 (0.31)	3.88 (0.46)	0.38?	0.1[illegible]	-0.81**	0.48	-0.12
Adjusted acceleration	41.96 (15.37)	50.49 (23.91)	45.16 (18.72)	49.97 (14.63)	48.41 (14.41)	49.01 (14.08)	6.31	3.4[illegible]	-5.00	-2.19	-15.50
Pause	2.65 (3.86)a	1.62 (5.52)a	2.39 (3.84)a	0.61 (4.74)a	2.34 (1.69)	1.40 (3.78)a	-5.13*	-4.[illegible]9?	4.50	-5.23	6.85
Within-word pause	0.00 (4.51)a	0.00 (6.25)a	0.00 (4.74)a	0.00 (NA)a	0.00 (0.00)a	0.00 (0.00)a	-2.54?	-0.16	0.68	-2.45	6.26
Iteration	0.00 (0.22)a	0.45 (0.59)	0.03 (0.41)a	0.00 (0.00)a	0.00 (0.06)a	0.00 (0.06)a	-0.15	0.2[illegible]	-0.18	-0.22	0.50
Within-word iteration	0.00 (11.81)a	6.25 (9.94)a	0.63 (9.36)a	0.00 (NA)a	0.00 (5.20)a	0.00 (0.52)a	-4.94	3.7[illegible]	-2.00	-5.60	12.10
Jitter /i/	2.43 (0.58)	1.94 (0.74)a	2.19 (0.78)a	2.81 (0.65)	2.24 (0.44)	2.45 (0.58)	0.39	-0.[illegible]6	-0.42	-0.03	0.49
Jitter /ɑ/	2.07 (1.22)a	1.73 (0.82)	1.97 (1.50)a	1.90 (0.60)	1.54 (0.48)	1.67 (0.54)	-0.50	-0.[illegible]1?	0.36	-0.83	1.77

Jitter /u/	1.76 (0.75)	1.55 (0.68)	1.69 (0.71)	1.98 (0.41)	1.79 (0.83)	1.86 (0.70)	0.18	-0.17	0.09	-0.57	1.08
Shimmer /i/	15.12 (2.28)	13.43 (2.62)	14.53 (2.48)	16.87 (1.70)	14.18 (1.41)	15.17 (1.99)	1.71?	-1.59?	-1.11	-1.67	3.51
Shimmer /ɑ/	15.10 (2.41)	14.67 (2.89)	14.95 (2.52)	17.25 (3.13)	15.20 (2.70)	15.95 (2.96)	2.07	-0.56	-1.49	-0.91	3.73
Shimmer /u/	13.39 (2.75)	11.61 (2.99)	12.77 (2.89)	16.21 (2.90)	12.81 (3.06)	14.06 (3.37)	2.64?	-2.00	-1.40	-1.72	2.84
HNR /i/	8.95 (2.70)	11.55 (2.68)	9.86 (2.92)	7.29 (1.38)	10.43 (1.29)	9.27 (2.02)	-1.58	2.47*	0.67	3.77*	-4.65?
HNR /ɑ/	8.20 (2.66)	9.94 (2.07)	8.81 (2.56)	7.31 (1.49)	10.00 (2.26)	9.01 (2.37)	-0.82	1.69	0.99	4.10**	-6.12**
HNR/u/	11.36 (3.02)	14.25 (2.88)	12.46 (3.28)	9.67 (1.51)	13.24 (2.27)	11.89 (2.72)	-1.68	2.51*	1.02	3.74*	-3.29
FCR	1.37 (0.24)a	1.37 (0.11)	1.35 (0.18)a	1.35 (0.09)	1.29 (0.12)	1.31 (0.11)	-0.08	-0.07	0.01	-0.09	0.13
SD of /s/ amplitude	1.91 (1.37)a	2.43 (0.83)	2.28 (0.71)	1.87 (0.32)	2.25 (0.36)	2.11 (0.40)	-0.33	0.20	0.19	-0.51	0.78
VOT /pɒ/	0.24 (0.06)	0.27 (0.08)	0.26 (0.07)	0.27 (0.07)	0.27 (0.06)	0.28 (0.06)	0.02	0.00	0.00	0.03	0.01
VOT /tɛ/	0.37 (0.12)	0.40 (0.06)	0.38 (0.10)	0.40 (0.06)	0.35 (0.08)	0.37 (0.07)	0.03	0.01	-0.07	0.09	-0.11
VOT /pɑ/	0.18 (0.08)	0.24 (0.08)	0.20 (0.86)	0.19 (0.06)a	0.16 (0.04)	0.16 (0.04)a	0.02	0.00	0.00	-0.01	0.01
VOT /tu/	0.32 (0.07)	0.36 (0.05)	0.34 (0.07)	0.35 (0.09)	0.30 (0.05)	0.32 (0.07)	0.03	0.03	-0.09?	0.05	-0.08
VOT /kɒ/	0.34 (0.07)	0.34 (0.06)	0.34 (0.07)	0.35 (0.04)	0.32 (0.07)	0.34 (0.06)	0.00	0.56	-0.01	0.07	-0.05

Descriptives are shown as mean (SD), unless marked with 'a' in which case they refer to median (IQR). * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, symbols in // are phonemes transcribed using the International Phonetic Alphabet. HNR = Harmonic to Noise Ratio, FCR = Formant Centralization Ratio, VOT = Voice Onset Time

Supplementary table 2. Statistical details for acoustic analysis of conversational sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA * Gender
Intensity	57.56 (5.12)	60.92 (5.89)	58.79 (5.51)	61.10 (4.70)	60.28 (4.51)	60.60 (4.47)	3.69	3.56	-4.92	4.73	-9.44?
Intensity decay	1.10 (5.15)	-0.95 (4.56)	0.35 (4.92)	1.32 (3.74)	-0.71 (8.20)	0.08 (6.75)	0.31	-1.57	-0.46	4.58	-3.97
Mean F_0	130.47 (16.11)	179.63 (23.50)	145.58 (30.60)	118.44 (21.60)	189.33 (37.94)	161.76 (47.70)	0.39	45.30***	24.00	19.90	-27.50
SD of F_0	23.06 (8.75)	27.45 (9.48)	24.68 (9.03)	18.01 (9.78)	33.59 (12.22)[a]	30.51 (15.58)	-2.95	7.94?	11.00	-0.46	-12.50
Speech rate	4.70 (0.64)	4.71 (0.74)	4.70 (0.66)	5.20 (0.52)	4.34 (0.71)	4.67 (0.76)	0.37	-0.19	-0.49	0.25	0.17
Acceleration	25.22 (39.70)	-4.05 (26.71)	14.44 (37.57)	6.88 (30.38)	11.43 (26.25)	9.66 (27.13)	-20.60	-31.00*	35.60	-13.70	6.17
Adjusted speech rate	4.93 (5.09)	4.96 (0.60)	4.94 (0.57)	5.54 (0.41)	4.62 (0.82)	4.98 (0.82)	0.51	-0.14	-0.65	0.32	0.10
Adjusted acceleration	13.07 (21.93)	-4.42 (20.03)	6.62 (22.42)	2.15 (26.81)	10.57 (22.39)	7.29 (23.80)	-12.60	-19.20?	27.60?	1.15	-5.16
Pause	6.05 (10.59)[a]	4.87 (5.40)	4.02 (9.84)[a]	6.50 (4.54)	4.44 (4.17)	4.77 (4.33)	1.01	-0.54	-2.13	-2.74	0.15
Within-word pause	0.00 (NA)[a]	0.00 (0.00)[a]	0.00 (0.00)[a]	0.00 (NA)[a]	0.00 (NA)[a]	0.00 (0.00)	0.00	0.90?	-0.90	0.00	1.44
Iteration	0.00 (0.10)[a]	0.40 (1.00)[a]	0.00 (0.35)[a]	0.34 (0.38)	0.00 (0.40)[a]	0.10 (0.40)[a]	0.31	0.72	-0.87**	0.01	0.66
Within-word iteration	0.00 (0.00)[a]	0.00 (19.00)[a]	0.00 (0.00)[a]	0.00 (10.00)[a]	0.00 (0.00)[a]	0.00 (0.00)	5.71*	7.38**	-12.30***	0.00	6.47

Descriptives are shown as mean (SD), unless marked with 'a' in which case they refer to median (IQR). * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, ? = $0.05 < p < 0.1$.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment.

Supplementary table 3. Statistical details of acoustic analysis for emotional conveyance sentences

Part A. Descriptives

	PD			CP		
	Male	Female	All	Male	Female	All
Intensity H	61.71 (5.21)	65.22 (3.61)	63.12 (4.86)	66.55 (2.43)	64.49 (3.57)	65.21 (3.30)
Mean F_0 H	168.98 (35.75)	204.39 (28.97)	183.15 (36.96)	155.97 (12.36)	240.15 (28.59)	210.69 (47.56)
SD of F_0 H	35.63 (14.04)	43.97 (12.16)	38.96 (13.64)	35.70 (11.54)a	63.40 (15.94)	55.16 (18.57)
Speech rate H	4.33 (0.63)	4.18 (0.51)	4.27 (0.57)	4.90 (0.49)	3.90 (0.38)	4.25 (0.63)
Adjusted speech rate H	4.46 (0.57)	4.19 (0.51)	4.35 (0.55)	4.91 (0.49)	3.91 (0.38)	4.26 (0.64)
Pause H	0.00 (4.53)a	0.00 (0.00)a	0.00 (3.00)a	0.00 (0.00)a	0.00 (0.00)a	0.00 (0.00)a
Intensity N	58.83 (5.33)	60.96 (4.45)	59.68 (4.99)	61.77 (3.46)	60.09 (4.28)	60.68 (4.00)
Mean F_0 N	132.84 (19.30)	172.90 (30.85)	148.86 (31.17)	117.66 (13.49)	186.46 (18.23)	162.38 (37.43)
SD of F_0 N	18.50 (5.59)a	29.67 (13.02)	20.82 (9.83)a	27.19 (4.31)	34.60 (9.35)	32.01 (8.62)
Speech rate N	4.45 (0.73)	4.60 (0.65)	4.51 (4.46)	4.77 (0.55)	4.21 (0.28)	4.41 (0.47)
Adjusted speech rate N	4.53 (0.67)	4.62 (0.63)	4.57 (0.64)	4.82 (0.54)	4.22 (0.27)	4.38 (0.47)a
Pause N	0.00 (1.62)a	0.00 (0.00)a	0.00 (0.82)a	0.00 (1.14)a	0.00 (0.00)a	0.00 (0.00)a
Intensity S	57.81 (6.19)	62.15 (3.69)	59.55 (5.65)	62.78 (2.50)	59.88 (4.88)	60.89 (4.36)
Mean F_0 S	133.00 (27.26)	172.45 (33.36)	148.78 (35.12)	116.04 (15.11)	186.91 (25.09)	162.10 (40.90)
SD of F_0 S	17.83 (8.95)a	31.64 (9.71)	25.29 (12.06)	23.86 (5.39)	34.60 (11.02)	30.85 (10.65)

Speech rate S	4.00 (0.74)	3.79 (0.56)	3.92 (0.66)	4.03 (0.64)	3.40 (0.44)	3.62 (0.59)
Adjusted speech rate S	4.02 (0.73)	3.80 (0.56)	3.93 (0.66)	4.03 (0.64)	3.41 (0.44)	3.63 (0.59)
Pause S	0.00 (NA)	0.00 (0.53)a	0.00 (0.00)a	0.00 (NA)	0.00 (0.56)a	0.00 (0.00)a

Descriptives are shown as mean (SD), unless marked with ‘a’ in which case they refer to median (IQR). H = happy mood, N = neutral mood, S = sad mood.

PD = people with Parkinson’s disease, CP = conversation partner controls, F_0 = fundamental frequency.

Part B. Mean differences associated with predictors

	Group	Gender	Group * Gender	MoCA	Mood (N-H)	Mood (S-H)	Gender * Mood (N-H)	Gender * Mood (S-H)	MoCA * Mood (N-H)	MoCA * Mood (S-H)	Group * Mood (N-H)	Group * Mood (S-H)
Intensity	4.83*	-3.49?	5.54*	1.86	-3.23***	-3.58***	-0.52	0.02	-1.59	-1.25	-0.97	-0.76
Mean F_0	-6.43	41.47***	36.32**	17.27	-32.24***	-32.60***	-5.10	-4.41	-12.09	-19.34	-12.75	-13.12
SD of F_0	9.91*	13.58***	4.44	4.06	-12.03***	-11.65***	-7.29	-5.08	-7.28	-7.22	-6.37	-9.36*
Speech rate	0.47?	-0.24	-0.66*	0.65*	0.09	-0.42***	0.37*	0.15	0.01	-0.21	-0.17	-0.32*
Adjusted speech rate	0.38	-0.32	-0.61*	0.56*	0.07	-0.51***	0.37*	0.21	0.03	-0.11	-0.13	-0.26
Pause	-2.03*	-1.85*	0.99	-2.07	-1.27*	-2.56***	0.64	1.78*	0.92	1.76	1.14	1.49?

F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, H = happy mood, N = neutral mood, S = sad mood. * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

BMJ Open

Speech and communication in Parkinson's disease: a cross-sectional perspective from the United Kingdom

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-014642.R1
Article Type:	Research
Date Submitted by the Author:	13-Dec-2016
Complete List of Authors:	Barnish, Maxwell; University of East Anglia, School of Health Sciences, Faculty of Medicine and Health Sciences Horton, Simon; UEA, Health Sciences Butterfint, Zoe; University of East Anglia, School of Health Sciences, Facilty of Medicine and Health Sciences Clark, Allan Atkinson, Rachel ; St Helier Hospital, London, UK, Adult Speech and Language Therapy Department Deane, Katherine; University of East Anglia, School of Health Sciences
Primary Subject Heading:	Rehabilitation medicine
Secondary Subject Heading:	Communication, Neurology
Keywords:	Parkinson-s disease < NEUROLOGY, REHABILITATION MEDICINE, GERIATRIC MEDICINE

Speech and communication in Parkinson's disease: a cross-sectional perspective from the United Kingdom

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ABSTRACT

Objective: To assess associations between cognitive status, intelligibility, acoustics and functional communication in PD.

Design: Cross-sectional study of functional communication, including a within-participants experimental design for listener assessment

Setting: A major academic medical centre in the East of England, United Kingdom.

Participants: Questionnaire data were assessed for 45 people with Parkinson's disease (PD) who had self-reported speech or communication difficulties and did not have clinical dementia. Acoustic and listener analyses were conducted on read and conversational speech for 20 people with PD and 20 familiar conversation partner (CP) controls without speech, language or cognitive difficulties.

Main outcome measures: Functional communication assessed by the Communicative Participation Item Bank (CPIB) and Communicative Effectiveness Survey (CES).

Results: People with PD had lower intelligibility than controls for both the read (81% vs 88% correct, p<0.01) and conversational (56% vs 72% correct, p<0.05) sentences. Intensity and pause were statistically significant predictors of intelligibility in read sentences. Listeners were less accurate identifying the intended emotion in the speech of people with PD (15% point difference across conditions, p<0.05) and this was associated with worse speaker cognitive status (17% point difference, p<0.05). Cognitive status was a significant predictor of functional communication using CPIB ($F=8.99$, $p=0.005$, $\eta^2 = 0.15$) but not CES. Intelligibility in conversation sentences was a statistically significant predictor of CPIB (F=4.96, p=0.04, $\eta^2 = 0.19$) and CES (F=13.65, p=0.002, $\eta^2 = 0.43$). Read sentence intelligibility was not a significant predictor of either outcome.

Conclusions: Cognitive status was an important predictor of functional communication – the role of intelligibility was modest and limited to conversational and not read speech. Our results highlight the importance of focusing on functional communication as well as physical speech impairment in Speech and Language Therapy (SLT) for PD. Our results could inform future trials of SLT techniques for PD.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- We provide the first same-study overview of associations at various stages along the potential pathway to reduced functional communication in Parkinson's disease (PD).
- Ours is the first study to consider the acoustic characteristics of the speech of British people with PD.
- Our study was cross-sectional and therefore cannot provide definitive insight into causality.
- Studies in this field, including ours, tend to have smaller sample sizes than many other fields in applied health science research, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population.

INTRODUCTION

Parkinson's disease (PD) affects around 1.5% of people aged over 65 in Europe.[1] Originally conceptualised predominantly in terms of its motor features,[2] PD is now recognised to be a multifaceted condition.[3] Indeed, non-motor symptoms, such as cognitive impairment affecting over a quarter of people with PD,[4] are believed to exert a substantial effect on quality of life.[5] Speech impairment,[6] at the impairment level of the International Classification of Functioning (ICF),[7] as well as functional communication difficulties,[8] at the ICF activity and participation levels, are also widespread in PD. The mainstay of medical treatment for PD is levodopa-based pharmacotherapy,[9] although non-adherence,[10] dyskinesia[11] and a lack of clear benefit on speech and cognition are problematic.[12-14] Therefore, a wide range of supplementary therapies can be used, including singing,[15] dance[16] and speech-and-language therapy (SLT). SLT is popular among people with PD and families alike,[17] but there is no definitive randomised controlled trial evidence for the effectiveness of currently tested SLT techniques.[18] Moreover, the content and focus of SLT provision can vary markedly between localities. In the UK, the focus has traditionally been on motor function. In a survey conducted in 2007, functional communication was not reported to constitute a major part of many UK SLT's clinical practice for PD,[19] although clinical contacts suggest that the situation has improved in recent years. Recently, M.S.B. and S.M.C.H. published a clinical magazine feature article[20] to emphasise the importance of functional communication to SLT clinicians.

Functional communication has been shown to be more important to people with PD than motoric speech impairment.[21] Moreover, although it is an important predictor of quality of life,[22] functional communication has received relatively limited research attention compared to motoric speech impairment. A systematic review of the literature up to July 2015[23] found that nine studies prior to ours had assessed the association between cognitive status and functional communication in PD, of which eight had found a positive association. However, none had used a cognitive assessment sensitive to mild cognitive impairment in PD and a validated outcome measure that assessed either communicative effectiveness or communicative participation as a unified concept. Therefore, these studies may have failed to detect mild cognitive impairment short of dementia and also to accurately capture the concept of functional communication, resulting in potential inaccurate measurement of both independent and dependent variables. In addition, while three prior studies had found an association between intelligibility and communicative outcomes, only one study[24-25] used a standardised validated assessment tool – the Communicative Effectiveness Survey (CES).[24-25] However, CES covers the ICF activity level, not the ICF participation level. Subsequent to our review, one further large study[22] has assessed functional communication outcomes in PD and found that people with PD with self-reported worse cognitive status and intelligibility had more difficulties in communicative participation. The size of this study is a major strength, but the study relied entirely on self-report data, which is a substantial limitation with regard to assessing cognitive status and intelligibility accurately.

Taking a wider perspective on communication difficulties in PD and potentially associated risk factors, it is important to note that no study in the published literature has provided an overview of the elements and potential mechanisms for change in the pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. There has been no comparative overview of which acoustic features are most predictive of reduced intelligibility. However, the available literature suggests that increased articulatory phonological distinctiveness[26-27] and loudness[28-29] may be associated with better intelligibility, with the latter having beneficial effects on the distinctiveness of speech in PD besides loudness itself.[29] Additionally, no study of speech acoustics has used speech that we considered to be naturalistic conversational dialogue – for example, the 'conversational' speech in the study by Goberman and Elmer[30] was a standard passage read out in the style of conversational speech. Moreover, the ability to communicate emotions effectively is important in everyday life[31] and studies have shown that reduced pitch variation and facial expression can cause negative evaluations of the personality of people with PD.[32-35] Additionally, people with PD have been shown to have impaired perception of the intended emotion in the speech of others,[36-38] which may relate at least partly to impaired mesolimbic processing.[39] However, normal listeners' ability to identify specific emotions in the speech of people with PD has attracted limited research attention. Miller *et* al[40] showed that listeners were less likely to correctly identify the intended emotion in the speech of people with PD when auditory and visual information were both available. It was suggested that this effect

may result from a lack of temporal synchronization in the speech of people with PD. Meanwhile, Pell *et al*[41] also found reduced ability to identify emotions in the speech of people with PD, especially for anger and disgust, but did not assess presentation modality.

Informed by limitations in the existing literature, we decided to conduct a study focusing on functional communication in PD as our primary outcome. This is an area that has received relatively little research attention, yet corresponds well to the priorities of people with PD.[21] We decided to conduct a study to provide an overview of associations along the potential pathway to functional communication difficulties in PD, since no prior study had done this. In addition, we added an aspect on emotional conveyance in order to further investigate the possibilities raised by Miller *et* al,[40] especially with regard to presentation modality effects. Our key research questions for this study are:

- How does cognitive status associate with functional communication in PD, as measured by the Communicative Participation Item Bank (CPIB, primary research question) and CES?
- What is the test-retest reliability and convergent validity of CPIB in our UK context?
- How does intelligibility, in both read and conversational sentences, associate with functional communication in PD?
- What were the acoustic differences between the speech of people with PD and CPs in our sample; how did the intelligibility of these groups

differ in read and conversational speech; and what acoustic factors predicted intelligibility outcomes?

- How did the emotional conveyance of people with PD and CPs differ, which mood contrasts were particularly affected, and did presentation modality (audio vs audiovisual) play a role?

MATERIALS AND METHODS

Design

In order to assess associations along the potential pathway to functional communication difficulties in PD, we used a cross-sectional design, into which we embedded a within-participants experimental psychology design for listener assessment. Since our methods are largely based on clinical psychology and clinical linguistics and are not epidemiology, there is no suitable reporting guideline to follow. Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Participants

Our study recruited from the Neurology and Medicine for the Elderly outpatient clinics at a major academic medical centre in the East of England region in 2012-2013. Patients were eligible for the study if they i) were aged at least 18, ii) had idiopathic PD according to the United Kingdom Parkinson's Disease Society Brain Bank criteria,[42] iii) had no clinical indication of dementia, iv) had no other serious medical conditions that would affect cognitive status or speech, v) were not considered by clinical staff to be unsuitable for the study, for example due to personal circumstances, vi) were native English speakers and vii) reported having some difficulty with their speech and/or communication. Participants with PD were asked to invite a familiar conversation partner control (CP) to join them in the study where possible. CPs had to i) be aged at least 18, ii) be a native English speaker, iii) not have PD and iv) not have any serious medical problems affecting cognition or speech. Written informed consent was obtained from all participants prior to the commencement of study procedures.

Measures and data collection

The study consisted of one appointment typically of around 45 minutes after consent, which could take place either at home or at the University of East Anglia. Initially, participants completed a demographic form, which for people with PD provided their medication information which allowed their Levodopa Equivalent Daily Dose (LEDD)[43] to be calculated. LEDD served as a proxy measure of non-speech-specific PD motor symptom severity. Validated assessments of cognitive status (Montreal Cognitive Assessment, MoCA[44-45]), mood (Hospital Anxiety and Depression Scale, HADS[46-48]), communicative effectiveness (CES[24-25,49]) and communicative participation (Communicative Participation Item Bank, CPIB[50-]) were completed. CPIB was chosen as our primary measure of functional communication since it specifically assesses ICF participation level difficulties that have been shown to be most important to people with PD,[21] and also has been thoroughly developed using item-response theory methods[50] and subsequent validated in PD in the United States and New Zealand, which are English-speaking countries.[51]Therefore, we assessed test-retest reliability by sending out a second copy of CPIB by post two weeks after the study visit and assessed convergent validity using CES in our UK setting. As per the terms of our ethical approval, cognitive, mood and functional communication assessments were only administered to participants with PD and not to CPs.

Audiovisual recordings were obtained of all participants' (PD and CP) speech at a standardised distance of 1.5m using Panasonic NV-GS17 (Panasonic, Corporation, Osaka, Japan) video cameras. Video was encoded in high quality 48 kHz AVI format, from which high quality 44.1 kHz WAV audio files could be extracted. Participants first read a standardised set of sixteen sentences taken from the Assessment of Intelligibility of Dysarthric Speech (AssIDS) assessment tool.[52] Then, participants held a short conversation on a topic of their choice in an exercise that was intended to offer as naturalistic speech as possible. Besides offering support to people with PD in completing questionnaires where required, this was the main advantage of including familiar CPs in the study – King and Gallegos-Santellan have shown that people with dysarthria use different strategies with familiar and unfamiliar conversation partners.[53] Finally, participants read four standardised sentences in three ways: happy, sad and neutral. All sentences contained words of moderate to high frequency and did not have an intrinsic emotional connotation. Three of the sentences were taken with permission from Miller *et al*[40], namely "The cake is too yellow", "You dropped the sausages in the trifle" and "Sam is not a dog". One further sentence was generated by the research team: "He went to the park".

Data analysis

Speech sample analysis (acoustics, intelligibility and emotional conveyance) was conducted on a purposive sample of 20 people with PD and 20 CPs. In order to generate our purposive sample, firstly, any samples that suffered from technical failure, other issues such as road noise and non-compliance with the task instructions were included. Then, selection sought to achieve a balanced profile of demographic and clinical features among people with PD and maximise comparability of demographics between the PD and CP groups, within the bounds of what was available in our sample. As we used standardised read sentences in the intelligibility assessment, we designed this part of the study so that each script sentence would only be rated twice by each assessor in order to avoid stimulus exposure effects and learning bias.[54-55] Assessment of self-report measures could be conducted on the full sample of 45 people with PD, but could not be conducted on CPs as we did not gather these data for ethical reasons.

Acoustic (phonetic) analysis was conducted by M.S.B. using Praat software (P. Boersma & D. Weenink, University of Amsterdam) and a reliability check of a randomly selected 10% sample of acoustic data points was completed by Senior Lecturer in Phonetics Z.R.B. Acoustic measures covered four broad domains[56-58] – initiation (the production of airflow), prosody (rhythm and melody), phonation (voicing) and articulation (the modification of sound waves by the resonant properties arising from different vocal tract configurations). A list of measures with a brief description of each is provided in Table 1. Sentence-level parameters were calculated for conversational and mood sentences. Phoneme-level parameters were additionally calculated for the set of 16 standardised read sentences.

Sixty-four assessors (88% female, median age 22) served as members of the study team to conduct assessment of speech samples for intelligibility and emotional conveyance. Assessors had to be i) members of the University of East Anglia (UEA, for ethical reasons), ii) fluent English speakers and iii) not having significant expertise in listening to disordered speech (for example SLT staff, final year SLT students and those with a close member with PD or working with groups or individuals with PD as part of their course or extra-curricular activities. Twenty tracks (each comprising a different combination of utterances and speakers) were created in EditStudio software (MediaChance, Ottawa, Canada) with stimulus allocation based on a Latin Square design[59] and randomised presentation order. All tracks were rated three times and four tracks were rated an additional time, meaning that each token spoken by each participant was rated by at least three different assessors. The intelligibility task was transcription and following AssIDS protocol, the outcome measure was % words correctly identified. This was scored separately for read and conversational sentences and the transcript for the latter was agreed between authors M.S.B. and S.M.C.H. The emotional conveyance task was to circle which of three options (happy, neutral or sad) the speaker intended to convey and the outcome measure was % moods correctly identified following Miller *et al*.[40] In the intelligibility task, all stimuli were presented audiovisually, while in the emotional conveyance tasks, half were presented audiovisually and half in audio only. In all listener assessment tasks, assessors could only listen to each sentence once and sentences from people with PD and CPs were matched for length. The rationale for including an audio-only condition in the emotional conveyance assessment was to test the preliminary finding by

Miller *et al*[40] that listeners were less likely to correctly identify the intended emotion in the speech of people with PD when auditory and visual information were both available. In contrast, for intelligibility assessment, we wanted to replicate the most common real-life listening conditions through presenting audiovisual information.

Statistical aspects of the study were overseen by Senior Lecturer in Medical Statistics A.B.C. The headline sample size of 45 for the questionnaire-based relationships was based on a power calculation for observational designs[60] to calculate the number of people with PD required to have 80% power to detect an expected association equivalent to r=0.5 for our primary relationship between cognitive status (MoCA) and functional communication (CPIB), allowing for issues such as non-completion and technical failure. The effect size to use for the power calculation was determined by senior statistician A.B.C. informed by i) preliminary systematic literature searches by the research team that later became our systematic review[23] and ii) the research team's combined wider theoretical, scientific and clinical knowledge and expertise about communication in neurological conditions such as PD, which both informed us to expect a moderate relationship between cognitive status and functional communication in PD. Stata (Stata Corp, College Station, Texas) and SPSS (IBM Inc, Armonk, New York) software was used for statistical analysis. Appropriate linear regression models were constructed to assess i) differences in speech acoustics between people with PD and CPs and the contribution of cognitive status to speech acoustics of people with PD, ii) differences in intelligibility and the contribution of cognitive status and particular acoustic characteristics, iii) differences in the acoustic correlates of happy, neutral and sad mood and the contribution of cognitive status, iv) differences in emotional conveyance and the contribution of cognitive status and particular acoustic characteristics, v) the contribution of cognitive status and intelligibility to functional communication as measured by CES and CPIB. The test-retest reliability of CPIB was assessed using interclass correlation and its convergent validity with CES using correlation. Due to the exploratory nature of the study and the fact that analysis was on a range of outcome measures rather than repeated analysis of the same outcome measure, it was decided a priori not to perform adjustment for multiple testing.[61] A p-value of $p<0.05$ was considered significant and variables associated at $p<0.1$ were retained in models as marginally significant. There were limited missing data, only one participant had missing data for the CPIB outcome measure and none for CES. Full case analysis was used.

RESULTS

Participants

Forty five people with PD and 29 CPs were recruited. Forty-five people with PD contributed to the questionnaire analysis. The mean age was 71.0 (SD 8.1), 28 (62%) were male and the most common educational category was to have no formal educational qualifications (n=17, 38%).

Among the 20 people with PD whose data were used for speech sample analysis, the mean age was 71.1 (SD 9.0), 23 (65%) were male and the most common educational category was shared between no formal educational qualifications and vocational qualifications (both n=7, 35%). Table 2 presents the clinical characteristics of both the full (n=45) and purposive (n=20) samples of people with PD.

Among the 20 CPs whose data were used for speech sample analysis, the mean age was 70.0 (SD 10.4), 7 (35%) were male and the most common educational category was to have vocational qualifications (n=8, 40%).

Speech acoustics and intelligibility

Table 3 profiles the principal speech and communication measures in our study. The overall concordance rate was r=0.99 for inter-rater reliability of acoustic measures. In read sentences, people with PD had lower speech intensity and greater pause time than CPs. For other measures, there was either no significant difference, a marginally significant difference or an effect that applied only for one gender. MoCA was associated with intensity, although the effect was in opposite directions for men and women – men with PD with better cognitive status spoke more loudly, while women with PD with better cognitive status spoke more quietly. MoCA was not associated with pause. In conversational sentences, people with PD had higher within-word iteration than CPs. This was not associated with MoCA. Statistical details on the main effects and interactions can be found in Supplementary tables 1 (read sentences) and 2 (conversational sentences).

Assessors were significantly less accurate in transcribing both the read (mean difference = 13.7 percentage points, $p<0.01$) and conversational (mean difference = 16.2 percentage points, $p<0.05$) speech of people with PD compared to CPs. In neither case was there an association between MoCA and intelligibility. In read sentences, intensity (mean difference = 2.4 percentage points per dB SPL, $p<0.05$) and pause (mean difference = 3.6 percentage points per percentage unit change in pause, $p<0.05$) were identified as significant predictors of listener accuracy – assessors were more accurate in transcribing the read speech of people with PD who spoke more loudly and paused less. No significant acoustic predictors of conversational sentence intelligibility were identified. Gender was not a statistically significant predictor of intelligibility.

Emotional conveyance

In the emotion sentences, men with PD spoke more quietly than CPs, women with PD had significantly reduced mean fundamental frequency compared to CPs, both men and women with PD had significantly reduced SD of fundamental frequency, men with PD had significantly reduced speech rate (but not adjusted speech rate) and both men and women with PD had significantly increased pause time. In the PD group, participants with MoCA below median had significantly lower speech rate and adjusted speech rate. Main effects of mood were found within the PD group for most measures, meaning that people with PD were on the whole able to distinguish emotions in their speech, although distinctions were reduced relative to CPs. Significant and marginally significant group by emotion interactions, for happy vs sad, suggest that people with PD were particularly impaired in the production of happy emotion. Statistical details on the main effects and interactions can be found in Supplementary table 3.

Listeners were significantly less accurate in identifying the intended emotion (happy, neutral or sad) in the speech of people with PD compared to CPs (mean difference = 14.8 percentage points, $p<0.05$). A significant interaction between group and emotion (mean difference for group * emotion (sad vs happy) = 17.8 percentage points, $p<0.001$) shows that the impact of PD on listener accuracy was greater for happy mood. There was no significant effect of presentation modality (audiovisual vs audio only) on listener accuracy. There was a significant effect of MoCA (mean difference = 16.7 percentage points between participants scoring above and below the median, $p<0.01$), showing that listeners had more difficulty in identifying emotion in the speech of people with PD with greater cognitive impairment. A significant interaction between MoCA and emotion (mean difference for MoCA (median split) * emotion (sad vs happy) = 23.2 percentage points, p=<0.01), showing that the differential effect of PD on happy mood conveyance was less for those with more intact cognition.

CPIB showed satisfactory test-retest reliability ($r=0.85$, $p<0.001$) and validity ($r=0.74$, $p<0.001$) in our population, noting that CPIB and CES are measures of related but not identical constructs, so a higher concordance would have been unexpected. In the full sample, MoCA ($F=8.99$, $p=0.005$, $\eta^2 = 0.15$) and HADS ($F=8.73$, $p=0.005$, $\eta^2 = 0.15$) were retained as significant predictors of CPIB, while HADS ($F=20.18$, $p<0.001$, $\eta^2 = 0.32$) was the only significant predictor of CES, but a marginally significant finding for LEDD ($F=3.72$, $p=0.06$, $\eta^2=0.06$). With regard to MoCA sub-domains, the Executive and Visuospatial ($F=3.22$, $p=0.08$, $\eta^2=0.05$) and Attention ($F=3.05$, $p=0.09$,

η^2=0.05) sub-domains were both marginally significant predictors of CPIB. Among the purposive sample for whom intelligibility scores were available, MoCA (F=5.32, p=0.04, η^2=0.20) and intelligibility in conversational sentences (F=4.96, p=0.04, η^2 = 0.19), but not intelligibility in read sentences, were significant predictors of CPIB, while only intelligibility in conversational sentences (F=13.65, p=0.002, η^2 = 0.43) was a significant predictor of CES.

DISCUSSION

The study presented in this article is the first to provide an overview of associations along the potential pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. We also include a combination of self-reported and observed measures, an approach which avoids one of the key limitations associated with larger studies, such as that by McAuliffe *et al*[22] that only include self-report measures. Ours is also the first to study the acoustics of the speech of British people with PD, mindful that there are notable acoustic differences between British and American English.[62-63]

The first main finding was that intelligibility was reduced in both read and conversational speech for people with PD compared to controls, and the effect was greater on conversational sentences, potentially reflecting the greater cognitive and perceptual challenges of spontaneous speech. The second main finding was that acoustic differences between people with PD and CPs in our sample were modest and few were statistically significant, although many participants in our study had relatively mild motoric speech difficulties. The results of our study reflect the natural hierarchy that can emerge in clinical practice, starting initially with work on physical aspects of read speech due to the cognitive demands of altering one's speech and then progressing to less structured tasks that generalize more readily to everyday conversation (R.A. Atkinson, personal communications).

The third main finding was that emotional conveyance, especially of happy emotion, was impaired in people with PD compared to CPs. The fourth main finding was that, despite a relatively mild profile of motoric speech deficits, participants often had difficulties with functional communication. Intelligibility did not account for a large proportion of variance in functional outcomes, emphasising the need to account for and include other elements in functional communication tasks in SLT for people with PD to overcome the challenge with generalization from the clinic to everyday life. Cognitive status predicted CPIB and emotional conveyance, but not intelligibility or CES. This may imply a greater role for cognitive status with regard to participation-level phenomena.

Our identification of reduced intelligibility in people with PD compared to CPs is in line with previous studies and in particular our identification of intensity as a key predictor of intelligibility (although only found for read sentences in our study) corroborates the prior findings of Tjaden and Sussman[28] and Neel,[29] while our identification of pause suggests a potentially novel acoustic correlate of intelligibility in PD. Our study is the first to compare conversational and read speech intelligibility in PD and found that intelligibility was lower in conversational sentences, which is explicable in terms of contextual effects and the lower distinctiveness of more spontaneous speech and therefore the potential for a lower ability on the behalf of listeners to adjust for phonetic alterations.

With regard to emotional conveyance, in keeping with Miller *et al*[40] and Pell *et al*[41] our findings support the view that people with PD were less successful in conveying emotion in their speech. Our findings show that the communication of happy emotion was particularly affected, although our study cannot confirm the mechanisms which might be causing this effect. Unlike Miller *et al*,[40] potentially due to lesser severity of speech impairment, we did not find that listeners were more accurate in the audio only condition compared to the audiovisual condition. Our identification that intelligibility contributes a relatively modest proportion of the variance in functional communication is consistent with Donovan *et al*,[24-25] although we advance this knowledge by demonstrating differences between conversational and read sentence intelligibility as well as communicative effectiveness and communicative participation. Previous studies in our review[9] and also McAuliffe *et al*[22] have generally found an association between cognitive status and functional communication. The prior study by Miller *et al*,[6,64] which did not find such as association used as a measure of cognitive status the Mini Mental State Examination,[65] which has been shown to be insensitive to mild cognitive impairment in PD.[66-69]

Communication is fundamental to humanity and in particular the development and maintenance of human relationships.[70] Although participation may mean different things to different people,[71] it is evident that participation aspects, including those of functional communication,[21] are of great importance to people with PD. Indeed, it is important than research and clinical priorities and perspectives match those of people with the condition as closely as possible.[72] The relatively modest contribution of intelligibility to functional communication outcomes shown by our study and others indicates that it is important for SLT for people with PD to focus on non-motoric issues affecting functional communication in addition to more traditionally recognised motoric issues. In environments where there has been a move to include a higher proportion of functional communication in therapy, this should be maintained. In environments where this has not yet happened, it is recommended that greater focus on functional communication be considered. In achieving this, it is important to consider what the particular client's communication needs and goals are, what challenges the client faces in accomplishing these, and what approaches may facilitate this. It is important to remember that communication needs differ between clients, and that clients differ in what they consider full participation in life.[71] Further research is required to investigate the effectiveness of SLT for PD. The pathway proposed by our study could be useful to inform future research into defining treatments to include in intervention trials. In addition, it is important to conduct further research into the gender-specific aspects of communication difficulties in PD, which have received limited research attention.

There are some limitations of this study that should be taken into account. The PhD time scale did not allow us to undertake a longitudinal study, so we cannot be definitive about causality. Secondly, it was not possible to use the entire sample size for speech sample analysis due to the constraints that read sentences impose upon the sample size in the intelligibility assessment so as to avoid learning biases. Thirdly, the sample we recruited had on average relatively mild motoric speech deficits, potentially due to greater reluctance to take part in speech studies among those with more severe speech impairment or alternatively due to an overrepresentation of people with early PD and greater insight into research. Fourthly, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population, sample sizes in this field, tend to be lower than in many other areas of applied health research. Fifthly, we were unable to measure motor disability directly. However, we offered LEDD as a proxy measure of motor disability to models assessing functional outcomes in order to minimise confounding by motor disability. Moreover, some studies have shown that cognitive impairment can be common in people with PD who are early on the motor decline pathway.[73-74]

In conclusion, we present the first study that provides an overview of the potential pathway from cognitive status and motoric speech impairment through reduced intelligibility to difficulties with emotional conveyance difficulties and functional communication in PD. Our results support the idea that SLT for people with PD should focus on functional communication as well as motor deficits, and could also inform future trials to identify the optimal form of therapy. The pathway to functional communication difficulties in PD is likely to involve complex, multi-factorial mechanisms for change, including for example motoric, cognitive and psychosocial elements. Future confirmatory research should aim to clarify the elements and mechanisms of this pathway, as well as how they may differ between individuals with PD, which is a condition known to vary considerably in its clinical expression.[75]

FOOTNOTES

Acknowledgements

This study constituted M.S.B.'s PhD work at the University of East Anglia (UEA). We thank Dr Carolyn Baylor, Prof Kathryn Yorkston and colleagues (University of Washington, USA) for prior information about the CPIB tool. We thank our participants and assessors, our recruiting clinicians at the Neurology and Medicine for the Elderly Clinics at the Norfolk and Norwich University Hospital as well as Mr Mike Stevens, formerly of UEA, who provided guidance and training in relation to audio-visual technology used in the study.

Contributors

M.S.B. was the Chief Investigator and K.H.O.D. the primary academic supervisor. S.M.C.H. and R.A.A. are registered SLTs and are specialists in adult neurological disorders. The study was conceptualised and overseen by M.S.B., S.M.C.H., Z.R.B. and K.H.O.D. Data were collected by M.S.B. Acoustic analysis was conducted by M.S.B. and Z.R.B. Listener assessment was conducted by our panel of assessors supervised by M.S.B with advice from S.M.C.H, Z.R.B. and K.H.O.D.. Statistical analysis was overseen by A.B.C. and conducted by M.S.B. and A.B.C. The first draft of the manuscript was written by M.S.B. Data were initially interpreted by M.S.B. and further interpretation provided by S.M.C.H., Z.R.B., A.B.C., R.A.A. and K.H.O.D. All authors contributed academically and/or clinically valuable revisions to the manuscript. All authors approved the submission.

Funding

We acknowledge funding from a UEA PhD studentship to M.S.B.

Competing interests

The authors declare no conflicts of interest with regard to this work

Ethics approval

Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Data sharing statement

No additional data are available

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Table 1. List of acoustic measures with a brief explanation of each

Domain	Measure	Explanation
Initiation	Intensity	Objective correlate of loudness, measured in db SPL
	Intensity decay	% decay in intensity from first to last sentence
Prosody	Mean fundamental frequency (F_0)	Objective correlate of pitch, measured in Hz
	Standard deviation of F_0	Objective correlate of pitch variation
	Speech rate	Speaking speed, measured in syllables per second
	Adjusted speech rate	As per speech rate, but excluding dysfluencies and pause
	Acceleration	% increase in speech rate from first to last sentence
	Adjusted acceleration	As per acceleration, but excluding dysfluencies and pause
	Pause	A measure of hesitation, calculated in ms and expressed as % of utterance time, using a threshold of 50ms as the minimum significant pause duration
	Within-word pause	% of pause that occurred within rather than between words
	Iteration	Number of instances of linguistic unit repetition
	Within-word iteration	% of instances of linguistic unit repetition that occurred within rather than between words
Phonation	Jitter	Relative percentage variation in glottal cycle duration (indicative of voicing frequency consistency)
	Shimmer	Relative percentage variation in glottal cycle amplitude (indicative of voicing amplitude consistency)
	Harmonic-to-noise ratio (HNR)	A measure of cycle-to-cycle variation in waveform shape (indicative of voicing strength)
Articulation	Formant Centralization Ratio (FCR)	A measure of vowel distinctiveness
	Standard deviation of /s/ amplitude	A measure of consonant articulation strength
	Voice Onset Time (VOT) ratio	A measure of the ability to differentiate for example 'bark'

		and 'park'

Table 2. Key clinical characteristics of people with PD in the full and purposive samples

Measure	Full sample	Purposive sample
Disease duration (years)	6.5 (8.3)*	9.0 (9.5)*
MoCA	22.9 (3.6)	22.2 (3.3)
HADS	11.0 (8.5)*	9.6 (4.8)
LEDD	640.5 (656.5)*	691.5 (1027.3)*

Figures are mean (SD), unless when marked with * in which case they are median (IQR). MoCA = Montreal Cognitive Assessment, HADS = Hospital Anxiety and Depression Scale and LEDD = Levodopa Equivalent Daily Dose

Table 3. Descriptive profile of principal speech and communication measures

	People with Parkinson's disease	Conversation partner controls
Read sentence intelligibility	81.1 (15.0)	87.9 (3.6)
Conversational sentence intelligibility	55.8 (26.5)	71.9 (13.0)
Emotional conveyance (happy audio)	36.5 (20.5)	55.6 (20.8)
Emotional conveyance (happy audiovisual, %)	54.1 (20.5)	61.4 (13.9)
Emotional conveyance (neutral audio, %)	55.4 (18.0)	46.7 (18.6)
Emotional conveyance (neutral audiovisual,%)	38.5 (25.3)	53.6 (20.8)
Emotional conveyance (sad audio, %)	55.8 (21.3)	64.8 (18.7)
Emotional conveyance (sad audiovisual,%)	55.8 (23.1)	63.0 (25.2)
Communicative Participation Item Bank (CPIB, T score)	53.0 (9.6)	NA
Communicative Participation Item Bank (CPIB, overall rating of degree to which PD affects communication, n(%))	Not at all: 11 (24%) A little: 24 (53%) Quite a bit: 9 (20%) Very much: 1 (2%)	NA

Figures are mean (SD) unless stated. Intelligibility is scored as % words correctly identified. Emotional conveyance is scored as % tokens for which emotion was correctly identified.

Supplementary table 1. Statistical details for acoustic analysis of read sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA *Gender
Intensity	59.54 (4.73)	62.27 (4.81)	61.98 (8.22)a	63.49 (1.81)	62.90 (2.75)	63.13 (2.39)	4.13*	2.83	-2.89	6.87**	-10.1*
Intensity decay	5.42 (4.72)	5.05 (3.87)	5.52 (4.60)	3.83 (3.34)	3.17 (5.67)	3.43 (4.79)	-1.73	-0.69	0.04	1.55	1.04
Mean F_0	137.30 (18.46)	185.80 (25.32)	155.96 (30.83)	116.00 (11.41)	190.10 (27.78)	161.28 (43.38)	-19.80?	42.80***	30.70*	28.70*	1.04
SD of F_0	21.36 (8.18)	26.60 (6.09)	23.32 (7.70)	20.73 (6.52)	38.13 (9.26)	31.36 (11.90)	0.95	7.01*	9.63?	6.92?	-14.5*
Speech rate	3.73 (0.43)	3.83 (0.80)	3.77 (0.57)	4.18 (0.43)	3.54 (0.33)	3.79 (0.48)	0.57*	0.26	-0.92**	0.64?	-0.34
Acceleration	40.28 (31.49)	55.63 (35.22)a	42.31 (30.06)	51.76 (8.80)	43.94 (14.50)	46.98 (12.90)	9.97	1.10	-9.02	-15.9	-1.85
Adjusted speech rate	3.90 (0.39)	4.03 (0.69)	3.95 (0.50)	4.27 (0.37)	3.63 (0.31)	3.88 (0.46)	0.38?	0.14	-0.81**	0.48	-0.12
Adjusted acceleration	41.96 (15.37)	50.49 (23.91)	45.16 (18.72)	49.97 (14.63)	48.41 (14.41)	49.01 (14.08)	6.31	3.43	-5.00	-2.19	-15.50
Pause	2.65 (3.86)a	1.62 (5.52)a	2.39 (3.84)a	0.61 (4.74)a	2.34 (1.69)	1.40 (3.78)a	-5.13*	-4.09?	4.50	-5.23	6.85
Within-word pause	0.00 (4.51)a	0.00 (6.25)a	0.00 (4.74)a	0.00 (NA)a	0.00 (0.00)a	0.00 (0.00)a	-2.54?	-0.16	0.68	-2.45	6.26
Iteration	0.00 (0.22)a	0.45 (0.59)	0.03 (0.41)a	0.00 (0.00)a	0.00 (0.06)a	0.00 (0.06)a	-0.15	0.21	-0.18	-0.22	0.50
Within-word iteration	0.00 (11.81)a	6.25 (9.94)a	0.63 (9.36)a	0.00 (NA)a	0.00 (5.20)a	0.00 (0.52)a	-4.94	3.73	-2.00	-5.60	12.10
Jitter /i/	2.43 (0.58)	1.94 (0.74)a	2.19 (0.78)a	2.81 (0.65)	2.24 (0.44)	2.45 (0.58)	0.39	-0.16	-0.42	-0.03	0.49
Jitter /ɑ/	2.07 (1.22)a	1.73 (0.82)	1.97 (1.50)a	1.90 (0.60)	1.54 (0.48)	1.67 (0.54)	-0.50	-0.31?	0.36	-0.83	1.77

Jitter /u/	1.76	1.55	1.69	1.98	1.79	1.86	0.18	-0.17	0.09	-0.57	1.08
	(0.75)	(0.68)	(0.71)	(0.41)	(0.83)	(0.70)					
Shimmer /i/	15.12	13.43	14.53	16.87	14.18	15.17	1.71?	-1.59?	-1.11	-1.67	3.51
	(2.28)	(2.62)	(2.48)	(1.70)	(1.41)	(1.99)					
Shimmer /ɑ/	15.10	14.67	14.95	17.25	15.20	15.95	2.07	-0.56	-1.49	-0.91	3.73
	(2.41)	(2.89)	(2.52)	(3.13)	(2.70)	(2.96)					
Shimmer /u/	13.39	11.61	12.77	16.21	12.81	14.06	2.64?	-2.00	-1.40	-1.72	2.84
	(2.75)	(2.99)	(2.89)	(2.90)	(3.06)	(3.37)					
HNR /i/	8.95	11.55	9.86	7.29	10.43	9.27	-1.58	2.41*	0.67	3.77*	-4.65?
	(2.70)	(2.68)	(2.92)	(1.38)	(1.29)	(2.02)					
HNR /ɑ/	8.20	9.94	8.81	7.31	10.00	9.01	-0.82	1.69	0.99	4.10**	-6.12**
	(2.66)	(2.07)	(2.56)	(1.49)	(2.26)	(2.37)					
HNR/u/	11.36	14.25	12.46	9.67	13.24	11.89	-1.68	2.51*	1.02	3.74*	-3.29
	(3.02)	(2.88)	(3.28)	(1.51)	(2.27)	(2.72)					
FCR	1.37	1.37	1.35	1.35	1.29	1.31	-0.08	-0.07	0.01	-0.09	0.13
	(0.24)a	(0.11)	(0.18)a	(0.09)	(0.12)	(0.11)					
SD of /s/ amplitude	1.91	2.43	2.28	1.87	2.25	2.11	-0.33	0.21	0.19	-0.51	0.78
	(1.37)a	(0.83)	(0.71)	(0.32)	(0.36)	(0.40)					
VOT /pɒ/	0.24	0.27	0.26	0.27	0.27	0.28	0.02	0.00	0.00	0.03	0.01
	(0.06)	(0.08)	(0.07)	(0.07)	(0.06)	(0.06)					
VOT /tɛ/	0.37	0.40	0.38	0.40	0.35	0.37	0.03	0.01	-0.07	0.09	-0.11
	(0.12)	(0.06)	(0.10)	(0.06)	(0.08)	(0.07)					
VOT /pɑ/	0.18	0.24	0.20	0.19	0.16	0.16	0.02	0.00	0.00	-0.01	0.01
	(0.08)	(0.08)	(0.86)	(0.06)a	(0.04)	(0.04)a					
VOT /tu/	0.32	0.36	0.34	0.35	0.30	0.32	0.03	0.01	-0.09?	0.05	-0.08
	(0.07)	(0.05)	(0.07)	(0.09)	(0.05)	(0.07)					
VOT /kɒ/	0.34	0.34	0.34	0.35	0.32	0.34	0.00	0.56	-0.01	0.07	-0.05
	(0.07)	(0.06)	(0.07)	(0.04)	(0.07)	(0.06)					

Descriptives are shown as mean (SD), unless marked with ‘a’ in which case they refer to median (IQR). * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, symbols in // are phonemes transcribed using the International Phonetic Alphabet. HNR = Harmonic to Noise Ratio, FCR = Formant Centralization Ratio, VOT = Voice Onset Time

Supplementary table 2. Statistical details for acoustic analysis of conversational sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA * Gender
Intensity	57.56 (5.12)	60.92 (5.89)	58.79 (5.51)	61.10 (4.70)	60.28 (4.51)	60.60 (4.47)	3.69	3.56	-4.92	4.73	-9.44?
Intensity decay	1.10 (5.15)	-0.95 (4.56)	0.35 (4.92)	1.32 (3.74)	-0.71 (8.20)	0.08 (6.75)	0.31	-1.57	-0.46	4.58	-3.97
Mean F_0	130.47 (16.11)	179.63 (23.50)	145.58 (30.60)	118.44 (21.60)	189.33 (37.94)	161.76 (47.70)	0.39	45.30***	24.00	19.90	-27.50
SD of F_0	23.06 (8.75)	27.45 (9.48)	24.68 (9.03)	18.01 (9.78)	33.59 (12.22)a	30.51 (15.58)	-2.95	7.94?	11.00	-0.46	-12.50
Speech rate	4.70 (0.64)	4.71 (0.74)	4.70 (0.66)	5.20 (0.52)	4.34 (0.71)	4.67 (0.76)	0.37	-0.19	-0.49	0.25	0.17
Acceleration	25.22 (39.70)	-4.05 (26.71)	14.44 (37.57)	6.88 (30.38)	11.43 (26.25)	9.66 (27.13)	-20.60	-31.00*	35.60	-13.70	6.17
Adjusted speech rate	4.93 (5.09)	4.96 (0.60)	4.94 (0.57)	5.54 (0.41)	4.62 (0.82)	4.98 (0.82)	0.51	-0.14	-0.65	0.32	0.10
Adjusted acceleration	13.07 (21.93)	-4.42 (20.03)	6.62 (22.42)	2.15 (26.81)	10.57 (22.39)	7.29 (23.80)	-12.60	-19.20?	27.60?	1.15	-5.16
Pause	6.05 (10.59)a	4.87 (5.40)	4.02 (9.84)a	6.50 (4.54)	4.44 (4.17)	4.77 (4.33)	1.01	-0.54	-2.13	-2.74	0.15
Within-word pause	0.00 (NA)a	0.00 (0.00)a	0.00 (0.00)a	0.00 (NA)a	0.00 (NA)a	0.00 (0.00)	0.00	0.90?	-0.90	0.00	1.44
Iteration	0.00 (0.10)a	0.40 (1.00)a	0.00 (0.35)a	0.34 (0.38)	0.00 (0.40)a	0.10 (0.40)a	0.31	0.72	-0.87**	0.01	0.66
Within-word iteration	0.00 (0.00)a	0.00 (19.00)a	0.00 (0.00)a	0.00 (10.00)a	0.00 (0.00)a	0.00 (0.00)	5.71*	7.38**	-12.30***	0.00	6.47

Descriptives are shown as mean (SD), unless marked with 'a' in which case they refer to median (IQR). * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment.

Supplementary table 3. Statistical details of acoustic analysis for emotional conveyance sentences

Part A. Descriptives

	PD			CP		
	Male	Female	All	Male	Female	All
Intensity H	61.71 (5.21)	65.22 (3.61)	63.12 (4.86)	66.55 (2.43)	64.49 (3.57)	65.21 (3.30)
Mean F_0 H	168.98 (35.75)	204.39 (28.97)	183.15 (36.96)	155.97 (12.36)	240.15 (28.59)	210.69 (47.56)
SD of F_0 H	35.63 (14.04)	43.97 (12.16)	38.96 (13.64)	35.70 (11.54)a	63.40 (15.94)	55.16 (18.57)
Speech rate H	4.33 (0.63)	4.18 (0.51)	4.27 (0.57)	4.90 (0.49)	[illegible].90 (0.38)	4.25 (0.63)
Adjusted speech rate H	4.46 (0.57)	4.19 (0.51)	4.35 (0.55)	4.91 (0.49)	[illegible].91 (0.38)	4.26 (0.64)
Pause H	0.00 (4.53)a	0.00 (0.00)a	0.00 (3.00)a	0.00 (0.00)a	0.00 (0.00)a	0.00 (0.00)a
Intensity N	58.83 (5.33)	60.96 (4.45)	59.68 (4.99)	61.77 (3.46)	60.09 (4.28)	60.68 (4.00)
Mean F_0 N	132.84 (19.30)	172.90 (30.85)	148.86 (31.17)	117.66 (13.49)	186.46 (18.23)	162.38 (37.43)
SD of F_0 N	18.50 (5.59)a	29.67 (13.02)	20.82 (9.83)a	27.19 (4.31)	34.60 (9.35)	32.01 (8.62)
Speech rate N	4.45 (0.73)	4.60 (0.65)	4.51 (4.46)	4.77 (0.55)	4.21 (0.28)	4.41 (0.47)
Adjusted speech rate N	4.53 (0.67)	4.62 (0.63)	4.57 (0.64)	4.82 (0.54)	4.22 (0.27)	4.38 (0.47)a
Pause N	0.00 (1.62)a	0.00 (0.00)a	0.00 (0.82)a	0.00 (1.14)a	0.00 (0.00)a	0.00 (0.00)a
Intensity S	57.81 (6.19)	62.15 (3.69)	59.55 (5.65)	62.78 (2.50)	59.88 (4.88)	60.89 (4.36)
Mean F_0 S	133.00 (27.26)	172.45 (33.36)	148.78 (35.12)	116.04 (15.11)	186.91 (25.09)	162.10 (40.90)
SD of F_0 S	17.83 (8.95)a	31.64 (9.71)	25.29 (12.06)	23.86 (5.39)	34.60 (11.02)	30.85 (10.65)

Speech rate S	4.00 (0.74)	3.79 (0.56)	3.92 (0.66)	4.03 (0.64)	3.40 (0.44)	3.62 (0.59)
Adjusted speech rate S	4.02 (0.73)	3.80 (0.56)	3.93 (0.66)	4.03 (0.64)	3.41 (0.44)	3.63 (0.59)
Pause S	0.00 (NA)	0.00 (0.53)a	0.00 (0.00)a	0.00 (NA)	0.00 (0.56)a	0.00 (0.00)a

Descriptives are shown as mean (SD), unless marked with 'a' in which case they refer to median (IQR). H = happy mood, N = neutral mood, S = sad mood.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency.

Part B. Mean differences associated with predictors

	Group	Gender	Group * Gender	MoCA	Mood (N-H)	Mood (S-H)	Gender * Mood (N-H)	Gender * Mood (S-H)	MoCA * Mood (N-H)	MoCA * Mood (S-H)	Group * Mood (N-H)	Group * Mood (S-H)
Intensity	4.83*	-3.49?	5.54*	1.86	-3.23***	-3.58***	-0.52	0.02	-1.59	-1.25	-0.97	-0.76
Mean F_0	-6.43	41.47***	36.32**	17.27	-32.24***	-32.60***	-5.10	-4.41	-12.09	-19.34	-12.75	-13.12
SD of F_0	9.91*	13.58***	4.44	4.06	-12.03***	-11.65***	-7.29	-5.08	-7.28	-7.22	-6.37	-9.36*
Speech rate	0.47?	-0.24	-0.66*	0.65*	0.09	-0.42***	0.37*	0.15	0.01	-0.21	-0.17	-0.32*
Adjusted speech rate	0.38	-0.32	-0.61*	0.56*	0.07	-0.51***	0.37*	0.21	0.03	-0.11	-0.13	-0.26
Pause	-2.03*	-1.85*	0.99	-2.07	-1.27*	-2.56***	0.64	1.78*	0.92	1.76	1.14	1.49?

F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, H = happy mood, N = neutral mood, S = sad mood. * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-014642.R2
Article Type:	Research
Date Submitted by the Author:	23-Jan-2017
Complete List of Authors:	Barnish, Maxwell; University of East Anglia, School of Health Sciences, Faculty of Medicine and Health Sciences Horton, Simon; UEA, Health Sciences Butterfint, Zoe; University of East Anglia, School of Health Sciences, Facilty of Medicine and Health Sciences Clark, Allan Atkinson, Rachel ; St Helier Hospital, London, UK, Adult Speech and Language Therapy Department Deane, Katherine; University of East Anglia, School of Health Sciences
Primary Subject Heading:	Rehabilitation medicine
Secondary Subject Heading:	Communication, Neurology
Keywords:	Parkinson-s disease < NEUROLOGY, REHABILITATION MEDICINE, GERIATRIC MEDICINE

Speech and communication in Parkinson's disease: a cross-sectional exploratory study in the United Kingdom

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ABSTRACT

Objective: To assess associations between cognitive status, intelligibility, acoustics and functional communication in PD.

Design: Cross-sectional exploratory study of functional communication, including a within-participants experimental design for listener assessment

Setting: A major academic medical centre in the East of England, United Kingdom.

Participants: Questionnaire data were assessed for 45 people with Parkinson's disease (PD) who had self-reported speech or communication difficulties and did not have clinical dementia. Acoustic and listener analyses were conducted on read and conversational speech for 20 people with PD and 20 familiar conversation partner (CP) controls without speech, language or cognitive difficulties.

Main outcome measures: Functional communication assessed by the Communicative Participation Item Bank (CPIB) and Communicative Effectiveness Survey (CES).

Results: People with PD had lower intelligibility than controls for both the read (mean difference 13.7%, p=0.009) and conversational (mean difference 16.2%, p=0.04) sentences. Intensity and pause were statistically significant predictors of intelligibility in read sentences. Listeners were less accurate identifying the intended emotion in the speech of people with PD (14.8% point difference across conditions, p=0.02) and this was associated with worse speaker cognitive status (16.7% point difference, p=0.04). Cognitive status was a significant predictor of functional communication using CPIB (F=8.99, p=0.005, $\eta^2 = 0.15$) but not CES. Intelligibility in conversation sentences was a statistically significant predictor of CPIB ($F=4.96$, $p=0.04$, $\eta^2 = 0.19$) and CES ($F=13.65$, $p=0.002$, $\eta^2 = 0.43$). Read sentence intelligibility was not a significant predictor of either outcome.

Conclusions: Cognitive status was an important predictor of functional communication – the role of intelligibility was modest and limited to conversational and not read speech. Our results highlight the importance of focusing on functional communication as well as physical speech impairment in Speech and Language Therapy (SLT) for PD. Our results could inform future trials of SLT techniques for PD.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- We provide the first same-study overview of associations at various stages along the potential pathway to reduced functional communication in Parkinson's disease (PD).
- Ours is the first study to consider the acoustic characteristics of the speech of British people with PD.
- Our study was cross-sectional and therefore cannot provide definitive insight into causality.
- Studies in this field, including ours, tend to have smaller sample sizes than many other fields in applied health science research, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population.

INTRODUCTION

Parkinson's disease (PD) affects around 1.5% of people aged over 65 in Europe.[1] Originally conceptualised predominantly in terms of its motor features,[2] PD is now recognised to be a multifaceted condition.[3] Indeed, non-motor symptoms, such as cognitive impairment affecting over a quarter of people with PD,[4] are believed to exert a substantial effect on quality of life.[5] Speech impairment,[6] at the impairment level of the International Classification of Functioning (ICF),[7] as well as functional communication difficulties,[8] at the ICF activity and participation levels, are also widespread in PD. The mainstay of medical treatment for PD is levodopa-based pharmacotherapy,[9] although non-adherence,[10] dyskinesia[11] and a lack of clear benefit on speech and cognition are problematic.[12-14] Therefore, a wide range of supplementary therapies can be used, including singing,[15] dance[16] and speech-and-language therapy (SLT). SLT is popular among people with PD and families alike,[17] but there is no definitive randomised controlled trial evidence for the effectiveness of currently tested SLT techniques.[18] Moreover, the content and focus of SLT provision can vary markedly between localities. In the UK, the focus has traditionally been on motor function. In a survey conducted in 2007, functional communication was not reported to constitute a major part of many UK SLT's clinical practice for PD,[19] although clinical contacts suggest that the situation has improved in recent years. Recently, M.S.B. and S.M.C.H. published a clinical magazine feature article[20] to emphasise the importance of functional communication to SLT clinicians.

Functional communication has been shown to be more important to people with PD than motoric speech impairment.[21] Moreover, although it is an important predictor of quality of life,[22] functional communication has received relatively limited research attention compared to motoric speech impairment. A systematic review of the literature up to July 2015[23] found that nine studies prior to ours had assessed the association between cognitive status and functional communication in PD, of which eight had found a positive association. However, none had used a cognitive assessment sensitive to mild cognitive impairment in PD and a validated outcome measure that assessed either communicative effectiveness or communicative participation as a unified concept. Therefore, these studies may have failed to detect mild cognitive impairment short of dementia and also to accurately capture the concept of functional communication, resulting in potential inaccurate measurement of both independent and dependent variables. In addition, while three prior studies had found an association between intelligibility and communicative outcomes, only one study[24-25] used a standardised validated assessment tool – the Communicative Effectiveness Survey (CES).[24-25] However, CES covers the ICF activity level, not the ICF participation level. Subsequent to our review, one further large study[22] has assessed functional communication outcomes in PD and found that people with PD with self-reported worse cognitive status and intelligibility had more difficulties in communicative participation. The size of this study is a major strength, but the study relied entirely on self-report data, which is a substantial limitation with regard to assessing cognitive status and intelligibility accurately.

Taking a wider perspective on communication difficulties in PD and potentially associated risk factors, it is important to note that no study in the published literature has provided an overview of the elements and potential mechanisms for change in the pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. There has been no comparative overview of which acoustic features are most predictive of reduced intelligibility. However, the available literature suggests that increased articulatory phonological distinctiveness[26-27] and loudness[28-29] may be associated with better intelligibility, with the latter having beneficial effects on the distinctiveness of speech in PD besides loudness itself.[29] Additionally, no study of speech acoustics has used speech that we considered to be naturalistic conversational dialogue – for example, the 'conversational' speech in the study by Goberman and Elmer[30] was a standard passage read out in the style of conversational speech. Moreover, the ability to communicate emotions effectively is important in everyday life[31] and studies have shown that reduced pitch variation and facial expression can cause negative evaluations of the personality of people with PD.[32-35] Additionally, people with PD have been shown to have impaired perception of the intended emotion in the speech of others,[36-38] which may relate at least partly to impaired mesolimbic processing.[39] However, normal listeners' ability to identify specific emotions in the speech of people with PD has attracted limited research attention. Miller *et* al[40] showed that listeners were less likely to correctly identify the intended emotion in the speech of people with PD when auditory and visual information were both available. It was suggested that this effect

may result from a lack of temporal synchronization in the speech of people with PD. Meanwhile, Pell *et al*[41] also found reduced ability to identify emotions in the speech of people with PD, especially for anger and disgust, but did not assess presentation modality.

Informed by limitations in the existing literature, we conducted an exploratory study focusing on functional communication in PD as our primary outcome. This is an area that has received relatively little research attention, yet corresponds well to the priorities of people with PD.[21] We conducted a study to provide an overview of associations along the potential pathway to functional communication difficulties in PD, since no prior study had done this. In addition, we added an aspect on emotional conveyance in order to further investigate the possibilities raised by Miller *et* al,[40] especially with regard to presentation modality effects. Our key research questions for this study are:

- How does cognitive status associate with functional communication in PD, as measured by the Communicative Participation Item Bank (CPIB, primary research question) and CES?
- What is the test-retest reliability and convergent validity of CPIB in our UK context?
- How does intelligibility, in both read and conversational sentences, associate with functional communication in PD?
- What were the acoustic differences between the speech of people with PD and CPs in our sample; how did the intelligibility of these groups

differ in read and conversational speech; and what acoustic factors predicted intelligibility outcomes?

- How did the emotional conveyance of people with PD and CPs differ, which mood contrasts were particularly affected, and did presentation modality (audio vs audiovisual) play a role?

MATERIALS AND METHODS

Design

In order to assess associations along the potential pathway to functional communication difficulties in PD, we used a cross-sectional design, into which we embedded a within-participants experimental psychology design for listener assessment. Since our methods are largely based on clinical psychology and clinical linguistics and are not epidemiology, there is no suitable reporting guideline to follow. Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Participants

Our study recruited from the Neurology and Medicine for the Elderly outpatient clinics at a major academic medical centre in the East of England region in 2012-2013. Patients were eligible for the study if they i) were aged at least 18, ii) had idiopathic PD according to the United Kingdom Parkinson's Disease Society Brain Bank criteria,[42] iii) had no clinical indication of dementia, iv) had no other serious medical conditions that would affect cognitive status or speech, v) were not considered by clinical staff to be unsuitable for the study, for example due to personal circumstances, vi) were native English speakers and vii) reported having some difficulty with their speech and/or communication. Participants with PD were asked to invite a familiar conversation partner control (CP) to join them in the study where possible. CPs had to i) be aged at least 18, ii) be a native English speaker, iii) not have PD and iv) not have any serious medical problems affecting cognition or speech. Written informed consent was obtained from all participants prior to the commencement of study procedures.

Measures and data collection

The study consisted of one appointment typically of around 45 minutes after consent, which could take place either at home or at the University of East Anglia. Initially, participants completed a demographic form, which for people with PD provided their medication information which allowed their Levodopa Equivalent Daily Dose (LEDD)[43] to be calculated. LEDD served as a proxy measure of non-speech-specific PD motor symptom severity. Validated assessments of cognitive status (Montreal Cognitive Assessment, MoCA[44-45]), mood (Hospital Anxiety and Depression Scale, HADS[46-48]), communicative effectiveness (CES[24-25,49]) and communicative participation (Communicative Participation Item Bank, CPIB[50-]) were completed. CPIB was chosen as our primary measure of functional communication since it specifically assesses ICF participation level difficulties that have been shown to be most important to people with PD,[21] and also has been thoroughly developed using item-response theory methods[50] and subsequent validated in PD in the United States and New Zealand, which are English-speaking countries.[51]Therefore, we assessed test-retest reliability by sending out a second copy of CPIB by post two weeks after the study visit and assessed convergent validity using CES in our UK setting. As per the terms of our ethical approval, cognitive, mood and functional communication assessments were only administered to participants with PD and not to CPs.

Audiovisual recordings were obtained of all participants' (PD and CP) speech at a standardised distance of 1.5m using Panasonic NV-GS17 (Panasonic, Corporation, Osaka, Japan) video cameras. Video was encoded in high quality 48 kHz AVI format, from which high quality 44.1 kHz WAV audio files could be extracted. Participants first read a standardised set of sixteen sentences taken from the Assessment of Intelligibility of Dysarthric Speech (AssIDS) assessment tool.[52] Then, participants held a short conversation on a topic of their choice in an exercise that was intended to offer as naturalistic speech as possible. Besides offering support to people with PD in completing questionnaires where required, this was the main advantage of including familiar CPs in the study – King and Gallegos-Santellan have shown that people with dysarthria use different strategies with familiar and unfamiliar conversation partners.[53] Finally, participants read four standardised sentences in three ways: happy, sad and neutral. All sentences contained words of moderate to high frequency and did not have an intrinsic emotional connotation. Three of the sentences were taken with permission from Miller *et al*[40], namely "The cake is too yellow", "You dropped the sausages in the trifle" and "Sam is not a dog". One further sentence was generated by the research team: "He went to the park".

Data analysis

Speech sample analysis (acoustics, intelligibility and emotional conveyance) was conducted on a purposive sample of 20 people with PD and 20 CPs. In order to generate our purposive sample, firstly, any samples that suffered from technical failure, other issues such as road noise and non-compliance with the task instructions were excluded. Then, selection sought to achieve a balanced profile of demographic and clinical features among people with PD and maximise comparability of demographics between the PD and CP groups, within the bounds of what was available in our sample. Only people with PD who provided a CP were considered. Age, gender, accent and perceived severity of speech disorder were also considered in selection. In particular, it was important to ensure generalisability of the PD sample. As we used standardised read sentences in the intelligibility assessment, we designed this part of the study so that each script sentence would only be rated twice by each assessor in order to avoid stimulus exposure effects and learning bias.[54-55] Assessment of self-report measures could be conducted on the full sample of 45 people with PD, but could not be conducted on CPs as we did not gather these data for ethical reasons.

Acoustic (phonetic) analysis was conducted by M.S.B. using Praat software (P. Boersma & D. Weenink, University of Amsterdam) and a reliability check of a randomly selected 10% sample of acoustic data points drawn from 10 different participants (25% of the phonetic analysis sample size) was completed by Senior Lecturer in Phonetics Z.R.B. Acoustic measures covered four broad domains[56-58] – initiation (the production of airflow), prosody (rhythm and melody), phonation (voicing) and articulation (the modification of sound waves by the resonant properties arising from different vocal tract configurations). A list of measures with a brief description of each is provided in Table 1. Sentence-level parameters were calculated for conversational and mood sentences. Phoneme-level parameters were additionally calculated for the set of 16 standardised read sentences.

Sixty-four assessors (88% female, median age 22) served as members of the study team to conduct assessment of speech samples for intelligibility and emotional conveyance. Assessors had to be i) members of the University of East Anglia (UEA, for ethical reasons), ii) fluent English speakers and iii) not having significant expertise in listening to disordered speech (for example SLT staff, final year SLT students and those with a close member with PD or working with groups or individuals with PD as part of their course or extra-curricular activities. Twenty tracks (each comprising a different combination of utterances and speakers) were created in EditStudio software (MediaChance, Ottawa, Canada) with stimulus allocation based on a Latin Square design[59] and randomised presentation order. All tracks were rated three times and four tracks were rated an additional time, meaning that each token spoken by each participant was rated by at least three different assessors. The intelligibility task was transcription and following AssIDS protocol, the outcome measure was % words correctly identified. This was scored separately for read and conversational sentences and the transcript for the latter was agreed between authors M.S.B. and S.M.C.H. The emotional conveyance task was to circle which of three options (happy, neutral or sad) the speaker intended to convey and the outcome measure was % moods correctly identified following Miller *et al*.[40] In the intelligibility task, all stimuli were presented audiovisually, while in the emotional conveyance tasks, half were presented audiovisually and half in audio only. In all listener assessment tasks, assessors could only listen to each sentence once and sentences from people with PD and CPs were matched for length. The rationale for including an audio-only condition in the emotional conveyance assessment was to test the preliminary finding by Miller *et al*[40] that listeners were less likely to correctly identify the intended emotion in the speech of people with PD when auditory and visual information were both available. In contrast, for intelligibility assessment, we wanted to replicate the most common real-life listening conditions through presenting audiovisual information.

Statistical aspects of the study were overseen by Senior Lecturer in Medical Statistics A.B.C. The headline sample size of 45 for the questionnaire-based relationships was based on a power calculation for observational designs[60] to calculate the number of people with PD required to have 80% power to detect an expected association equivalent to r=0.5 for our primary relationship between cognitive status (MoCA) and functional communication (CPIB), allowing for issues such as non-completion and technical failure. The effect size to use for the power calculation was determined by senior statistician A.B.C. informed by i) preliminary systematic literature searches by the research team that later became our systematic review[23] and ii) the research team's combined wider theoretical, scientific and clinical knowledge and expertise about communication in neurological conditions such as PD, which both informed us to expect a moderate relationship between cognitive status and functional communication in PD. Stata (Stata Corp, College Station, Texas) and SPSS (IBM Inc, Armonk, New York) software was used for statistical analysis. Appropriate linear regression models were constructed to assess i) differences in speech acoustics between people with PD and CPs and the contribution of cognitive status to speech acoustics of people with PD, ii) differences in intelligibility and the contribution of cognitive status and particular acoustic characteristics, iii) differences in the acoustic correlates of happy, neutral and sad mood and the contribution of cognitive status, iv) differences in emotional conveyance and the contribution of cognitive status and particular acoustic characteristics, v) the contribution of cognitive status and intelligibility to functional communication as measured by CES and CPIB. The test-retest reliability of CPIB was assessed using interclass correlation and its convergent validity with CES using correlation. Due to the exploratory nature of the study and the fact that analysis was on a range of outcome measures rather than repeated analysis of the same outcome measure, it was decided a priori not to perform adjustment for multiple testing.[61] A p-value of $p<0.05$ was considered significant and variables associated at $p<0.1$ were retained in models as marginally significant. There were limited missing data, only one participant had missing data for the CPIB outcome measure and none for CES. Full case analysis was used.

RESULTS

Participants

Forty five people with PD and 29 CPs were recruited. Forty-five people with PD contributed to the questionnaire analysis. The mean age was 71.0 (SD 8.1), 28 (62%) were male and the most common educational category was to have no formal educational qualifications (n=17, 38%).

Among the 20 people with PD whose data were used for speech sample analysis, the mean age was 71.1 (SD 9.0), 23 (65%) were male and the most common educational category was shared between no formal educational qualifications and vocational qualifications (both n=7, 35%). Table 2 presents the clinical characteristics of both the full (n=45) and purposive (n=20) samples of people with PD.

Among the 20 CPs whose data were used for speech sample analysis, the mean age was 70.0 (SD 10.4), 7 (35%) were male and the most common educational category was to have vocational qualifications (n=8, 40%).

Speech acoustics and intelligibility

Table 3 profiles the principal speech and communication measures in our study. The overall concordance rate was r=0.99 for inter-rater reliability of acoustic measures. In read sentences, people with PD had lower speech intensity and greater pause time than CPs. For other measures, there was either no significant difference, a marginally significant difference or an effect that applied only for one gender. MoCA was associated with intensity, although the effect was in opposite directions for men and women – men with PD with better cognitive status spoke more loudly, while women with PD with better cognitive status spoke more quietly. MoCA was not associated with pause. In conversational sentences, people with PD had higher within-word iteration than CPs. This was not associated with MoCA. Statistical details on the main effects and interactions can be found in Supplementary tables 1 (read sentences) and 2 (conversational sentences).

Assessors were significantly less accurate in transcribing both the read (mean difference = 13.7 percentage points, p=0.009) and conversational (mean difference = 16.2 percentage points, p=0.04) speech of people with PD compared to CPs. In neither case was there an association between MoCA and intelligibility. In read sentences, intensity (mean difference = 2.4 percentage points per dB SPL, p=0.04) and pause (mean difference = 3.6 percentage points per percentage unit change in pause, p=0.04) were identified as significant predictors of listener accuracy – assessors were more accurate in transcribing the read speech of people with PD who spoke more loudly and paused less. No significant acoustic predictors of conversational sentence intelligibility were identified. Gender was not a statistically significant predictor of intelligibility.

Emotional conveyance

In the emotion sentences, men with PD spoke more quietly than CPs, women with PD had significantly reduced mean fundamental frequency compared to CPs, both men and women with PD had significantly reduced SD of fundamental frequency, men with PD had significantly reduced speech rate (but not adjusted speech rate) and both men and women with PD had significantly increased pause time. In the PD group, participants with MoCA below median had significantly lower speech rate and adjusted speech rate. Main effects of mood were found within the PD group for most measures, meaning that people with PD were on the whole able to distinguish emotions in their speech, although distinctions were reduced relative to CPs. Significant and marginally significant group by emotion interactions, for happy vs sad, suggest that people with PD were particularly impaired in the production of happy emotion. Statistical details on the main effects and interactions can be found in Supplementary table 3.

Listeners were significantly less accurate in identifying the intended emotion (happy, neutral or sad) in the speech of people with PD compared to CPs (mean difference = 14.8 percentage points, p=0.04). A significant interaction between group and emotion (mean difference for group * emotion (sad vs happy) = 17.8 percentage points, p<0.001) shows that the impact of PD on listener accuracy was greater for happy mood. There was no significant effect of presentation modality (audiovisual vs audio only) on listener accuracy. There was a significant effect of MoCA (mean difference = 16.7 percentage points between participants scoring above and below the median, p=0.04), showing that listeners had more difficulty in identifying emotion in the speech of people with PD with greater cognitive impairment. A significant interaction between MoCA and emotion (mean difference for MoCA (median split) * emotion (sad vs happy) = 23.2 percentage points, p=0.009), showing that the differential effect of PD on happy mood conveyance was less for those with more intact cognition.

CPIB showed satisfactory test-retest reliability (r=0.85, p<0.001) and validity (r=0.74, p<0.001) in our population, noting that CPIB and CES are measures of related but not identical constructs, so a higher concordance would have been unexpected. In the full sample, MoCA (F=8.99, p=0.005, η^2 = 0.15) and HADS (F=8.73, p=0.005, η^2 = 0.15) were retained as significant predictors of CPIB, while HADS (F=20.18, p<0.001, η^2 = 0.32) was the only significant predictor of CES, but a marginally significant finding for LEDD (F=3.72, p=0.06, η^2=0.06). With regard to MoCA sub-domains, the Executive and Visuospatial (F=3.22, p=0.08, η^2=0.05) and Attention (F=3.05, p=0.09, η^2=0.05) sub-domains were both marginally significant predictors of CPIB. Among the purposive sample for whom intelligibility scores were available, MoCA (F=5.32, p=0.04, η^2=0.20) and intelligibility in conversational sentences (F=4.96, p=0.04, η^2 = 0.19), but not intelligibility in read sentences, were significant predictors of CPIB, while only intelligibility in conversational sentences (F=13.65, p=0.002, η^2 = 0.43) was a significant predictor of CES.

DISCUSSION

The study presented in this article is the first to provide an overview of associations along the potential pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. We also include a combination of self-reported and observed measures, an approach which avoids one of the key limitations associated with larger studies, such as that by McAuliffe *et al*[22] that only include self-report measures. Ours is also the first to study the acoustics of the speech of British people with PD, mindful that there are notable acoustic differences between British and American English.[62-63]

The first main finding was that intelligibility was reduced in both read and conversational speech for people with PD compared to controls, and the effect was greater on conversational sentences, potentially reflecting the greater cognitive and perceptual challenges of spontaneous speech. The second main finding was that acoustic differences between people with PD and CPs in our sample were modest and few were statistically significant, although many participants in our study had relatively mild motoric speech difficulties. The results of our study reflect the natural hierarchy that can emerge in clinical practice, starting initially with work on physical aspects of read speech due to the cognitive demands of altering one's speech and then progressing to less structured tasks that generalize more readily to everyday conversation (R.A. Atkinson, personal communications).

The third main finding was that emotional conveyance, especially of happy emotion, was impaired in people with PD compared to CPs. The fourth main finding was that, despite a relatively mild profile of motoric speech deficits, participants often had difficulties with functional communication. Intelligibility did not account for a large proportion of variance in functional outcomes, emphasising the need to account for and include other elements in functional communication tasks in SLT for people with PD to overcome the challenge with generalization from the clinic to everyday life. Cognitive status predicted CPIB and emotional conveyance, but not intelligibility or CES. This may imply a greater role for cognitive status with regard to participation-level phenomena.

Our identification of reduced intelligibility in people with PD compared to CPs is in line with previous studies and in particular our identification of intensity as a key predictor of intelligibility (although only found for read sentences in our study) corroborates the prior findings of Tjaden and Sussman[28] and Neel,[29] while our identification of pause suggests a potentially novel acoustic correlate of intelligibility in PD. Our study is the first to compare conversational and read speech intelligibility in PD and found that intelligibility was lower in conversational sentences, which is explicable in terms of contextual effects and the lower distinctiveness of more spontaneous speech and therefore the potential for a lower ability on the behalf of listeners to adjust for phonetic alterations.

With regard to emotional conveyance, in keeping with Miller *et al*[40] and Pell *et al*[41] our findings support the view that people with PD were less successful in conveying emotion in their speech. Our findings show that the communication of happy emotion was particularly affected, although our study cannot confirm the mechanisms which might be causing this effect. Unlike Miller *et al*,[40] potentially due to lesser severity of speech impairment, we did not find that listeners were more accurate in the audio only condition compared to the audiovisual condition. Our identification that intelligibility contributes a relatively modest proportion of the variance in functional communication is consistent with Donovan *et al*,[24-25] although we advance this knowledge by demonstrating differences between conversational and read sentence intelligibility as well as communicative effectiveness and communicative participation. Previous studies in our review[9] and also McAuliffe *et al*[22] have generally found an association between cognitive status and functional communication. The prior study by Miller *et al*,[6,64] which did not find such as association used as a measure of cognitive status the Mini Mental State

Examination,[65] which has been shown to be insensitive to mild cognitive impairment in PD.[66-69]

Communication is fundamental to humanity and in particular the development and maintenance of human relationships.[70] Although participation may mean different things to different people,[71] it is evident that participation aspects, including those of functional communication,[21] are of great importance to people with PD. Indeed, it is important than research and clinical priorities and perspectives match those of people with the condition as closely as possible.[72] The relatively modest contribution of intelligibility to functional communication outcomes shown by our study and others indicates that it is important for SLT for people with PD to focus on non-motoric issues affecting functional communication in addition to more traditionally recognised motoric issues. In environments where there has been a move to include a higher proportion of functional communication in therapy, this should be maintained. In environments where this has not yet happened, it is recommended that greater focus on functional communication be considered. In achieving this, it is important to consider what the particular client's communication needs and goals are, what challenges the client faces in accomplishing these, and what approaches may facilitate this. It is important to remember that communication needs differ between clients, and that clients differ in what they consider full participation in life.[71] Further research is required to investigate the effectiveness of SLT for PD. The pathway proposed by our study could be useful to inform future research into defining treatments to include in intervention trials. In addition, it is important to conduct further research into the gender-specific aspects of communication difficulties in PD, which have received limited research attention.

There are some limitations of this study that should be taken into account. The PhD time scale did not allow us to undertake a longitudinal study, so we cannot be definitive about causality. Secondly, it was not possible to use the entire sample size for speech sample analysis due to the constraints that read sentences impose upon the sample size in the intelligibility assessment so as to avoid learning biases. Thirdly, the sample we recruited had on average relatively mild motoric speech deficits, potentially due to greater reluctance to take part in speech studies among those with more severe speech impairment or alternatively due to an overrepresentation of people with early PD and greater insight into research. Fourthly, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population, sample sizes in this field, tend to be lower than in many other areas of applied health research. Fifthly, we were unable to measure motor disability directly. However, we offered LEDD as a proxy measure of motor disability to models assessing functional outcomes in order to minimise confounding by motor disability. Moreover, some studies have shown that cognitive impairment can be common in people with PD who are early on the motor decline pathway.[73-74] However, LEDD has limitations as a proxy measure of motor status. For example, one study[75] found no significant association between LEDD and Hoehn and Yahr staging. Therefore, future studies should consider assessing how scores from explicit motor assessments, such as the Universal Parkinson's Disease Rating Scale (UPDRS)[76] predict functional communication outcomes.

In conclusion, we present the first study that provides an overview of the potential pathway from cognitive status and motoric speech impairment through reduced intelligibility to difficulties with emotional conveyance difficulties and functional communication in PD. Our results support the idea that SLT for people with PD should focus on functional communication as well as motor deficits, and could also inform future trials to identify the optimal form of therapy. The pathway to functional communication difficulties in PD is likely to involve complex, multi-factorial mechanisms for change, including for example motoric, cognitive and psychosocial elements. Since our study is exploratory, future confirmatory research is required to validate and extend our findings. This should include clarification of the elements and mechanisms of this pathway, as well as how they may differ between individuals with PD, which is a condition known to vary considerably in its clinical expression.[77]

FOOTNOTES

Acknowledgements

This study constituted M.S.B.'s PhD work at the University of East Anglia (UEA). We thank Dr Carolyn Baylor, Prof Kathryn Yorkston and colleagues (University of Washington, USA) for prior information about the CPIB tool. We thank our participants and assessors, our recruiting clinicians at the Neurology and Medicine for the Elderly Clinics at the Norfolk and Norwich University Hospital as well as Mr Mike Stevens, formerly of UEA, who

provided guidance and training in relation to audio-visual technology used in the study.

Contributors

M.S.B. was the Chief Investigator and K.H.O.D. the primary academic supervisor. S.M.C.H. and R.A.A. are registered SLTs and are specialists in adult neurological disorders. The study was conceptualised and overseen by M.S.B., S.M.C.H., Z.R.B. and K.H.O.D. Data were collected by M.S.B. Acoustic analysis was conducted by M.S.B. and Z.R.B. Listener assessment was conducted by our panel of assessors supervised by M.S.B with advice from S.M.C.H, Z.R.B. and K.H.O.D.. Statistical analysis was overseen by A.B.C. and conducted by M.S.B. and A.B.C. The first draft of the manuscript was written by M.S.B. Data were initially interpreted by M.S.B. and further interpretation provided by S.M.C.H., Z.R.B., A.B.C., R.A.A. and K.H.O.D. All authors contributed academically and/or clinically valuable revisions to the manuscript. All authors approved the submission.

Funding

We acknowledge funding from a UEA PhD studentship to M.S.B.

Competing interests

The authors declare no conflicts of interest with regard to this work

Ethics approval

Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Data sharing statement

No additional data are available

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Table 1. List of acoustic measures with a brief explanation of each

Domain	Measure	Explanation
Initiation	Intensity	Objective correlate of loudness, measured in db SPL
	Intensity decay	% decay in intensity from first to last sentence
Prosody	Mean fundamental frequency (F_0)	Objective correlate of pitch, measured in Hz
	Standard deviation of F_0	Objective correlate of pitch variation
	Speech rate	Speaking speed, measured in syllables per second
	Adjusted speech rate	As per speech rate, but excluding dysfluencies and pause
	Acceleration	% increase in speech rate from first to last sentence
	Adjusted acceleration	As per acceleration, but excluding dysfluencies and pause
	Pause	A measure of hesitation, calculated in ms and expressed as % of utterance time, using a threshold of 50ms as the minimum significant pause duration
	Within-word pause	% of pause that occurred within rather than between words
	Iteration	Number of instances of linguistic unit repetition
	Within-word iteration	% of instances of linguistic unit repetition that occurred within rather than between words
Phonation	Jitter	Relative percentage variation in glottal cycle duration (indicative of voicing frequency consistency)
	Shimmer	Relative percentage variation in glottal cycle amplitude (indicative of voicing amplitude consistency)
	Harmonic-to-noise ratio (HNR)	A measure of cycle-to-cycle variation in waveform shape (indicative of voicing strength)
Articulation	Formant Centralization Ratio (FCR)	A measure of vowel distinctiveness
	Standard deviation of /s/ amplitude	A measure of consonant articulation strength
	Voice Onset Time (VOT) ratio	A measure of the ability to differentiate for example 'bark'

		and ‘park’

Table 2. Key clinical characteristics of people with PD in the full and purposive samples

Measure	Full sample	Purposive sample
Disease duration (years)	6.5 (8.3)*	9.0 (9.5)*
MoCA	22.9 (3.6)	22.2 (3.3)
HADS	11.0 (8.5)*	9.6 (4.8)
LEDD	640.5 (656.5)*	691.5 (1027.3)*

Figures are mean (SD), unless when marked with * in which case they are median (IQR). MoCA = Montreal Cognitive Assessment, HADS = Hospital Anxiety and Depression Scale and LEDD = Levodopa Equivalent Daily Dose

Table 3. Descriptive profile of principal speech and communication measures

	People with Parkinson's disease	Conversation partner controls
Read sentence intelligibility	81.1 (15.0)	87.9 (3.6)
Conversational sentence intelligibility	55.8 (26.5)	71.9 (13.0)
Emotional conveyance (happy audio)	36.5 (20.5)	55.6 (20.8)
Emotional conveyance (happy audiovisual, %)	54.1 (20.5)	61.4 (13.9)
Emotional conveyance (neutral audio, %)	55.4 (18.0)	46.7 (18.6)
Emotional conveyance (neutral audiovisual,%)	38.5 (25.3)	53.6 (20.8)
Emotional conveyance (sad audio, %)	55.8 (21.3)	64.8 (18.7)
Emotional conveyance (sad audiovisual,%)	55.8 (23.1)	63.0 (25.2)
Communicative Participation Item Bank (CPIB, T score)	53.0 (9.6)	NA
Communicative Participation Item Bank (CPIB, overall rating of degree to which PD affects communication, n(%))	Not at all: 11 (24%) A little: 24 (53%) Quite a bit: 9 (20%) Very much: 1 (2%)	NA

Figures are mean (SD) unless stated. Intelligibility is scored as % words correctly identified. Emotional conveyance is scored as % tokens for which emotion was correctly identified.

Supplementary table 1. Statistical details for acoustic analysis of read sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA *Gender
Intensity	59.54 (4.73)	62.27 (4.81)	61.98 (8.22)a	63.49 (1.81)	62.90 (2.75)	63.13 (2.39)	4.13*	2.81	-2.89	6.87**	-10.1*
Intensity decay	5.42 (4.72)	5.05 (3.87)	5.52 (4.60)	3.83 (3.34)	3.17 (5.67)	3.43 (4.79)	-1.73	-0.69	0.04	1.55	1.04
Mean F_0	137.30 (18.46)	185.80 (25.32)	155.96 (30.83)	116.00 (11.41)	190.10 (27.78)	161.28 (43.38)	-19.80?	42.80***	30.70*	28.70*	1.04
SD of F_0	21.36 (8.18)	26.60 (6.09)	23.32 (7.70)	20.73 (6.52)	38.13 (9.26)	31.36 (11.90)	0.95	7.01*	9.63?	6.92?	-14.5*
Speech rate	3.73 (0.43)	3.83 (0.80)	3.77 (0.57)	4.18 (0.43)	3.54 (0.33)	3.79 (0.48)	0.57*	0.26	-0.92**	0.64?	-0.34
Acceleration	40.28 (31.49)	55.63 (35.22)a	42.31 (30.06)	51.76 (8.80)	43.94 (14.50)	46.98 (12.90)	9.97	1.10	-9.02	-15.9	-1.85
Adjusted speech rate	3.90 (0.39)	4.03 (0.69)	3.95 (0.50)	4.27 (0.37)	3.63 (0.31)	3.88 (0.46)	0.38?	0.14	-0.81**	0.48	-0.12
Adjusted acceleration	41.96 (15.37)	50.49 (23.91)	45.16 (18.72)	49.97 (14.63)	48.41 (14.41)	49.01 (14.08)	6.31	3.43	-5.00	-2.19	-15.50
Pause	2.65 (3.86)a	1.62 (5.52)a	2.39 (3.84)a	0.61 (4.74)a	2.34 (1.69)	1.40 (3.78)a	-5.13*	-4.09?	4.50	-5.23	6.85
Within-word pause	0.00 (4.51)a	0.00 (6.25)a	0.00 (4.74)a	0.00 (NA)a	0.00 (0.00)a	0.00 (0.00)a	-2.54?	-0.16	0.68	-2.45	6.26
Iteration	0.00 (0.22)a	0.45 (0.59)	0.03 (0.41)a	0.00 (0.00)a	0.00 (0.06)a	0.00 (0.06)a	-0.15	0.21	-0.18	-0.22	0.50
Within-word iteration	0.00 (11.81)a	6.25 (9.94)a	0.63 (9.36)a	0.00 (NA)a	0.00 (5.20)a	0.00 (0.52)a	-4.94	3.73	-2.00	-5.60	12.10
Jitter /i/	2.43 (0.58)	1.94 (0.74)a	2.19 (0.78)a	2.81 (0.65)	2.24 (0.44)	2.45 (0.58)	0.39	-0.16	-0.42	-0.03	0.49
Jitter /ɑ/	2.07 (1.22)a	1.73 (0.82)	1.97 (1.50)a	1.90 (0.60)	1.54 (0.48)	1.67 (0.54)	-0.50	-0.71?	0.36	-0.83	1.77

Jitter /u/	1.76 (0.75)	1.55 (0.68)	1.69 (0.71)	1.98 (0.41)	1.79 (0.83)	1.86 (0.70)	0.18	-0.17	0.09	-0.57	1.08
Shimmer /i/	15.12 (2.28)	13.43 (2.62)	14.53 (2.48)	16.87 (1.70)	14.18 (1.41)	15.17 (1.99)	1.71?	-1.59?	-1.11	-1.67	3.51
Shimmer /ɑ/	15.10 (2.41)	14.67 (2.89)	14.95 (2.52)	17.25 (3.13)	15.20 (2.70)	15.95 (2.96)	2.07	-0.56	-1.49	-0.91	3.73
Shimmer /u/	13.39 (2.75)	11.61 (2.99)	12.77 (2.89)	16.21 (2.90)	12.81 (3.06)	14.06 (3.37)	2.64?	-2.00	-1.40	-1.72	2.84
HNR /i/	8.95 (2.70)	11.55 (2.68)	9.86 (2.92)	7.29 (1.38)	10.43 (1.29)	9.27 (2.02)	-1.58	2.47*	0.67	3.77*	-4.65?
HNR /ɑ/	8.20 (2.66)	9.94 (2.07)	8.81 (2.56)	7.31 (1.49)	10.00 (2.26)	9.01 (2.37)	-0.82	1.69	0.99	4.10**	-6.12**
HNR/u/	11.36 (3.02)	14.25 (2.88)	12.46 (3.28)	9.67 (1.51)	13.24 (2.27)	11.89 (2.72)	-1.68	2.55*	1.02	3.74*	-3.29
FCR	1.37 (0.24)a	1.37 (0.11)	1.35 (0.18)a	1.35 (0.09)	1.29 (0.12)	1.31 (0.11)	-0.08	-0.07	0.01	-0.09	0.13
SD of /s/ amplitude	1.91 (1.37)a	2.43 (0.83)	2.28 (0.71)	1.87 (0.32)	2.25 (0.36)	2.11 (0.40)	-0.33	0.20	0.19	-0.51	0.78
VOT /pɒ/	0.24 (0.06)	0.27 (0.08)	0.26 (0.07)	0.27 (0.07)	0.27 (0.06)	0.28 (0.06)	0.02	0.00	0.00	0.03	0.01
VOT /tɛ/	0.37 (0.12)	0.40 (0.06)	0.38 (0.10)	0.40 (0.06)	0.35 (0.08)	0.37 (0.07)	0.03	0.01	-0.07	0.09	-0.11
VOT /pɑ/	0.18 (0.08)	0.24 (0.08)	0.20 (0.86)	0.19 (0.06)a	0.16 (0.04)	0.16 (0.04)a	0.02	0.00	0.00	-0.01	0.01
VOT /tu/	0.32 (0.07)	0.36 (0.05)	0.34 (0.07)	0.35 (0.09)	0.30 (0.05)	0.32 (0.07)	0.03	0.05	-0.09?	0.05	-0.08
VOT /kɒ/	0.34 (0.07)	0.34 (0.06)	0.34 (0.07)	0.35 (0.04)	0.32 (0.07)	0.34 (0.06)	0.00	0.56	-0.01	0.07	-0.05

Descriptives are shown as mean (SD), unless marked with ‘a’ in which case they refer to median (IQR). * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, symbols in // are phonemes transcribed using the International Phonetic Alphabet. HNR = Harmonic to Noise Ratio, FCR = Formant Centralization Ratio, VOT = Voice Onset Time

Supplementary table 2. Statistical details for acoustic analysis of conversational sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA * Gender
Intensity	57.56 (5.12)	60.92 (5.89)	58.79 (5.51)	61.10 (4.70)	60.28 (4.51)	60.60 (4.47)	3.69	3.56	-4.92	4.73	-9.44?
Intensity decay	1.10 (5.15)	-0.95 (4.56)	0.35 (4.92)	1.32 (3.74)	-0.71 (8.20)	0.08 (6.75)	0.31	-1.57	-0.46	4.58	-3.97
Mean F_0	130.47 (16.11)	179.63 (23.50)	145.58 (30.60)	118.44 (21.60)	189.33 (37.94)	161.76 (47.70)	0.39	45.30***	24.00	19.90	-27.50
SD of F_0	23.06 (8.75)	27.45 (9.48)	24.68 (9.03)	18.01 (9.78)	33.59 (12.22)[a]	30.51 (15.58)	-2.95	7.94?	11.00	-0.46	-12.50
Speech rate	4.70 (0.64)	4.71 (0.74)	4.70 (0.66)	5.20 (0.52)	4.34 (0.71)	4.67 (0.76)	0.37	-0.19	-0.49	0.25	0.17
Acceleration	25.22 (39.70)	-4.05 (26.71)	14.44 (37.57)	6.88 (30.38)	11.43 (26.25)	9.66 (27.13)	-20.60	-31.00*	35.60	-13.70	6.17
Adjusted speech rate	4.93 (5.09)	4.96 (0.60)	4.94 (0.57)	5.54 (0.41)	4.62 (0.82)	4.98 (0.82)	0.51	-0.14	-0.65	0.32	0.10
Adjusted acceleration	13.07 (21.93)	-4.42 (20.03)	6.62 (22.42)	2.15 (26.81)	10.57 (22.39)	7.29 (23.80)	-12.60	-19.20?	27.60?	1.15	-5.16
Pause	6.05 (10.59)[a]	4.87 (5.40)	4.02 (9.84)[a]	6.50 (4.54)	4.44 (4.17)	4.77 (4.33)	1.01	-0.54	-2.13	-2.74	0.15
Within-word pause	0.00 (NA)[a]	0.00 (0.00)[a]	0.00 (0.00)[a]	0.00 (NA)[a]	0.00 (NA)[a]	0.00 (0.00)	0.00	0.90?	-0.90	0.00	1.44
Iteration	0.00 (0.10)[a]	0.40 (1.00)[a]	0.00 (0.35)[a]	0.34 (0.38)	0.00 (0.40)[a]	0.10 (0.40)[a]	0.31	0.72	-0.87**	0.01	0.66
Within-word iteration	0.00 (0.00)[a]	0.00 (19.00)[a]	0.00 (0.00)[a]	0.00 (10.00)[a]	0.00 (0.00)[a]	0.00 (0.00)	5.71*	7.38**	-12.30***	0.00	6.47

Descriptives are shown as mean (SD), unless marked with 'a' in which case they refer to median (IQR). * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, ? = $0.05 < p < 0.1$.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment.

Supplementary table 3. Statistical details of acoustic analysis for emotional conveyance sentences

Part A. Descriptives

	PD			CP		
	Male	Female	All	Male	Female	All
Intensity H	61.71 (5.21)	65.22 (3.61)	63.12 (4.86)	66.55 (2.43)	64.49 (3.57)	65.21 (3.30)
Mean F_0 H	168.98 (35.75)	204.39 (28.97)	183.15 (36.96)	155.97 (12.36)	240.15 (28.59)	210.69 (47.56)
SD of F_0 H	35.63 (14.04)	43.97 (12.16)	38.96 (13.64)	35.70 (11.54)a	63.40 (15.94)	55.16 (18.57)
Speech rate H	4.33 (0.63)	4.18 (0.51)	4.27 (0.57)	4.90 (0.49)	4.90 (0.38)	4.25 (0.63)
Adjusted speech rate H	4.46 (0.57)	4.19 (0.51)	4.35 (0.55)	4.91 (0.49)	4.91 (0.38)	4.26 (0.64)
Pause H	0.00 (4.53)a	0.00 (0.00)a	0.00 (3.00)a	0.00 (0.00)a	0.00 (0.00)a	0.00 (0.00)a
Intensity N	58.83 (5.33)	60.96 (4.45)	59.68 (4.99)	61.77 (3.46)	60.09 (4.28)	60.68 (4.00)
Mean F_0 N	132.84 (19.30)	172.90 (30.85)	148.86 (31.17)	117.66 (13.49)	186.46 (18.23)	162.38 (37.43)
SD of F_0 N	18.50 (5.59)a	29.67 (13.02)	20.82 (9.83)a	27.19 (4.31)	34.60 (9.35)	32.01 (8.62)
Speech rate N	4.45 (0.73)	4.60 (0.65)	4.51 (4.46)	4.77 (0.55)	4.21 (0.28)	4.41 (0.47)
Adjusted speech rate N	4.53 (0.67)	4.62 (0.63)	4.57 (0.64)	4.82 (0.54)	4.22 (0.27)	4.38 (0.47)a
Pause N	0.00 (1.62)a	0.00 (0.00)a	0.00 (0.82)a	0.00 (1.14)a	0.00 (0.00)a	0.00 (0.00)a
Intensity S	57.81 (6.19)	62.15 (3.69)	59.55 (5.65)	62.78 (2.50)	59.88 (4.88)	60.89 (4.36)
Mean F_0 S	133.00 (27.26)	172.45 (33.36)	148.78 (35.12)	116.04 (15.11)	186.91 (25.09)	162.10 (40.90)
SD of F_0 S	17.83 (8.95)a	31.64 (9.71)	25.29 (12.06)	23.86 (5.39)	34.60 (11.02)	30.85 (10.65)

Speech rate S	4.00 (0.74)	3.79 (0.56)	3.92 (0.66)	4.03 (0.64)	3.40 (0.44)	3.62 (0.59)
Adjusted speech rate S	4.02 (0.73)	3.80 (0.56)	3.93 (0.66)	4.03 (0.64)	3.41 (0.44)	3.63 (0.59)
Pause S	0.00 (NA)	0.00 (0.53)a	0.00 (0.00)a	0.00 (NA)	0.00 (0.56)a	0.00 (0.00)a

Descriptives are shown as mean (SD), unless marked with ‘a’ in which case they refer to median (IQR). H = happy mood, N = neutral mood, S = sad mood.

PD = people with Parkinson’s disease, CP = conversation partner controls, F_0 = fundamental frequency.

Part B. Mean differences associated with predictors

	Group	Gender	Group * Gender	MoCA	Mood (N-H)	Mood (S-H)	Gender * Mood (N-H)	Gender * Mood (S-H)	MoCA * Mood (N-H)	MoCA * Mood (S-H)	Group * Mood (N-H)	Group * Mood (S-H)
Intensity	4.83*	-3.49?	5.54*	1.86	-3.23***	-3.58***	-0.52	0.02	-1.59	-1.25	-0.97	-0.76
Mean F_0	-6.43	41.47***	36.32**	17.27	-32.24***	-32.60***	-5.10	-4.41	-12.09	-19.34	-12.75	-13.12
SD of F_0	9.91*	13.58***	4.44	4.06	-12.03***	-11.65***	-7.29	-5.08	-7.28	-7.22	-6.37	-9.36*
Speech rate	0.47?	-0.24	-0.66*	0.65*	0.09	-0.42***	0.37*	0.15	0.01	-0.21	-0.17	-0.32*
Adjusted speech rate	0.38	-0.32	-0.61*	0.56*	0.07	-0.51***	0.37*	0.21	0.03	-0.11	-0.13	-0.26
Pause	-2.03*	-1.85*	0.99	-2.07	-1.27*	-2.56***	0.64	1.78*	0.92	1.76	1.14	1.49?

F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, H = happy mood, N = neutral mood, S = sad mood. * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

BMJ Open

Speech and communication in Parkinson's disease: a cross-sectional exploratory study in the United Kingdom

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2016-014642.R3
Article Type:	Research
Date Submitted by the Author:	19-Mar-2017
Complete List of Authors:	Barnish, Maxwell; University of East Anglia, School of Health Sciences, Faculty of Medicine and Health Sciences Horton, Simon; UEA, Health Sciences Butterfint, Zoe; University of East Anglia, School of Health Sciences, Facilty of Medicine and Health Sciences Clark, Allan Atkinson, Rachel ; St Helier Hospital, London, UK, Adult Speech and Language Therapy Department Deane, Katherine; University of East Anglia, School of Health Sciences
Primary Subject Heading:	Rehabilitation medicine
Secondary Subject Heading:	Communication, Neurology
Keywords:	Parkinson-s disease < NEUROLOGY, REHABILITATION MEDICINE, GERIATRIC MEDICINE

Speech and communication in Parkinson's disease: a cross-sectional exploratory study in the United Kingdom

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ABSTRACT

Objective: To assess associations between cognitive status, intelligibility, acoustics and functional communication in PD.

Design: Cross-sectional exploratory study of functional communication, including a within-participants experimental design for listener assessment

Setting: A major academic medical centre in the East of England, United Kingdom.

Participants: Questionnaire data were assessed for 45 people with Parkinson's disease (PD) who had self-reported speech or communication difficulties and did not have clinical dementia. Acoustic and listener analyses were conducted on read and conversational speech for 20 people with PD and 20 familiar conversation partner (CP) controls without speech, language or cognitive difficulties.

Main outcome measures: Functional communication assessed by the Communicative Participation Item Bank (CPIB) and Communicative Effectiveness Survey (CES).

Results: People with PD had lower intelligibility than controls for both the read (mean difference 13.7%, p=0.009) and conversational (mean difference 16.2%, p=0.04) sentences. Intensity and pause were statistically significant predictors of intelligibility in read sentences. Listeners were less accurate identifying the intended emotion in the speech of people with PD (14.8% point difference across conditions, p=0.02) and this was associated with worse speaker cognitive status (16.7% point difference, p=0.04). Cognitive status was a significant predictor of functional communication using CPIB (F=8.99, p=0.005, $\eta^2 = 0.15$) but not CES. Intelligibility in conversation sentences was a statistically significant predictor of CPIB (F=4.96, p=0.04, $\eta^2 = 0.19$) and CES (F=13.65, p=0.002, $\eta^2 = 0.43$). Read sentence intelligibility was not a significant predictor of either outcome.

Conclusions: Cognitive status was an important predictor of functional communication – the role of intelligibility was modest and limited to conversational and not read speech. Our results highlight the importance of focusing on functional communication as well as physical speech impairment in Speech and Language Therapy (SLT) for PD. Our results could inform future trials of SLT techniques for PD.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- We provide the first same-study overview of associations at various stages along the potential pathway to reduced functional communication in Parkinson's disease (PD).
- Ours is the first study to consider the acoustic characteristics of the speech of British people with PD.
- Our study was cross-sectional and therefore cannot provide definitive insight into causality.
- Studies in this field, including ours, tend to have smaller sample sizes than many other fields in applied health science research, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population.

INTRODUCTION

Parkinson's disease (PD) affects around 1.5% of people aged over 65 in Europe.[1] Originally conceptualised predominantly in terms of its motor features,[2] PD is now recognised to be a multifaceted condition.[3] Indeed, non-motor symptoms, such as cognitive impairment affecting over a quarter of people with PD,[4] are believed to exert a substantial effect on quality of life.[5] Speech impairment,[6] at the impairment level of the International Classification of Functioning (ICF),[7] as well as functional communication difficulties,[8] at the ICF activity and participation levels, are also widespread in PD. The mainstay of medical treatment for PD is levodopa-based pharmacotherapy,[9] although non-adherence,[10] dyskinesia[11] and a lack of clear benefit on speech and cognition are problematic.[12-14] Therefore, a wide range of supplementary therapies can be used, including singing,[15] dance[16] and speech-and-language therapy (SLT). SLT is popular among people with PD and families alike,[17] but there is no definitive randomised controlled trial evidence for the effectiveness of currently tested SLT techniques.[18] Moreover, the content and focus of SLT provision can vary markedly between localities. In the UK, the focus has traditionally been on motor function. In a survey conducted in 2007, functional communication was not reported to constitute a major part of many UK SLT's clinical practice for PD,[19] although clinical contacts suggest that the situation has improved in recent years. Recently, M.S.B. and S.M.C.H. published a clinical magazine feature article[20] to emphasise the importance of functional communication to SLT clinicians.

Functional communication has been shown to be more important to people with PD than motoric speech impairment.[21] Moreover, although it is an important predictor of quality of life,[22] functional communication has received relatively limited research attention compared to motoric speech impairment. A systematic review of the literature up to July 2015[23] found that nine studies prior to ours had assessed the association between cognitive status and functional communication in PD, of which eight had found a positive association. However, none had used a cognitive assessment sensitive to mild cognitive impairment in PD and a validated outcome measure that assessed either communicative effectiveness or communicative participation as a unified concept. Therefore, these studies may have failed to detect mild cognitive impairment short of dementia and also to accurately capture the concept of functional communication, resulting in potential inaccurate measurement of both independent and dependent variables. In addition, while three prior studies had found an association between intelligibility and communicative outcomes, only one study[24-25] used a standardised validated assessment tool – the Communicative Effectiveness Survey (CES).[24-25] However, CES covers the ICF activity level, not the ICF participation level. Subsequent to our review, one further large study[22] has assessed functional communication outcomes in PD and found that people with PD with self-reported worse cognitive status and intelligibility had more difficulties in communicative participation. The size of this study is a major strength, but the study relied entirely on self-report data, which is a substantial limitation with regard to assessing cognitive status and intelligibility accurately.

Taking a wider perspective on communication difficulties in PD and potentially associated risk factors, it is important to note that no study in the published literature has provided an overview of the elements and potential mechanisms for change in the pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. There has been no comparative overview of which acoustic features are most predictive of reduced intelligibility. However, the available literature suggests that increased articulatory phonological distinctiveness[26-27] and loudness[28-29] may be associated with better intelligibility, with the latter having beneficial effects on the distinctiveness of speech in PD besides loudness itself.[29] Additionally, no study of speech acoustics has used speech that we considered to be naturalistic conversational dialogue – for example, the 'conversational' speech in the study by Goberman and Elmer[30] was a standard passage read out in the style of conversational speech. Moreover, the ability to communicate emotions effectively is important in everyday life[31] and studies have shown that reduced pitch variation and facial expression can cause negative evaluations of the personality of people with PD.[32-35] Additionally, people with PD have been shown to have impaired perception of the intended emotion in the speech of others,[36-38] which may relate at least partly to impaired mesolimbic processing.[39] However, normal listeners' ability to identify specific emotions in the speech of people with PD has attracted limited research attention. Miller *et* al[40] showed that listeners were less likely to correctly identify the intended emotion in the speech of people with PD when auditory and visual information were both available. It was suggested that this effect

may result from a lack of temporal synchronization in the speech of people with PD. Meanwhile, Pell *et al*[41] also found reduced ability to identify emotions in the speech of people with PD, especially for anger and disgust, but did not assess presentation modality.

Informed by limitations in the existing literature, we conducted an exploratory study focusing on functional communication in PD as our primary outcome. This is an area that has received relatively little research attention, yet corresponds well to the priorities of people with PD.[21] We conducted a study to provide an overview of associations along the potential pathway to functional communication difficulties in PD, since no prior study had done this. In addition, we added an aspect on emotional conveyance in order to further investigate the possibilities raised by Miller *et* al,[40] especially with regard to presentation modality effects. Our key research questions for this study are:

- How does cognitive status associate with functional communication in PD, as measured by the Communicative Participation Item Bank (CPIB, primary research question) and CES?
- What is the test-retest reliability and convergent validity of CPIB in our UK context?
- How does intelligibility, in both read and conversational sentences, associate with functional communication in PD?
- What were the acoustic differences between the speech of people with PD and CPs in our sample; how did the intelligibility of these groups

differ in read and conversational speech; and what acoustic factors predicted intelligibility outcomes?

- How did the emotional conveyance of people with PD and CPs differ, which mood contrasts were particularly affected, and did presentation modality (audio vs audiovisual) play a role?

MATERIALS AND METHODS

Design

In order to assess associations along the potential pathway to functional communication difficulties in PD, we used a cross-sectional design, into which we embedded a within-participants experimental design for listener assessment. Ours is a clinical linguistics/ academic SLT study, rather than epidemiology. Our study also draws on some methods commonly used in psychology. Therefore, there is no suitable reporting guideline to follow. Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Participants

Our study recruited from the Neurology and Medicine for the Elderly outpatient clinics at a major academic medical centre in the East of England region in 2012-2013. Patients were eligible for the study if they i) were aged at least 18, ii) had idiopathic PD according to the United Kingdom Parkinson's Disease Society Brain Bank criteria,[42] iii) had no clinical indication of dementia, iv) had no other serious medical conditions that would affect cognitive status or speech, v) were not considered by clinical staff to be unsuitable for the study, for example due to personal circumstances, vi) were native English speakers and vii) reported having some difficulty with their speech and/or communication. Participants with PD were asked to invite a familiar conversation partner control (CP) to join them in the study where possible. CPs had to i) be aged at least 18, ii) be a native English speaker, iii) not have PD and iv) not have any serious medical problems affecting cognition or speech. Written informed consent was obtained from all participants prior to the commencement of study procedures.

Measures and data collection

The study consisted of one appointment typically of around 45 minutes after consent, which could take place either at home or at the University of East Anglia. Initially, participants completed a demographic form, which for people with PD provided their medication information which allowed their Levodopa Equivalent Daily Dose (LEDD)[43] to be calculated. LEDD served as a proxy measure of non-speech-specific PD motor symptom severity. Validated assessments of cognitive status (Montreal Cognitive Assessment, MoCA[44-45]), mood (Hospital Anxiety and Depression Scale, HADS[46-48]), communicative effectiveness (CES[24-25,49]) and communicative participation (Communicative Participation Item Bank, CPIB[50-]) were completed. CPIB was chosen as our primary measure of functional communication since it specifically assesses ICF participation level difficulties that have been shown to be most important to people with PD,[21] and also has been thoroughly developed using item-response theory methods[50] and subsequent validated in PD in the United States and New Zealand, which are English-speaking countries.[51]Therefore, we assessed test-retest reliability by sending out a second copy of CPIB by post two weeks after the study visit and assessed convergent validity using

CES in our UK setting. As per the terms of our ethical approval, cognitive, mood and functional communication assessments were only administered to participants with PD and not to CPs.

Audiovisual recordings were obtained of all participants' (PD and CP) speech at a standardised distance of 1.5m using Panasonic NV-GS17 (Panasonic, Corporation, Osaka, Japan) video cameras. Video was encoded in high quality 48 kHz AVI format, from which high quality 44.1 kHz WAV audio files could be extracted. Participants first read a standardised set of sixteen sentences taken from the Assessment of Intelligibility of Dysarthric Speech (AssIDS) assessment tool.[52] Then, participants held a short conversation on a topic of their choice in an exercise that was intended to offer as naturalistic speech as possible. Besides offering support to people with PD in completing questionnaires where required, this was the main advantage of including familiar CPs in the study – King and Gallegos-Santellan have shown that people with dysarthria use different strategies with familiar and unfamiliar conversation partners.[53] Finally, participants read four standardised sentences in three ways: happy, sad and neutral. All sentences contained words of moderate to high frequency and did not have an intrinsic emotional connotation. Three of the sentences were taken with permission from Miller *et al*[40], namely "The cake is too yellow", "You dropped the sausages in the trifle" and "Sam is not a dog". One further sentence was generated by the research team: "He went to the park".

Data analysis

Speech sample analysis (acoustics, intelligibility and emotional conveyance) was conducted on a purposive sample of 20 people with PD and 20 CPs. In order to generate our purposive sample, firstly, any samples that suffered from technical failure, other issues such as road noise and non-compliance with the task instructions were excluded. Then, selection sought to achieve a balanced profile of demographic and clinical features among people with PD and maximise comparability of demographics between the PD and CP groups, within the bounds of what was available in our sample. Only people with PD who provided a CP were considered. Age, gender, accent and perceived severity of speech disorder were also considered in selection. In particular, it was important to ensure generalisability of the PD sample. As we used standardised read sentences in the intelligibility assessment, we designed this part of the study so that each script sentence would only be rated twice by each assessor in order to avoid stimulus exposure effects and learning bias.[54-55] Assessment of self-report measures could be conducted on the full sample of 45 people with PD, but could not be conducted on CPs as we did not gather these data for ethical reasons.

Acoustic (phonetic) analysis was conducted by M.S.B. using Praat software (P. Boersma & D. Weenink, University of Amsterdam) and a reliability check of a randomly selected 10% sample of acoustic data points drawn from 10 different participants (25% of the phonetic analysis sample size) was completed by Senior Lecturer in Phonetics Z.R.B. Acoustic measures covered four broad domains[56-58] – initiation (the production of airflow), prosody (rhythm and melody), phonation (voicing) and articulation (the modification of sound waves by the resonant properties arising from different vocal tract configurations). A list of measures with a brief description of each is provided in Table 1. Sentence-level parameters were calculated for conversational and mood sentences. Phoneme-level parameters were additionally calculated for the set of 16 standardised read sentences.

Sixty-four assessors (88% female, median age 22) served as members of the study team to conduct assessment of speech samples for intelligibility and emotional conveyance. Assessors had to be i) members of the University of East Anglia (UEA, for ethical reasons), ii) fluent English speakers and iii) not having significant expertise in listening to disordered speech (for example SLT staff, final year SLT students and those with a close member with PD or working with groups or individuals with PD as part of their course or extra-curricular activities. Twenty tracks (each comprising a different combination of utterances and speakers) were created in EditStudio software (MediaChance, Ottawa, Canada) with stimulus allocation based on a Latin Square design[59] and randomised presentation order. All tracks were rated three times and four tracks were rated an additional time, meaning that each token spoken by each participant was rated by at least three different assessors. The intelligibility task was transcription and following AssIDS protocol, the outcome measure was % words correctly identified. This was scored separately for read and conversational sentences and the transcript for the latter was agreed between authors M.S.B. and S.M.C.H. The emotional conveyance task was to circle which of three options (happy, neutral or sad) the speaker intended to convey and the outcome measure was % moods correctly identified following Miller *et* *al*.[40] In the intelligibility task, all stimuli were presented audiovisually, while in the emotional conveyance tasks, half were presented audiovisually and half in audio only. In all listener assessment tasks, assessors could only listen to each sentence once and sentences from people with PD and CPs were matched for length. The rationale for including an audio-only condition in the emotional conveyance assessment was to test the preliminary finding by Miller *et al*[40] that listeners were less likely to correctly identify the intended emotion in the speech of people with PD when auditory and visual information were both available. In contrast, for intelligibility assessment, we wanted to replicate the most common real-life listening conditions through presenting audiovisual information.

Statistical aspects of the study were overseen by Senior Lecturer in Medical Statistics A.B.C. The sample size was powered on the primary research question, to assess the relationship between cognitive status and CPIB scores in people with PD. Since this is an association rather than a group difference, we used a power calculation tool for observational designs .[60] The effect size to use for the power calculation was determined by senior statistician A.B.C. informed by i) preliminary systematic literature searches by the research team that later became our systematic review[23] and ii) the research team's combined wider theoretical, scientific and clinical knowledge and expertise about communication in neurological conditions such as PD, which both informed us to expect a moderate relationship between cognitive status and functional communication in PD. Therefore, a power calculation was run to state the minimum number of people with PD we would require to have 80% power to detect an expected association equivalent to r=0.5 for this relationship. This gave us an uncorrected target sample size of 30. Following discussion with our steering committee, as approved by the ethics board, we decided to recruit a minimum of 40 and a maximum of 45 people with PD as our attrition and exclusion corrected target sample size. The reasons for seeking to recruit a minimum of 10 additional participants (33%) above the minimum target from the power calculation were that: i) we were recruiting from an older, often frail population whose clinical severity we did not know ahead of the study visit for ethical reasons, ii) our study population was a group that may experience high fatigue, making the risk of non-completion of the study visit difficult to predict, iii) the potential of withdrawal of scheduled participants due to death, serious illness or other personal reasons, iv) the potential that scheduled participants may be ineligible or unwilling/unable to give informed consent at the study visit, and v) the fact that our study involved making audiovisual recordings in participants' homes where our speech science experts predicted an elevated risk of technical failure and issues with recording quality for example due to pets or road noise. . Stata (Stata Corp, College Station, Texas) and SPSS (IBM Inc, Armonk, New York) software was used for statistical analysis. Appropriate linear regression models were constructed to assess i) differences in speech acoustics between people with PD and CPs and the contribution of cognitive status to speech acoustics of people with PD, ii) differences in intelligibility and the contribution of cognitive status and particular acoustic characteristics, iii) differences in the acoustic correlates of happy, neutral and sad mood and the contribution of cognitive status, iv) differences in emotional conveyance and the contribution of cognitive status and particular acoustic characteristics, v) the contribution of cognitive status and intelligibility to functional communication as measured by CES and CPIB. The test-retest reliability of CPIB was assessed using interclass correlation and its convergent validity with CES using correlation. Due to the exploratory nature of the study, the fact that analysis was on a range of outcome measures rather than repeated analysis of the same outcome measure and the fact that all comparisons were planned in advance, it was decided a priori not to perform adjustment for multiple testing[61]. A p-value of $p<0.05$ was considered significant and variables associated at $p<0.1$ were retained in models as marginally significant. There were limited missing data, only one participant had missing data for the CPIB outcome measure and none for CES. Full case analysis was used.

RESULTS

Participants

Forty five people with PD and 29 CPs were recruited. Forty-five people with PD contributed to the questionnaire analysis. The mean age was 71.0 (SD 8.1), 28 (62%) were male and the most common educational category was to have no formal educational qualifications (n=17, 38%).

Among the 20 people with PD whose data were used for speech sample analysis, the mean age was 71.1 (SD 9.0), 23 (65%) were male and the most common educational category was shared between no formal educational qualifications and vocational qualifications (both n=7, 35%). Table 2 presents the clinical characteristics of both the full (n=45) and purposive (n=20) samples of people with PD.

Among the 20 CPs whose data were used for speech sample analysis, the mean age was 70.0 (SD 10.4), 7 (35%) were male and the most common educational category was to have vocational qualifications (n=8, 40%).

Speech acoustics and intelligibility

Table 3 profiles the principal speech and communication measures in our study. The overall concordance rate was r=0.99 for inter-rater reliability of acoustic measures. In read sentences, people with PD had lower speech intensity and greater pause time than CPs. For other measures, there was either no significant difference, a marginally significant difference or an effect that applied only for one gender. MoCA was associated with intensity, although the effect was in opposite directions for men and women – men with PD with better cognitive status spoke more loudly, while women with PD with better cognitive status spoke more quietly. MoCA was not associated with pause. In conversational sentences, people with PD had higher within-word iteration than CPs. This was not associated with MoCA. Statistical details on the main effects and interactions can be found in Supplementary tables 1 (read sentences) and 2 (conversational sentences).

Assessors were significantly less accurate in transcribing both the read (mean difference = 13.7 percentage points, p=0.009) and conversational (mean difference = 16.2 percentage points, p=0.04) speech of people with PD compared to CPs. In neither case was there an association between MoCA and intelligibility. In read sentences, intensity (mean difference = 2.4 percentage points per dB SPL, p=0.04) and pause (mean difference = 3.6

percentage points per percentage unit change in pause, p=0.04) were identified as significant predictors of listener accuracy – assessors were more accurate in transcribing the read speech of people with PD who spoke more loudly and paused less. No significant acoustic predictors of conversational sentence intelligibility were identified. Gender was not a statistically significant predictor of intelligibility.

Emotional conveyance

In the emotion sentences, men with PD spoke more quietly than CPs, women with PD had significantly reduced mean fundamental frequency compared to CPs, both men and women with PD had significantly reduced SD of fundamental frequency, men with PD had significantly reduced speech rate (but not adjusted speech rate) and both men and women with PD had significantly increased pause time. In the PD group, participants with MoCA below median had significantly lower speech rate and adjusted speech rate. Main effects of mood were found within the PD group for most measures, meaning that people with PD were on the whole able to distinguish emotions in their speech, although distinctions were reduced relative to CPs. Significant and marginally significant group by emotion interactions, for happy vs sad, suggest that people with PD were particularly impaired in the production of happy emotion. Statistical details on the main effects and interactions can be found in Supplementary table 3.

Listeners were significantly less accurate in identifying the intended emotion (happy, neutral or sad) in the speech of people with PD compared to CPs (mean difference = 14.8 percentage points, p=0.04). A significant interaction between group and emotion (mean difference for group * emotion (sad vs happy) = 17.8 percentage points, $p<0.001$) shows that the impact of PD on listener accuracy was greater for happy mood. There was no significant effect of presentation modality (audiovisual vs audio only) on listener accuracy. There was a significant effect of MoCA (mean difference = 16.7 percentage points between participants scoring above and below the median, $p=0.04$), showing that listeners had more difficulty in identifying emotion in the speech of people with PD with greater cognitive impairment. A significant interaction between MoCA and emotion (mean difference for MoCA (median split) * emotion (sad vs happy) = 23.2 percentage points, $p=0.009$), showing that the differential effect of PD on happy mood conveyance was less for those with more intact cognition.

CPIB showed satisfactory test-retest reliability ($r=0.85$, $p<0.001$) and validity ($r=0.74$, $p<0.001$) in our population, noting that CPIB and CES are measures of related but not identical constructs, so a higher concordance would have been unexpected. In the full sample, MoCA ($F=8.99$, $p=0.005$, $\eta^2 = 0.15$) and HADS ($F=8.73$, $p=0.005$, $\eta^2 = 0.15$) were retained as significant predictors of CPIB, while HADS ($F=20.18$, $p<0.001$, $\eta^2 = 0.32$) was the only significant predictor of CES, but a marginally significant finding for LEDD ($F=3.72$, $p=0.06$, $\eta^2=0.06$). With regard to MoCA sub-domains, the Executive and Visuospatial ($F=3.22$, $p=0.08$, $\eta^2=0.05$) and Attention ($F=3.05$, $p=0.09$, $\eta^2=0.05$) sub-domains were both marginally significant predictors of CPIB. Among the purposive sample for whom intelligibility scores were available, MoCA ($F=5.32$, $p=0.04$, $\eta^2=0.20$) and intelligibility in conversational sentences

(F=4.96, p=0.04, $\eta^2 = 0.19$), but not intelligibility in read sentences, were significant predictors of CPIB, while only intelligibility in conversational sentences (F=13.65, p=0.002, $\eta^2 = 0.43$) was a significant predictor of CES.

DISCUSSION

The study presented in this article is the first to provide an overview of associations along the potential pathway from cognitive status and motoric speech impairment (acoustics) through reduced intelligibility to difficulties with emotional conveyance and functional communication in PD. We also include a combination of self-reported and observed measures, an approach which avoids one of the key limitations associated with larger studies, such as that by McAuliffe *et al*[22] that only include self-report measures. Ours is also the first to study the acoustics of the speech of British people with PD, mindful that there are notable acoustic differences between British and American English.[62-63]

The first main finding was that intelligibility was reduced in both read and conversational speech for people with PD compared to controls, and the effect was greater on conversational sentences, potentially reflecting the greater cognitive and perceptual challenges of spontaneous speech. The second main finding was that acoustic differences between people with PD and CPs in our sample were modest and few were statistically significant, although many participants in our study had relatively mild motoric speech difficulties. The results of our study reflect the natural hierarchy that can emerge in clinical practice, starting initially with work on physical aspects of read speech due to the cognitive demands of altering one's speech and then progressing to less structured tasks that generalize more readily to everyday conversation (R.A. Atkinson, personal communications).

The third main finding was that emotional conveyance, especially of happy emotion, was impaired in people with PD compared to CPs. The fourth main finding was that, despite a relatively mild profile of motoric speech deficits, participants often had difficulties with functional communication. Intelligibility did not account for a large proportion of variance in functional outcomes, emphasising the need to account for and include other elements in functional communication tasks in SLT for people with PD to overcome the challenge with generalization from the clinic to everyday life. Cognitive status predicted CPIB and emotional conveyance, but not intelligibility or CES. This may imply a greater role for cognitive status with regard to participation-level phenomena.

Our identification of reduced intelligibility in people with PD compared to CPs is in line with previous studies and in particular our identification of intensity as a key predictor of intelligibility (although only found for read sentences in our study) corroborates the prior findings of Tjaden and Sussman[28] and Neel,[29] while our identification of pause suggests a potentially novel acoustic correlate of intelligibility in PD. Our study is the first to compare conversational and read speech intelligibility in PD and found that intelligibility was lower in conversational sentences, which is explicable in terms of contextual effects and the lower distinctiveness of more spontaneous speech and therefore the potential for a lower ability on the behalf of listeners to adjust for phonetic alterations.

With regard to emotional conveyance, in keeping with Miller *et al*[40] and Pell *et al*[41] our findings support the view that people with PD were less successful in conveying emotion in their speech. Our findings show that the communication of happy emotion was particularly affected, although our study cannot confirm the mechanisms which might be causing this effect. Unlike Miller *et al*,[40] potentially due to lesser severity of speech impairment, we did not find that listeners were more accurate in the audio only condition compared to the audiovisual condition. Our identification that intelligibility contributes a relatively modest proportion of the variance in functional communication is consistent with Donovan *et al*,[24-25] although we advance this knowledge by demonstrating differences between conversational and read sentence intelligibility as well as communicative effectiveness and communicative participation. Previous studies in our review[9] and also McAuliffe *et al*[22] have generally found an association between cognitive status and functional communication. The prior study by Miller *et al*,[6,64] which did not find such as association used as a measure of cognitive status the Mini Mental State Examination,[65] which has been shown to be insensitive to mild cognitive impairment in PD.[66-69]

Communication is fundamental to humanity and in particular the development and maintenance of human relationships.[70] Although participation may mean different things to different people,[71] it is evident that participation aspects, including those of functional communication,[21] are of great importance to people with PD. Indeed, it is important than research and clinical priorities and perspectives match those of people with the condition as closely as possible.[72] The relatively modest contribution of intelligibility to functional communication outcomes shown by our study and others indicates that it is important for SLT for people with PD to focus on non-motoric issues affecting functional communication in addition to more traditionally recognised motoric issues. In environments where there has been a move to include a higher proportion of functional communication in therapy, this should be maintained. In environments where this has not yet happened, it is recommended that greater focus on functional communication be considered. In achieving this, it is important to consider what the particular client's communication needs and goals are, what challenges the client faces in accomplishing these, and what approaches may facilitate this. It is important to remember that communication needs differ between clients, and that clients differ in what they consider full participation in life.[71] Further research is required to investigate the effectiveness of SLT for PD. The pathway proposed by our study could be useful to inform future research into defining treatments to include in intervention trials. In addition, it is important to conduct further research into the gender-specific aspects of communication difficulties in PD, which have received limited research attention.

There are some limitations of this study that should be taken into account. The PhD time scale did not allow us to undertake a longitudinal study, so we cannot be definitive about causality. Secondly, it was not possible to use the entire sample size for speech sample analysis due to the constraints that read sentences impose upon the sample size in the intelligibility assessment so as to avoid learning biases. Thirdly, the sample we recruited had on average relatively mild motoric speech deficits, potentially due to greater reluctance to take part in speech studies among those with more severe speech impairment or alternatively due to an overrepresentation of people with early PD and greater insight into research. Fourthly, reflecting both the methodological challenges of speech analysis and the challenges of recruiting from this population, sample sizes in this field, tend to be lower than in many other areas of applied health research. Fifthly, we were unable to measure motor disability directly. However, we offered LEDD as a proxy measure of motor disability to models assessing functional outcomes in order to minimise confounding by motor disability. Moreover, some studies have shown that cognitive impairment can be common in people with PD who are early on the motor decline pathway.[73-74] However, LEDD has limitations as a proxy measure of motor status. For example, one study[75] found no significant association between LEDD and Hoehn and Yahr staging. Therefore, future studies should consider assessing how scores from explicit motor assessments, such as the Universal Parkinson's Disease Rating Scale (UPDRS)[76] predict functional communication outcomes. Sixthly, due to regulatory constraints, we were unable to conduct further analyses following the Chief Investigator's departure from the host institution on completion of his PhD. Without this restriction, we may have been able to consider whether different modelling or reporting options may have been preferable.

In conclusion, we present the first study that provides an overview of the potential pathway from cognitive status and motoric speech impairment through reduced intelligibility to difficulties with emotional conveyance difficulties and functional communication in PD. Our results support the idea that SLT for people with PD should focus on functional communication as well as motor deficits, and could also inform future trials to identify the optimal form of therapy. The pathway to functional communication difficulties in PD is likely to involve complex, multi-factorial mechanisms for change, including for example motoric, cognitive and psychosocial elements. Since our study is exploratory, future confirmatory research is required to validate and extend our findings. This should include clarification of the elements and mechanisms of this pathway, as well as how they may differ between individuals with PD, which is a condition known to vary considerably in its clinical expression.[77]

FOOTNOTES

Acknowledgements

This study constituted M.S.B.'s PhD work at the University of East Anglia (UEA). We thank Dr Carolyn Baylor, Prof Kathryn Yorkston and colleagues (University of Washington, USA) for prior information about the CPIB tool. We thank our participants and assessors, our recruiting clinicians at the Neurology and Medicine for the Elderly Clinics at the Norfolk and Norwich University Hospital as well as Mr Mike Stevens, formerly of UEA, who provided guidance and training in relation to audio-visual technology used in the study.

Contributors

M.S.B. was the Chief Investigator and K.H.O.D. the primary academic supervisor. S.M.C.H. and R.A.A. are registered SLTs and are specialists in adult neurological disorders. The study was conceptualised and overseen by M.S.B., S.M.C.H., Z.R.B. and K.H.O.D. Data were collected by M.S.B. Acoustic analysis was conducted by M.S.B. and Z.R.B. Listener assessment was conducted by our panel of assessors supervised by M.S.B with advice from S.M.C.H, Z.R.B. and K.H.O.D.. Statistical analysis was overseen by A.B.C. and conducted by M.S.B. and A.B.C. The first draft of the manuscript was written by M.S.B. Data were initially interpreted by M.S.B. and further interpretation provided by S.M.C.H., Z.R.B., A.B.C., R.A.A. and K.H.O.D. All authors contributed academically and/or clinically valuable revisions to the manuscript. All authors approved the submission.

Funding

We acknowledge funding from a UEA PhD studentship to M.S.B.

Competing interests

The authors declare no conflicts of interest with regard to this work

Ethics approval

Ethical approval for this study was granted by the National Research Ethics Service (NRES) Committee East of England – Norfolk. All requisite local governance approvals were obtained.

Data sharing statement

No additional data are available

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Table 1. List of acoustic measures with a brief explanation of each

Domain	**Measure**	**Explanation**
Initiation	Intensity	Objective correlate of loudness, measured in db SPL
	Intensity decay	% decay in intensity from first to last sentence
Prosody	Mean fundamental frequency (F_0)	Objective correlate of pitch, measured in Hz
	Standard deviation of F_0	Objective correlate of pitch variation
	Speech rate	Speaking speed, measured in syllables per second
	Adjusted speech rate	As per speech rate, but excluding dysfluencies and pause
	Acceleration	% increase in speech rate from first to last sentence
	Adjusted acceleration	As per acceleration, but excluding dysfluencies and pause
	Pause	A measure of hesitation, calculated in ms and expressed as % of utterance time, using a threshold of 50ms as the minimum significant pause duration
	Within-word pause	% of pause that occurred within rather than between words
	Iteration	Number of instances of linguistic unit repetition
	Within-word iteration	% of instances of linguistic unit repetition that occurred within rather than between words
Phonation	Jitter	Relative percentage variation in glottal cycle duration (indicative of voicing frequency consistency)
	Shimmer	Relative percentage variation in glottal cycle amplitude (indicative of voicing amplitude consistency)
	Harmonic-to-noise ratio (HNR)	A measure of cycle-to-cycle variation in waveform shape (indicative of voicing strength)
Articulation	Formant Centralization Ratio (FCR)	A measure of vowel distinctiveness
	Standard deviation of /s/ amplitude	A measure of consonant articulation strength
	Voice Onset Time (VOT) ratio	A measure of the ability to differentiate for example ‘bark’

		and ‘park’

Table 2. Key clinical characteristics of people with PD in the full and purposive samples

Measure	Full sample	Purposive sample
Disease duration (years)	6.5 (8.3)*	9.0 (9.5)*
MoCA	22.9 (3.6)	22.2 (3.3)
HADS	11.0 (8.5)*	9.6 (4.8)
LEDD	640.5 (656.5)*	691.5 (1027.3)*

Figures are mean (SD), unless when marked with * in which case they are median (IQR). MoCA = Montreal Cognitive Assessment, HADS = Hospital Anxiety and Depression Scale and LEDD = Levodopa Equivalent Daily Dose

Table 3. Descriptive profile of principal speech and communication measures

	People with Parkinson's disease	Conversation partner controls
Read sentence intelligibility	81.1 (15.0)	87.9 (3.6)
Conversational sentence intelligibility	55.8 (26.5)	71.9 (13.0)
Emotional conveyance (happy audio)	36.5 (20.5)	55.6 (20.8)
Emotional conveyance (happy audiovisual, %)	54.1 (20.5)	61.4 (13.9)
Emotional conveyance (neutral audio, %)	55.4 (18.0)	46.7 (18.6)
Emotional conveyance (neutral audiovisual,%)	38.5 (25.3)	53.6 (20.8)
Emotional conveyance (sad audio, %)	55.8 (21.3)	64.8 (18.7)
Emotional conveyance (sad audiovisual,%)	55.8 (23.1)	63.0 (25.2)
Communicative Participation Item Bank (CPIB, T score)	53.0 (9.6)	NA
Communicative Participation Item Bank (CPIB, overall rating of degree to which PD affects communication, n(%))	Not at all: 11 (24%) A little: 24 (53%) Quite a bit: 9 (20%) Very much: 1 (2%)	NA

Figures are mean (SD) unless stated. Intelligibility is scored as % words correctly identified. Emotional conveyance is scored as % tokens for which emotion was correctly identified.

Supplementary table 1. Statistical details for acoustic analysis of read sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA *Gender
Intensity	59.54 (4.73)	62.27 (4.81)	61.98 (8.22)a	63.49 (1.81)	62.90 (2.75)	63.13 (2.39)	4.13*	2.81	-2.89	6.87**	-10.1*
Intensity decay	5.42 (4.72)	5.05 (3.87)	5.52 (4.60)	3.83 (3.34)	3.17 (5.67)	3.43 (4.79)	-1.73	-0.69	0.04	1.55	1.04
Mean F_0	137.30 (18.46)	185.80 (25.32)	155.96 (30.83)	116.00 (11.41)	190.10 (27.78)	161.28 (43.38)	-19.80?	42.80***	30.70*	28.70*	1.04
SD of F_0	21.36 (8.18)	26.60 (6.09)	23.32 (7.70)	20.73 (6.52)	38.13 (9.26)	31.36 (11.90)	0.95	7.01*	9.63?	6.92?	-14.5*
Speech rate	3.73 (0.43)	3.83 (0.80)	3.77 (0.57)	4.18 (0.43)	3.54 (0.33)	3.79 (0.48)	0.57*	0.26	-0.92**	0.64?	-0.34
Acceleration	40.28 (31.49)	55.63 (35.22)a	42.31 (30.06)	51.76 (8.80)	43.94 (14.50)	46.98 (12.90)	9.97	1.10	-9.02	-15.9	-1.85
Adjusted speech rate	3.90 (0.39)	4.03 (0.69)	3.95 (0.50)	4.27 (0.37)	3.63 (0.31)	3.88 (0.46)	0.38?	0.14	-0.81**	0.48	-0.12
Adjusted acceleration	41.96 (15.37)	50.49 (23.91)	45.16 (18.72)	49.97 (14.63)	48.41 (14.41)	49.01 (14.08)	6.31	3.43	-5.00	-2.19	-15.50
Pause	2.65 (3.86)a	1.62 (5.52)a	2.39 (3.84)a	0.61 (4.74)a	2.34 (1.69)	1.40 (3.78)a	-5.13*	-4.09?	4.50	-5.23	6.85
Within-word pause	0.00 (4.51)a	0.00 (6.25)a	0.00 (4.74)a	0.00 (NA)a	0.00 (0.00)a	0.00 (0.00)a	-2.54?	-0.16	0.68	-2.45	6.26
Iteration	0.00 (0.22)a	0.45 (0.59)	0.03 (0.41)a	0.00 (0.00)a	0.00 (0.06)a	0.00 (0.06)a	-0.15	0.21	-0.18	-0.22	0.50
Within-word iteration	0.00 (11.81)a	6.25 (9.94)a	0.63 (9.36)a	0.00 (NA)a	0.00 (5.20)a	0.00 (0.52)a	-4.94	3.71	-2.00	-5.60	12.10
Jitter /i/	2.43 (0.58)	1.94 (0.74)a	2.19 (0.78)a	2.81 (0.65)	2.24 (0.44)	2.45 (0.58)	0.39	-0.16	-0.42	-0.03	0.49
Jitter /ɑ/	2.07 (1.22)a	1.73 (0.82)	1.97 (1.50)a	1.90 (0.60)	1.54 (0.48)	1.67 (0.54)	-0.50	-0.31?	0.36	-0.83	1.77

Jitter /u/	1.76 (0.75)	1.55 (0.68)	1.69 (0.71)	1.98 (0.41)	1.79 (0.83)	1.86 (0.70)	0.18	-0.17	0.09	-0.57	1.08
Shimmer /i/	15.12 (2.28)	13.43 (2.62)	14.53 (2.48)	16.87 (1.70)	14.18 (1.41)	15.17 (1.99)	1.71?	-1.59?	-1.11	-1.67	3.51
Shimmer /ɑ/	15.10 (2.41)	14.67 (2.89)	14.95 (2.52)	17.25 (3.13)	15.20 (2.70)	15.95 (2.96)	2.07	-0.56	-1.49	-0.91	3.73
Shimmer /u/	13.39 (2.75)	11.61 (2.99)	12.77 (2.89)	16.21 (2.90)	12.81 (3.06)	14.06 (3.37)	2.64?	-2.00	-1.40	-1.72	2.84
HNR /i/	8.95 (2.70)	11.55 (2.68)	9.86 (2.92)	7.29 (1.38)	10.43 (1.29)	9.27 (2.02)	-1.58	2.47*	0.67	3.77*	-4.65?
HNR /ɑ/	8.20 (2.66)	9.94 (2.07)	8.81 (2.56)	7.31 (1.49)	10.00 (2.26)	9.01 (2.37)	-0.82	1.69	0.99	4.10**	-6.12**
HNR/u/	11.36 (3.02)	14.25 (2.88)	12.46 (3.28)	9.67 (1.51)	13.24 (2.27)	11.89 (2.72)	-1.68	2.57*	1.02	3.74*	-3.29
FCR	1.37 (0.24)a	1.37 (0.11)	1.35 (0.18)a	1.35 (0.09)	1.29 (0.12)	1.31 (0.11)	-0.08	-0.07	0.01	-0.09	0.13
SD of /s/ amplitude	1.91 (1.37)a	2.43 (0.83)	2.28 (0.71)	1.87 (0.32)	2.25 (0.36)	2.11 (0.40)	-0.33	0.21	0.19	-0.51	0.78
VOT /pɒ/	0.24 (0.06)	0.27 (0.08)	0.26 (0.07)	0.27 (0.07)	0.27 (0.06)	0.28 (0.06)	0.02	0.00	0.00	0.03	0.01
VOT /tɛ/	0.37 (0.12)	0.40 (0.06)	0.38 (0.10)	0.40 (0.06)	0.35 (0.08)	0.37 (0.07)	0.03	0.01	-0.07	0.09	-0.11
VOT /pɑ/	0.18 (0.08)	0.24 (0.08)	0.20 (0.86)	0.19 (0.06)a	0.16 (0.04)	0.16 (0.04)a	0.02	0.00	0.00	-0.01	0.01
VOT /tu/	0.32 (0.07)	0.36 (0.05)	0.34 (0.07)	0.35 (0.09)	0.30 (0.05)	0.32 (0.07)	0.03	0.03	-0.09?	0.05	-0.08
VOT /kɒ/	0.34 (0.07)	0.34 (0.06)	0.34 (0.07)	0.35 (0.04)	0.32 (0.07)	0.34 (0.06)	0.00	0.58	-0.01	0.07	-0.05

Descriptives are shown as mean (SD), unless marked with ‘a’ in which case they refer to median (IQR). * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.

PD = people with Parkinson's disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, symbols in // are phonemes transcribed using the International Phonetic Alphabet. HNR = Harmonic to Noise Ratio, FCR = Formant Centralization Ratio, VOT = Voice Onset Time

Supplementary table 2. Statistical details for acoustic analysis of conversational sentences

	Descriptives (PD)			Descriptives (CP)			Mean difference				
	Male	Female	All	Male	Female	All	Group	Gender	Group * Gender	MoCA	MoCA * Gender
Intensity	57.56 (5.12)	60.92 (5.89)	58.79 (5.51)	61.10 (4.70)	60.28 (4.51)	60.60 (4.47)	3.69	3.56	-4.92	4.73	-9.44?
Intensity decay	1.10 (5.15)	-0.95 (4.56)	0.35 (4.92)	1.32 (3.74)	-0.71 (8.20)	0.08 (6.75)	0.31	-1.57	-0.46	4.58	-3.97
Mean F_0	130.47 (16.11)	179.63 (23.50)	145.58 (30.60)	118.44 (21.60)	189.33 (37.94)	161.76 (47.70)	0.39	45.30***	24.00	19.90	-27.50
SD of F_0	23.06 (8.75)	27.45 (9.48)	24.68 (9.03)	18.01 (9.78)	33.59 (12.22)$_a$	30.51 (15.58)	-2.95	7.94?	11.00	-0.46	-12.50
Speech rate	4.70 (0.64)	4.71 (0.74)	4.70 (0.66)	5.20 (0.52)	4.34 (0.71)	4.67 (0.76)	0.37	-0.19	-0.49	0.25	0.17
Acceleration	25.22 (39.70)	-4.05 (26.71)	14.44 (37.57)	6.88 (30.38)	11.43 (26.25)	9.66 (27.13)	-20.60	-31.00*	35.60	-13.70	6.17
Adjusted speech rate	4.93 (5.09)	4.96 (0.60)	4.94 (0.57)	5.54 (0.41)	4.62 (0.82)	4.98 (0.82)	0.51	-0.14	-0.65	0.32	0.10
Adjusted acceleration	13.07 (21.93)	-4.42 (20.03)	6.62 (22.42)	2.15 (26.81)	10.57 (22.39)	7.29 (23.80)	-12.60	-19.20?	27.60?	1.15	-5.16
Pause	6.05 (10.59)$_a$	4.87 (5.40)	4.02 (9.84)$_a$	6.50 (4.54)	4.44 (4.17)	4.77 (4.33)	1.01	-0.54	-2.13	-2.74	0.15
Within-word pause	0.00 (NA)$_a$	0.00 (0.00)$_a$	0.00 (0.00)$_a$	0.00 (NA)$_a$	0.00 (NA)$_a$	0.00 (0.00)	0.00	0.90?	-0.90	0.00	1.44
Iteration	0.00 (0.10)$_a$	0.40 (1.00)$_a$	0.00 (0.35)$_a$	0.34 (0.38)	0.00 (0.40)$_a$	0.10 (0.40)$_a$	0.31	0.72	-0.87**	0.01	0.66
Within-word iteration	0.00 (0.00)$_a$	0.00 (19.00)$_a$	0.00 (0.00)$_a$	0.00 (10.00)$_a$	0.00 (0.00)$_a$	0.00 (0.00)	5.71*	7.38**	-12.30***	0.00	6.47

Descriptives are shown as mean (SD), unless marked with ‘a’ in which case they refer to median (IQR). * = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, ? = $0.05 < p < 0.1$.

PD = people with Parkinson’s disease, CP = conversation partner controls, F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment.

Supplementary table 3. Statistical details of acoustic analysis for emotional conveyance sentences

Part A. Descriptives

	PD			CP		
	Male	Female	All	Male	Female	All
Intensity H	61.71 (5.21)	65.22 (3.61)	63.12 (4.86)	66.55 (2.43)	64.49 (3.57)	65.21 (3.30)
Mean F_0 H	168.98 (35.75)	204.39 (28.97)	183.15 (36.96)	155.97 (12.36)	240.15 (28.59)	210.69 (47.56)
SD of F_0 H	35.63 (14.04)	43.97 (12.16)	38.96 (13.64)	35.70 (11.54)a	63.40 (15.94)	55.16 (18.57)
Speech rate H	4.33 (0.63)	4.18 (0.51)	4.27 (0.57)	4.90 (0.49)	3.90 (0.38)	4.25 (0.63)
Adjusted speech rate H	4.46 (0.57)	4.19 (0.51)	4.35 (0.55)	4.91 (0.49)	3.91 (0.38)	4.26 (0.64)
Pause H	0.00 (4.53)a	0.00 (0.00)a	0.00 (3.00)a	0.00 (0.00)a	0.00 (0.00)a	0.00 (0.00)a
Intensity N	58.83 (5.33)	60.96 (4.45)	59.68 (4.99)	61.77 (3.46)	60.09 (4.28)	60.68 (4.00)
Mean F_0 N	132.84 (19.30)	172.90 (30.85)	148.86 (31.17)	117.66 (13.49)	186.46 (18.23)	162.38 (37.43)
SD of F_0 N	18.50 (5.59)a	29.67 (13.02)	20.82 (9.83)a	27.19 (4.31)	34.60 (9.35)	32.01 (8.62)
Speech rate N	4.45 (0.73)	4.60 (0.65)	4.51 (4.46)	4.77 (0.55)	4.21 (0.28)	4.41 (0.47)
Adjusted speech rate N	4.53 (0.67)	4.62 (0.63)	4.57 (0.64)	4.82 (0.54)	4.22 (0.27)	4.38 (0.47)a
Pause N	0.00 (1.62)a	0.00 (0.00)a	0.00 (0.82)a	0.00 (1.14)a	0.00 (0.00)a	0.00 (0.00)a
Intensity S	57.81 (6.19)	62.15 (3.69)	59.55 (5.65)	62.78 (2.50)	59.88 (4.88)	60.89 (4.36)
Mean F_0 S	133.00 (27.26)	172.45 (33.36)	148.78 (35.12)	116.04 (15.11)	186.91 (25.09)	162.10 (40.90)
SD of F_0 S	17.83 (8.95)a	31.64 (9.71)	25.29 (12.06)	23.86 (5.39)	34.60 (11.02)	30.85 (10.65)

Speech rate S	4.00 (0.74)	3.79 (0.56)	3.92 (0.66)	4.03 (0.64)	3.40 (0.44)	3.62 (0.59)
Adjusted speech rate S	4.02 (0.73)	3.80 (0.56)	3.93 (0.66)	4.03 (0.64)	3.41 (0.44)	3.63 (0.59)
Pause S	0.00 (NA)	0.00 (0.53)a	0.00 (0.00)a	0.00 (NA)	0.00 (0.56)a	0.00 (0.00)a

Descriptives are shown as mean (SD), unless marked with ‘a’ in which case they refer to median (IQR). H = happy mood, N = neutral mood, S = sad mood.

PD = people with Parkinson’s disease, CP = conversation partner controls, F_0 = fundamental frequency.

Part B. Mean differences associated with predictors

	Group	Gender	Group * Gender	MoCA	Mood (N-H)	Mood (S-H)	Gender * Mood (N-H)	Gender * Mood (S-H)	MoCA * Mood (N-H)	MoCA * Mood (S-H)	Group * Mood (N-H)	Group * Mood (S-H)
Intensity	4.83*	-3.49?	5.54*	1.86	-3.23***	-3.58***	-0.52	0.02	-1.59	-1.25	-0.97	-0.76
Mean F_0	-6.43	41.47***	36.32**	17.27	-32.24***	-32.60***	-5.10	-4.41	-12.09	-19.34	-12.75	-13.12
SD of F_0	9.91*	13.58***	4.44	4.06	-12.03***	-11.65***	-7.29	-5.08	-7.28	-7.22	-6.37	-9.36*
Speech rate	0.47?	-0.24	-0.66*	0.65*	0.09	-0.42***	0.37*	0.15	0.01	-0.21	-0.17	-0.32*
Adjusted speech rate	0.38	-0.32	-0.61*	0.56*	0.07	-0.51***	0.37*	0.21	0.03	-0.11	-0.13	-0.26
Pause	-2.03*	-1.85*	0.99	-2.07	-1.27*	-2.56***	0.64	1.78*	0.92	1.76	1.14	1.49?

F_0 = fundamental frequency, MoCA = Montreal Cognitive Assessment, H = happy mood, N = neutral mood, S = sad mood. * = p<0.05, ** = p<0.01, *** = p<0.001, ? = 0.05 < p <0.1.