Journal of Communication Disorders 58 (2015) 91–105

Contents lists available at ScienceDirect

Journal of Communication Disorders

The effect of intensive speech rate and intonation therapy on intelligibility in Parkinson's disease

Heidi Martens [a,*], Gwen Van Nuffelen [a,b,c], Tomas Dekens [d], Maria Hernández-Díaz Huici [a], Hector Arturo Kairuz Hernández-Díaz [e], Miet De Letter [c], Marc De Bodt [a,b,c]

[a] Antwerp University, Faculty of Medicine and Health Sciences, Universiteitsplein 1, B-2610 Wilrijk, Belgium
[b] Antwerp University Hospital, Rehabilitation Centre for Communication Disorders, Wilrijkstraat 10, B-2650 Edegem, Belgium
[c] Ghent University, Department of Speech, Language, and Hearing Sciences, De Pintelaan 185, B-9000 Ghent, Belgium
[d] Vrije Universiteit Brussel, Department of ETRO-DSSP, Pleinlaan 2, B-1050 Brussels, Belgium
[e] Center for Studies on Electronics and Information Technologies, Universidad Central Marta Abreu de Las Villas, 54830 Santa Clara, Cuba

ARTICLE INFO

Article history:
Received 7 August 2014
Received in revised form 8 September 2015
Accepted 8 October 2015
Available online 14 October 2015

Keywords:
Parkinson's disease
Dysarthria
Prosody
Intelligibility
Speech rate
Intonation
Speech therapy

ABSTRACT

Purpose: Most studies on treatment of prosody in individuals with dysarthria due to Parkinson's disease are based on intensive treatment of loudness. The present study investigates the effect of intensive treatment of speech rate and intonation on the intelligibility of individuals with dysarthria due to Parkinson's disease.
Methods: A one group pretest–posttest design was used to compare intelligibility, speech rate, and intonation before and after treatment. Participants included eleven Dutch-speaking individuals with predominantly moderate dysarthria due to Parkinson's disease, who received five one-hour treatment sessions per week during three weeks. Treatment focused on lowering speech rate and magnifying the phrase final intonation contrast between statements and questions. Intelligibility was perceptually assessed using a standardized sentence intelligibility test. Speech rate was automatically assessed during the sentence intelligibility test as well as during a passage reading task and a storytelling task. Intonation was perceptually assessed using a sentence reading task and a sentence repetition task, and also acoustically analyzed in terms of maximum fundamental frequency.
Results: After treatment, there was a significant improvement of sentence intelligibility (effect size .83), a significant increase of pause frequency during the passage reading task, a significant improvement of correct listener identification of statements and questions, and a significant increase of the maximum fundamental frequency in the final syllable of questions during both intonation tasks.
Conclusion: The findings suggest that participants were more intelligible and more able to manipulate pause frequency and statement-question intonation after treatment. However, the relationship between the change in intelligibility on the one hand and the changes in speech rate and intonation on the other hand is not yet fully understood. Results are nuanced in the light of the operated research design.

* Corresponding author.
E-mail addresses: heidi.martens@edpnet.be, heidi.martens@student.uantwerpen.be (H. Martens), Gwen.van.nuffelen@uza.be (G. Van Nuffelen), tdekens@etro.vub.ac.be (T. Dekens), MariaE.Hernandez-Diaz@uantwerpen.be (M. Hernández-Díaz Huici), akairuz@uclv.edu.cu (H.A. Kairuz Hernández-Díaz), Miet.DeLetter@UGent.be (M. De Letter), Marc.de.bodt@uza.be (M. De Bodt).

http://dx.doi.org/10.1016/j.jcomdis.2015.10.004
0021-9924/

Learning outcomes: The reader will be able to: (1) describe the effect of intensive speech rate and intonation treatment on intelligibility of speakers with dysarthria due to PD, (2) describe the effect of intensive speech rate treatment on rate manipulation by speakers with dysarthria due to PD, and (3) describe the effect of intensive intonation treatment on manipulation of the phrase final intonation contrast between statements and questions by speakers with dysarthria due to PD.

1. Introduction

Parkinson's disease (PD) is a common, slowly progressive idiopathic neurologic disease caused by basal ganglia circuit control pathology. The majority of individuals with PD develop speech symptoms as the disease progresses (Adams & Dykstra, 2009; Skodda, Rinsche, & Schlegel, 2009). PD is prototypically associated with hypokinetic dysarthria, a perceptually distinctive motor speech disorder, the characteristics of which are most evident in articulation, voice, and prosody (Duffy, 2005). Dysprosody in parkinsonian dysarthria is caused by alterations in speech rate, pause time, speech intensity, and pitch variation (Skodda et al., 2009) leading to variable speech rate, short phrases, short rushes of speech, inappropriate silences, reduced stress, monoloudness, and monopitch (Duffy, 2005). Such prosody breakdowns have a potentially detrimental impact on speech intelligibility (De Bodt, Hernández-Díaz Huici, & Van De Heyning, 2002; Patel, 2011) and speech naturalness (Patel, 2011), which may lead to a reduced ability to communicate properly and thus function fully in society (Baylor, Burns, Eadie, Britton, & Yorkston, 2011).

Since the eighties, a substantial number of studies have examined the effect of behavioural speech therapy on the prosodic skills of individuals with PD, as can be deduced from reviews covering this topic (Atkinson-Clement, Sadat, & Pinto, 2015; Hargrove, Anderson, & Jones, 2009; Herd et al., 2012; Yorkston, Hakel, Beukelman, & Fager, 2007). As reduced loudness is often considered a classical perceptual feature of hypokinetic dysarthria in PD (Adams & Dykstra, 2009; Yorkston et al., 2007), it is not surprising that the overwhelming majority of these studies deals with treatment of loudness. Ramig, Countryman, Thompson, and Horii (1995), Ramig, Sapir, Fox, and Countryman (2001), and Ramig, Sapir, and Countryman (2001) conducted a systematic line of treatment research based on the Lee Silverman Voice Treatment (LSVT) programme, a well described high-effort speech treatment protocol aimed at increasing vocal loudness. LSVT focuses on training this single target in order to enhance the voice source and trigger improvement across the entire speech production system (Fox, Ebersbach, Ramig, & Sapir, 2012). LSVT is an intensive therapy programme consisting of four one-hour sessions each week during four weeks. Treatment effectiveness in PD has predominantly been demonstrated in terms of acoustic measures, such as intensity and fundamental frequency (F_0) variation (e.g. Ramig et al., 1995; Ramig, Countryman, O'Brien, Hoehn, & Thompson, 1996; Ramig, Sapir, Fox, et al., 2001; Ramig, Sapir, & Countryman, 2001), and also utterance and pause duration (Ramig et al., 1995), but a few studies also report effectiveness in terms of functional measures, such as intelligibility (e.g. Cannito et al., 2012; Ramig et al., 1995; case study by Theodoros, Thompson-Ward, Murdoch, Lethlean, & Silburn, 1999). An alternative treatment programme for remedying loudness in PD is the Pitch Limiting Voice Treatment (PLVT) by de Swart, Willemse, Maassen, and Horstink (2003). They considered that LSVT ('speak loud') may lead to a high-pitched, strained, screaming voice. PLVT ('speak loud and low') is designed to prevent an increase of pitch and of laryngeal muscle tone and resistance, in order to maintain a socially acceptable, natural sounding voice.

Although reduced loudness is generally considered to be one of the cardinal speech symptoms in PD, not all individuals with dysarthria due to PD are perceived as speaking with reduced loudness (Adams & Dykstra, 2009; Ludlow & Bassich, 1984). Moreover, poor outcomes of LSVT in individuals with significant rate disorders were recently advanced as being one of the limitations of this programme by the founders themselves (Fox et al., 2012). In such cases, loudness-based therapy programmes such as LSVT or PLVT may not be the most appropriate treatment option, and the literature provides arguments for focusing treatment on other aspects of speech, such as intonation or speech rate.

Concerning intonation, Anand and Stepp (2015) demonstrated that monopitch and speech naturalness are highly correlated in PD speech, and the authors suggest integrating intonation as a therapeutic target to improve speech naturalness and consequently social communication and quality of life. Another reason for treating monopitch is that intonation also conveys meaning. Ma, Whitehill, and So (2010), for instance, studied the intonation contrast between questions and statements in a group of 14 Cantonese speakers with hypokinetic dysarthria due to PD, and found that not all speakers were able to mark this contrast clearly enough. More precisely, listeners were able to identify statements quite accurately (95.83% correct), but failed to identify questions correctly (44.86% correct), mainly due to the absence of a clear F_0 rise at the final syllable of questions. The authors suggest directing treatment at improving the ability of F_0 variation in speakers who are unable to systematically vary F_0 to mark the statement-question contrast. We consider this a relevant therapy goal, because it has the potential to enable listeners to better understand prosodic meaning expressed by speakers with PD.

Concerning speech rate, rate abnormalities can be a prominent and highly distinctive feature of hypokinetic dysarthria, and individuals with PD can be perceived to speak both abnormally slow or abnormally fast (Duffy, 2005), the last condition apparently being unique for hypokinetic dysarthria (Darley, Aronson, & Brown, 1975). Speech rate is sometimes considered the most modifiable variable for improving intelligibility (Blanchet & Snyder, 2009), and a number of studies have indeed provided suggestive evidence of the beneficial effect of rate control methods such as pacing or delayed auditory feedback on intelligibility in individuals with PD (e.g. Hammen, Yorkston, & Minifie, 1994; Hanson & Metter, 1983; Van Nuffelen, De Bodt, Vanderwegen, Van de Heyning, & Wuyts, 2010; Yorkston, Hammen, Beukelman, & Traynor, 1990).

Despite the aforementioned arguments in favour of treating speech rate and intonation in PD, studies on the benefits of (more or less intensive) treatment programmes specifically targeting these speech aspects in PD are scarce. Reports on the effect of prosthetic management devices such as delayed auditory feedback (Dagenais, Southwood, & Lee, 1998) or altered auditory feedback (Lowit, Dobinson, Timmins, Howell, & Kröger, 2010) remain inconclusive with regard to the effect on rate reduction and intelligibility. Reports on the effect of behavioural management seem to be more promising: improvements in prosodic abnormality, intelligibility or dysarthria severity have already been stated in studies on the effectiveness of treatment including intonation exercises (Johnson & Pring, 1990; Scott & Caird, 1983; case study by Le Dorze, Dionne, Rialls, Julien, & Ouellet, 1992) and speech rate exercises (Le Dorze et al., 1992).

The present study aims to do what none of the behavioural management studies mentioned before have done: to investigate the effectiveness of a truly intensive treatment schedule, combining speech rate and intonation training, on the intelligibility of a group of speakers with hypokinetic dysarthria due to PD. To this end, the 'Prosodietrainer' (Martens, Latacz, et al., 2013; Martens, Dekens, et al., 2013) was used, a recently developed freely available software tool for assessing and training speech rate and intonation in Dutch-speaking individuals with dysarthria. Regarding intonation, we specifically focused on the intonational contrast between statement and question, because at the time of the present research, this was the first prosodic aspect (next to speech rate) to be fully operational in the Prosodietrainer. For more details about structure and content of the treatment programme and about the feedback provided by the tool, we refer the reader to Section 2.4. From here on, the treatment programme contained within this software tool will be referred to as 'SPRINT', short for SPeech Rate and INtonation Therapy. Treatment intensity, one of the principles of motor learning, is considered beneficial for rehabilitation because it promotes activity-dependent neuroplasticity (Kleim & Jones, 2008; Kleim, Jones, & Schallert, 2003). As evidence suggests that focused, intensive speech treatment can be effective (Fox et al., 2012; Johnson & Pring, 1990; Le Dorze et al., 1992; Scott & Caird, 1983), we decided to investigate whether a similar effectiveness could be achieved by means of an intensive SPRINT therapy schedule. The three research questions examined in this paper are: (1) Does an intensive intonation and rate reduction therapy lead to a significant improvement of intelligibility in individuals with dysarthria due to PD? (2) Does an intensive intonation therapy lead to a significant improvement of the production of the intonation contrast between question and statement in individuals with dysarthria due to PD? and (3) Does an intensive rate reduction therapy lead to a significant decrease in speech rate in individuals with dysarthria due to PD?

2. Materials and methods

2.1. Participants

A group of 42 potential participants was recruited from nursing homes and local patient support groups, and by referral from speech and language therapists in hospitals and private practices and from general practitioners. The diagnosis of idiopathic PD and the absence of any comorbid neurological disorders were confirmed by the participants' attending neurologists. The flow chart in Fig. 1 visualizes how the final group of participants was selected. Participants were screened for eligibility during a preliminary interview, an intelligibility test, and a receptive prosody test (as will be explained in the following paragraphs). The screening was supervised by the first author of the present study and performed by four master's level speech-language pathology students who were well familiar with the subject of motor speech disorders, and who had been thoroughly instructed regarding the entire screening procedure.

During an interview, the potential participants were immediately informed that participation in this study would involve a substantial and sustained investment of time and energy during three weeks. At the end of the interview, only individuals who still articulated the wish to participate and who managed to convince the interviewer of their determination and ability to proceed were included in the study, a decision which was based on clinician judgement. During the interview, intactness or sufficiency of audition, vision, cognition, language skills, and reading skills of participants was also determined by clinician judgement.

Only participants with reduced speech intelligibility were included in this study, to allow room for a demonstrable improvement of intelligibility upon finishing the intensive therapy programme. To this end, participants took the Dutch Sentence Intelligibility Assessment (Martens, Van Nuffelen, & De Bodt, 2010a), and were excluded if their score exceeded 90%.

Finally, considering the fact that prosodic speech therapy relies on modelling and auditory-perceptual feedback, and considering the growing awareness that individuals with PD can present with both productive and receptive prosodic deficiencies (Pell, Cheang, & Leonard, 2006), only participants with sufficient receptive prosodic skills were included in the study, in order to assure a solid base for training productive prosodic skills. To this end, a receptive prosodic skills test, specifically developed for this purpose, was administered to potential participants. The test assessed comprehension and perception of the intonational statement-question contrast by means of two tasks. The first task tested comprehension of prosodic meaning. Participants listened to 16 utterances, i.e. 8 statements (e.g. 'Hij kocht een winterjas.'; translation 'He bought a winter coat.') and 8 declarative questions (e.g. 'Karen speelt tennis?'; translation 'Karen plays tennis?') in an

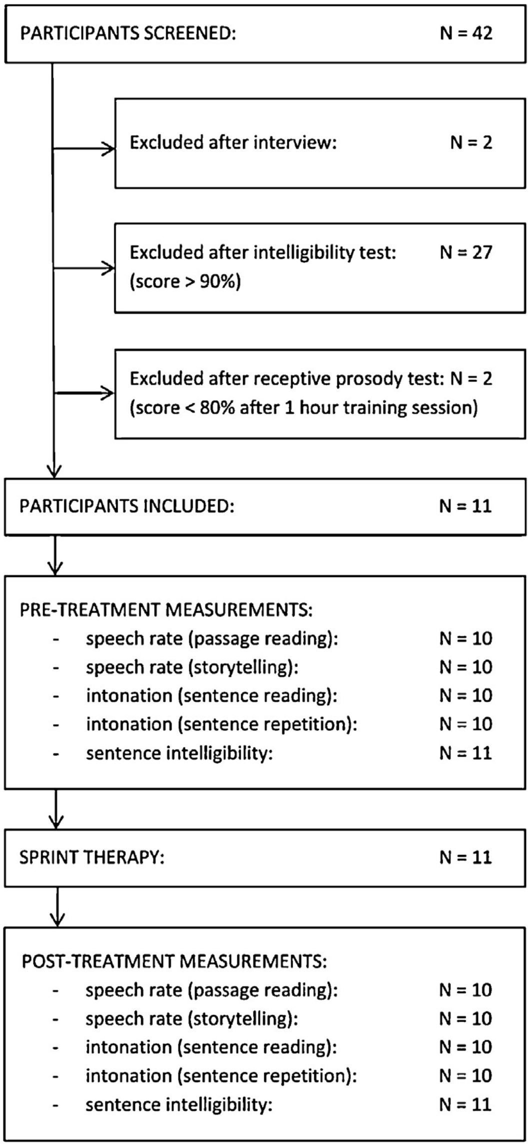

Fig. 1. Flow chart of the participant selection and sample collection process. All instances of numbers represent numbers of participants. For technical reasons, one participant had to be excluded from the pre-treatment and post-treatment speech rate and intonation tests (see Sections 2.3.1 and 2.3.2).

randomized order, and each time decided whether they understood the utterance as a statement or a question. The second task tested perception of prosodic form. Participants listened to 16 pre-recorded model utterance pairs (e.g. a statement and a declarative question, two declarative questions, or two statements) and decided whether the paired utterances sounded similar or different. Participants scoring below 80% were given a one-hour receptive prosodic skills training session and were immediately retested with a parallel version of the test. If their score fell below 80% again, they were excluded from the study.

In this way, a final group of eleven speakers (seven men and four women) was selected for this study. All participants signed an informed consent, approved by the Ethics Committee of the Antwerp University Hospital (Belgian registration number B300201215074). Demographic and clinical characteristics of the selected participants can be found in Table 1. Speaker age ranged between 52 and 94 years ($M = 70$, $SD = 11$). Participants spoke Dutch as a native language and represented all Flemish provinces. They all had been diagnosed with idiopathic PD. Number of years post diagnosis ranged between 4 and 29 ($M = 16$, $SD = 8$). All participants took antiparkinson medication and four of them also received deep brain stimulation (DBS). Their attending neurologists confirmed that both the pharmacological and the DBS treatment had already been properly adjusted before the start of the present study. Five individuals (Speakers 2, 3, 7, 9, and 11) were or had been involved in speech therapy for dysarthria, based on increasing vocal loudness and/or reducing speech rate.

Table 1
Demographic and clinical speaker characteristics.

No.	Gender[a]	Age (years)	Diagnosis (years)	Antiparkinson medication	DBS[b]	Dysarthria severity	Sentence intelligibility (%)
1	M	94	19	Prolopa	No	Moderate	79
2	M	68	10	Mirapexin	No	Moderate	64
3	M	65	17	Mirapexin, Stalevo	Yes	Mild	89
4	F	79	4	Mirapexin, Stalevo	No	Moderate	69
5	M	52	18	Stalevo	Yes	Moderate	74
6	F	74	29	Azilect, Prolopa, Requip	Yes	Moderate	82
7	M	62	22	Duodopa	No	Moderate	66
8	M	62	4	Prolopa	No	Mild	86
9	F	71	21	Stalevo	No	Undetermined	86
10	M	70	18	Stalevo	Yes	Moderate	76
11	F	75	10	Azilect, Mirapexin, Stalevo	No	Moderate	90

[a] M, male; F, female.
[b] DBS, deep brain stimulation.

Dysarthria severity was determined by three qualified speech and language therapists experienced in the field of motor speech disorders. They classified each speaker as having 'no dysarthria', 'mild dysarthria', 'moderate dysarthria', or 'severe dysarthria', by means of listening to a sample of each participant reading the first seven sentences of a Dutch standard passage (this sample was part of the pre-treatment passage reading task sample of the speech rate test; see Section 2.3.1). For the severity rating in Table 1, the majority rule was used: e.g. if two judges attributed the label 'moderate' and one judge the label 'mild', the final rating was 'moderate'. In one instance, severity could not be determined on the basis of this sample, because it had not been saved properly by the Prosodietrainer programme.

2.2. Research design

A one-group pretest–posttest design was used to compare speech data obtained before and after intensive treatment of speech rate and intonation. In consultation with the participants and their treating speech therapist, it was decided to temporarily interrupt participants' habitual speech treatment programme (if any) for the course of this study, and replace it with the SPRINT treatment protocol.

2.3. Pre-treatment and post-treatment measurements

During the pre-treatment measurement protocol, participants performed three tests (described in Sections 2.3.1–2.3.3), in the same fixed order. Pre-treatment testing was done maximally two weeks before the start of SPRINT therapy. The post-treatment measurement protocol was identical to the pre-treatment one. Post-treatment testing was done at most three days after termination of SPRINT therapy.

Speech samples were recorded in a quiet environment, with a Sennheiser headset microphone (type PC131 or PC146) connected to a laptop computer (MAC OS X MacBook 10.6.8, MAC OS X MacBook Pro 10.6.8, Acer Aspire 7730G, or Samsung NP-RC720), through a Sennheiser USB-adapter (type UUSB1). The same microphone and laptop computer were used for each participant's pre-treatment and post-treatment test recordings. Speech rate and intonation samples were recorded using the Prosodietrainer version 1.05 (Martens, Latacz, et al., 2013; Martens, Dekens, et al., 2013), a recently developed software programme for testing and training prosody in native speakers of Dutch with dysarthria. Sentence intelligibility samples were recorded using Audacity® software version 2.0.1 (freely available, sampling rate 44.1 kHz, 24 bit, mono) (Audacity Team, 2012), with each sentence afterwards being saved as a separate wav-file.

2.3.1. Speech rate test

As prosodic control is highly task dependent (Patel, 2011), speech rate was tested by means of both a structured (passage reading) task and a nonstructured (narrative) task. In this way, two different speaking styles could be compared (Lowit-Leuschel & Docherty, 2001).

Passage reading task – Participants were instructed to read aloud a Dutch phonetically balanced standard passage that appeared on a monitor (Martens, Van Nuffelen, & De Bodt, 2010b). The text is composed of 14 sentences and 129 syllables, and contains a timeless story, easy to retell. In devising this novel reading passage, care was taken to use simple vocabulary and grammar, in order to minimize the risk of reading errors and dysfluencies (Patel, 2011).

Storytelling task – The previously read story was made invisible and participants were asked to retell the story in their own words, only helped by six key words visible on the monitor.

Due to a software problem, the speech rate pre-treatment test samples of participant 9 were not saved properly. As a result, this participant had to be excluded from the speech rate test. For each of the remaining ten participants, four samples were collected (pre-treatment passage reading, pre-treatment storytelling, post-treatment passage reading, and post-treatment storytelling), yielding a total amount of 40 samples for speech rate (see Fig. 1).

2.3.2. Intonation test

Intonation was also tested by means of two tasks: a sentence reading task, to determine whether a speaker could spontaneously produce a clear intonational contrast between a statement (by means of a final F_0 fall) and a question (by means of a final F_0 rise), and a sentence repetition task, to determine whether a speaker was at all able to imitate these two intonation patterns. This procedure was more or less congruent with the approach of Peppé, McCann, Gibbon, O'Hare, & Rutherford (2007), who developed a prosody assessment for English-speaking children with high-functioning autism, a difference being that these authors made use of pictorial stimuli to test the spontaneous production of prosody. For both tasks, the test database contained 16 minimal pairs, each consisting of a statement (e.g. 'Tot zondag.'; translation 'See you on Sunday.') and a declarative question (e.g. 'Tot zondag?'; translation 'See you on Sunday?'), that did not figure in the therapy exercises. To dissociate the effect of stress and intonation in the final syllable of an utterance, the test items were designed in such a way that the final syllable could not carry stress. The Prosodietrainer (Martens, Latacz, et al., 2013) randomly picked one item of each minimal pair, in order to generate a test list of 16 utterances. In this way, predictability during retesting was reduced.

Sentence reading task – Participants were instructed to read aloud 16 utterances (varying in length between three and ten syllables) that appeared one by one on a monitor. Eight statements and eight declarative questions were shown in a random order. Participants were instructed to make the utterance sound like a genuine statement whenever the utterance ended in a full stop, or like a genuine question whenever the utterance ended in a question mark.

Sentence repetition task – Participants listened to 16 pre-recorded model utterances. Eight statements and eight declarative questions were presented in a random order and participants were instructed to imitate these utterances as well as they could.

Due to the same technical problem mentioned in Section 2.3.1, the intonation pre-treatment test samples of participant 9 were not saved properly. As a result, this participant had to be excluded from the intonation assessment. For each of the remaining ten participants, four sample blocks of 16 sentences each were collected (pre-treatment sentence reading, pre-treatment sentence repetition, post-treatment sentence reading, and post-treatment sentence repetition), yielding a total of 40 sample blocks for intonation (see Fig. 1).

2.3.3. Sentence intelligibility test

Participants took the Dutch Sentence Intelligibility Assessment developed by Martens et al. (2010a). This test consisted of reading aloud a list of 18 nonsense sentences (e.g. 'De kat kocht een bank'; translation: 'The cat bought a bank'). Each list was randomly generated from a pool of 1200 sentences and contained three sentences of each of the following lengths: 5, 7, 9, 11, 13, and 15 syllables. For each of the 11 participants, two sample blocks of 18 sentences each were collected (a pre-treatment block and a post-treatment block), yielding a total of 22 sample blocks for intelligibility (see Fig. 1).

2.4. SPRINT therapy (speech rate and intonation therapy)

SPRINT therapy was delivered by the same four speech-language pathology students who assisted in the selection of the participants (see Section 2.1). The therapists received training to use the Prosodietrainer (Martens, Latacz, et al., 2013) by the first author of the study. In order to ensure that they would actually implement the intervention as designed, they all operated on the basis of a treatment protocol that described frequency and duration of the therapy sessions, content and hierarchy of the therapy exercises, and instructions on feedback delivery (as will be explained further in this section). In addition, the therapists were supervised by the first author throughout the course of the study during discussions on therapy and participant evolution.

Before the start of each therapy session, participants were explicitly asked about the time they had taken in their antiparkinson medication and about whether they felt it had reached its optimum effect. As soon as this was the case, SPRINT therapy was started. Treatment was designed to be intensive (15 one-hour sessions in three weeks) and focused on two speech aspects: speech rate therapy during the first half hour, and intonation therapy during the second half hour. At the beginning of the therapy phase, the therapists explained that these two therapy goals were chosen in function of the final goal of improving intelligibility. In the course of the study, however, no specific attention was directed towards improvement of intelligibility. The immediate goal of speech rate therapy was to slow down speech rate, regardless of the speaker's habitual speech rate, considering its potentially beneficial effect on intelligibility (Van Nuffelen et al., 2010). To this end, participants were instructed to speak half as fast as they normally did. When speaking more slowly on demand did not prove to be helpful, other techniques such as modelling and hand tapping were introduced. No specific instructions were given regarding lengthening sounds or words or inserting pauses. The immediate goal of intonation therapy was to optimize the prosodic difference between questions and statements. To this end, participants were instructed to produce statements with a clear end-fall intonation pattern and questions with a clear end-rise intonation pattern.

During therapy, the Prosodietrainer version 1.05 (Martens, Latacz, et al., 2013; Martens, Dekens, et al., 2013) was used. A replay button enables the speaker to listen to his own performance, thus providing auditory feedback. The tool also provides post hoc automated visual feedback. However, at the time the present study was performed, the automated visual feedback was still in an experimental phase and feedback reliability could not yet be sufficiently warranted. Therefore, the feedback area on the monitor was covered, to ensure that participants would give their undivided attention to the external feedback provided by the therapist. The tool's user interface, on the other hand, was fully operational, and the therapeutic programme content is structured along the following three principles. First, in terms of prosodic targets, the treatment programme consists of two parts: speech rate and intonation (in particular the statement-question contrast). Second, on a linguistic level, the tool allows speech therapy on sentence level and, in the case of speech rate, also on text level. The therapist can select exercises containing a particular item length (for speech rate: 5-syllable sentences up to 15-syllable sentences, and short, medium-length, and long texts; for intonation: 3-syllable sentences up to 10-syllable sentences). Finally, in terms of speech task nature, the programme includes a hierarchy of various tasks ranging from non-communicative tasks to more challenging semi-spontaneous tasks (for speech rate: repetition, reading, storytelling, answering questions, reacting to a situation; for intonation: repetition, reading, completing sentences). For more details about the training programme, we refer the reader to the Prosodietrainer (Martens, Latacz, et al., 2013). During therapy sessions, increasing complexity was strived for in terms of linguistic level as well as speech task nature. However, treatment was tailored in the sense that the individual participant's capacity guided the therapist in deciding if and when a new complexity level could be presented.

Further therapy management choices were based on the principles of motor learning as described by Duffy (2005) and Maas et al. (2008). Pre-practice considerations included providing clear and brief instructions and also providing a reference of correctness through modelling. As far as practice conditions (Maas et al., 2008) were concerned, we opted for massed practice distribution by means of an intensive three-week treatment of 15 one-hour sessions, which is more or less comparable to the LSVT programme design (Ramig et al., 1995; Ramig, Sapir, Fox, et al., 2001; Ramig, Sapir, & Countryman, 2001). As far as feedback conditions (Maas et al., 2008) were concerned, the therapists adhered to the following feedback delivery principles. They provided both feedback on performance (supported by the Prosodietrainer's replay functionality) and feedback on results (Did the speaker manage to speak at a lower target speech rate? Did the speaker manage to get across a statement or a question consistent with the original instruction?). In order to facilitate the speaker's self-monitoring, feedback timing was gradually delayed and feedback frequency was gradually reduced during practice.

2.5. Perceptual assessment

After the post-treatment measurements had been collected, the intelligibility and intonation samples were judged by the same three qualified speech and language therapists who had rated dysarthria severity (see Section 2.1). In order to avoid listener fatigue, perceptual assessment of dysarthria severity, intelligibility, and intonation took place on separate days. The judges were native speakers of Dutch and reported adequate hearing. Judgement of the samples took place in a quiet office room. Samples were presented through Creative SBS260 speakers connected to a notebook (MAC OS X MacBook 10.6.8) and judged simultaneously by all three judges. Each sample was played only once, unless the judges explicitly asked for a sample replay, which occurred only occasionally.

For intelligibility, the 22 pre-treatment and post-treatment sample blocks were presented in a random order. Judges orthographically transcribed the first sample block of 18 sentences (produced by one individual during one test session), and then repeated this process for the remaining 21 sample blocks. For each block, the intelligibility score was calculated in terms of the percentage of words correctly identified by each judge separately. Afterwards, the judges' mean score was calculated.

For intonation, the 40 pre-treatment and post-treatment sentence reading and sentence repetition sample blocks were presented in a random order. Judges rated the first sample block of 16 utterances (produced by one individual during one test session) by classifying each utterance as either a statement or a question, and then repeated this process for the remaining 39 sample blocks. For each block, the intonation score was calculated in terms of percentage of utterances classified in agreement with the original target intonation pattern. This was first done for each judge separately, and afterwards the judges' mean score was calculated.

2.6. Automated assessment

Instrumental analysis of the 40 speech rate samples as well as the 396 intelligibility samples was performed with the Prosodietrainer version 1.19 beta 1 (Martens, Latacz, et al., 2013), as follows. First, active speech duration was determined by a voice activity detector (Dekens & Verhelst, 2011). In this way, pauses at the edges of a sample were excluded from further analysis. Then, the following measures of global speech timing (i.e. speech and pause characteristics) were calculated by a speech rate algorithm (Dekens, Martens, Van Nuffelen, De Bodt, & Verhelst, 2014) for the remainder of the sample: speech rate (the number of syllables per second inclusive of pauses), articulation rate (the number of syllables per second exclusive of pauses), mean pause time (the mean duration of pauses in seconds), and pause frequency (the number of pauses). For this matter, a pause (within the sample) was defined as a silent period in the speech waveform of at least 200 milliseconds (Turner & Weismer, 1993).

2.7. Acoustic analysis

Apart from being perceptually assessed (see Section 2.5), the 640 intonation samples were also acoustically analyzed to evaluate how participants marked the statement-question intonation contrast before and after SPRINT therapy. The acoustic analysis was performed in Matlab (version R 2015a), using a semi-automatic procedure. An novel algorithm, developed by Gonzalez-Moreira et al. (2015) and mainly based upon the method described by Wang and Narayanan (2007), was used to plot the syllables of an utterance over its spectrogram, to automatically detect the syllable nuclei, and to calculate the maximum fundamental frequency value (F_0-max) of each syllable nucleus in semitones ($ST = 12 \times \log2$ (F_0-max value in Hz)), a speaker independent frequency unit ('t Hart, Collier, & Cohen, 1990). Afterwards, the results of the automatic analysis were verified by the first author through audio-visual inspection of the spectrogram. Syllable nucleus boundaries were manually edited if necessary. Boundaries were removed when the algorithm had erroneously marked a waveform part as a separate syllable nucleus, were added when the algorithm had erroneously overseen a waveform part as a separate syllable nucleus, or were shifted when the algorithm had set the boundaries too wide or too narrow. After the editing, the algorithm automatically recalculated the F_0-max values. Manual correction of F_0-max values was required in 12 samples (1.88%): in the case of pitch doubling, values were halved, and in the case of subharmonics, values were multiplied. The manually corrected values were used for further analysis. Finally, two measurements were selected for the data analysis of each stimulus: median F_0-max of the sentence (obtained through manual calculation of the median value of all semi-automatically generated F_0-max values for a particular sentence), and F_0-max of the final syllable. To determine rater consistency, a random data sample of 10% was re-analyzed three weeks after the original analysis.

2.8. Data analysis

Statistical analysis of the results was done by means of SPSS (version 20). Due to the small number of participants and the non-normal distribution of the data, a non-parametric test was chosen: to compare pre-treatment and post-treatment intelligibility, intonation, and global speech timing results, the Wilcoxon matched pairs signed ranks test was used (alpha level .05). As the data for intelligibility were non-normally distributed and paired, we determined the non-parametric effect size for intelligibility by dividing the standardized test statistic (2.756) by the square root of the number of participants (3.32). Regarding the perceptual assessment, a two-way random consistency single measures intraclass correlation coefficient was used for calculating interrater reliability. Regarding the acoustic analysis, a two-way mixed consistency single measures intraclass correlation coefficient was used for calculating intrarater reliability.

3. Results

The interrater reliability analysis for the perceptual data showed high correlations for both the pre-treatment (ICC = .831) and post-treatment (ICC = .933) intelligibility measures, and also for both the pre-treatment (ICC = .935) and post-treatment (ICC = .799) intonation measures. The intrarater reliability analysis for the acoustic data showed high correlations for the F_0-max values of the entire sentence (ICC = .998) and of the final syllable (ICC = .997).

Concerning intelligibility, a statistically significant difference was found between pre-treatment and post-treatment intelligibility scores for the group of 11 participants in this study (see Table 2 and Fig. 2). The non-parametric effect size for this analysis was .83, which indicates a large effect.

Regarding the intonation data obtained through perceptual assessment (see Table 2 and Fig. 3), there was a statistically significant difference between pre-treatment and post-treatment total scores. An analysis according to sentence mode revealed a significant difference between pre-treatment and post-treatment scores for questions, but no significant difference for statements. An analysis according to task type revealed a significant difference between pre-treatment and post-treatment sentence reading task scores, but no significant difference for sentence repetition task scores. Regarding the intonation data obtained through acoustic analysis (see Table 3), there was no significant difference between pre-treatment and post-treatment median F_0-max values of the statements or questions. Post-treatment F_0-max values of the final syllable in statements were not significantly lower than the pre-treatment values. Conversely, post-treatment F_0-max values of the final syllable in questions were significantly higher than the pre-treatment values during both intonation tasks.

As for global speech timing (see Table 2), there was a statistically significant difference between pre-treatment and post-treatment pause frequency during the passage reading task only, and there were no significant differences whatsoever for speech rate, articulation rate, and mean pause time. Individual pre-treatment and post-treatment results for intelligibility, intonation, and global speech timing are presented in Tables 4 and 5.

4. Discussion

4.1. Principal findings

The present study investigated whether an intensive speech rate and intonation therapy in speakers with dysarthria due to PD leads to (1) improved intelligibility, (2) an improved intonational contrast between questions and statements, and (3) a decreased speech rate.

The results suggest that the first research question can be answered positively: after treatment, the participant group demonstrated a significant improvement of their intelligibility score. Moreover, in terms of practical significance, the effect size seems to indicate that the pre-treatment to post-treatment change in intelligibility is of considerable magnitude. Although one group pretest–posttest design results should always be interpreted with caution, there are a few reasons why the results of the present study are relevant. First, several measures were taken to minimize extraneous factors: optimization of pharmacological and medical treatment had already been corroborated by the attending neurologists prior to the study, habitual speech therapy was interrupted and replaced with SPRINT therapy, and participants were consistently tested and

Table 2
Pre-treatment versus post-treatment intelligibility, intonation, and global speech timing: group results.

Parameter	Pre-treatment median (Q1–Q3)[a]		Post-treatment median (Q1–Q3)[a]		*P*-value[b]
Intelligibility (%)	72.70	(58.90–82.10)	90.30	(83.37–95.33)	0.006*
Intonation (%)					
Total	69.81	(57.06–77.88)	93.23	(78.93–96.90)	0.005*
Statements	94.90	(89.64–98.16)	94.79	(91.82–100.00)	0.594
Questions	52.19	(30.78–64.06)	89.58	(71.25–98.59)	0.005*
Sentence reading	59.40	(50.03–63.05)	86.47	(75.53–95.35)	0.005*
Sentence repetition	85.45	(56.80–94.28)	97.93	(81.28–100.00)	0.053
Speech rate (syll/s)					
Passage reading	2.68	(2.55–2.82)	1.82	(1.78–2.88)	0.058
Storytelling	2.17	(1.51–2.79)	2.04	(1.61–2.29)	0.505
Intelligibility test	3.24	(2.27–3.62)	2.63	(2.41–3.04)	0.062
Articulation rate (syll/s)					
Passage reading	3.66	(3.25–4.04)	2.92	(2.67–3.87)	0.092
Storytelling	3.34	(2.74–3.88)	2.89	(2.73–3.81)	0.919
Intelligibility test	3.30	(2.62–3.66)	2.74	(2.54–3.21)	0.062
Mean pause time (s)					
Passage reading	0.83	(0.66–1.01)	0.99	(0.78–1.26)	0.259
Storytelling	1.21	(0.76–1.70)	1.47	(1.11–1.81)	0.154
Intelligibility test	0.00	(0.00–0.10)	0.00	(0.00–0.45)	0.144
Pauses (number)					
Passage reading	14.00	(12.75–16.00)	19.00	(13.75–23.00)	0.012*
Storytelling	9.50	(7.50–11.50)	12.50	(10.25–16.00)	0.050
Intelligibility test	0.00	(0.00–0.50)	0.00	(0.00–1.00)	1.000

[a] Because of the non-normal distribution of the data, medians are reported instead of means, and first quartile (Q1) and third quartile (Q3) values instead of standard deviations.
[b] *P*-value resulting from the Wilcoxon matched pairs signed ranks test. Significant results ($P < 0.05$) are marked with an asterisk.

treated in the 'on' phase of their medication cycle. Second, Yorkston et al. (2007) put forth improved speech performance following intervention in the face of a progressive disorder as a factor suggesting control. In the present study, the patient group improved its post-treatment median intelligibility score in spite of the diagnosis of PD, the substantial mean number of years post-diagnosis, and the relatively high mean group age, and in spite of the fact that the majority of the participants had a moderate dysarthria, which can often be challenging to address in speakers with PD.

As far as the second research question is concerned, the total group scores in Table 2 as well as most of the individual scores in Table 4 showed a significant improvement in the intonational statement-question contrast during the intonation

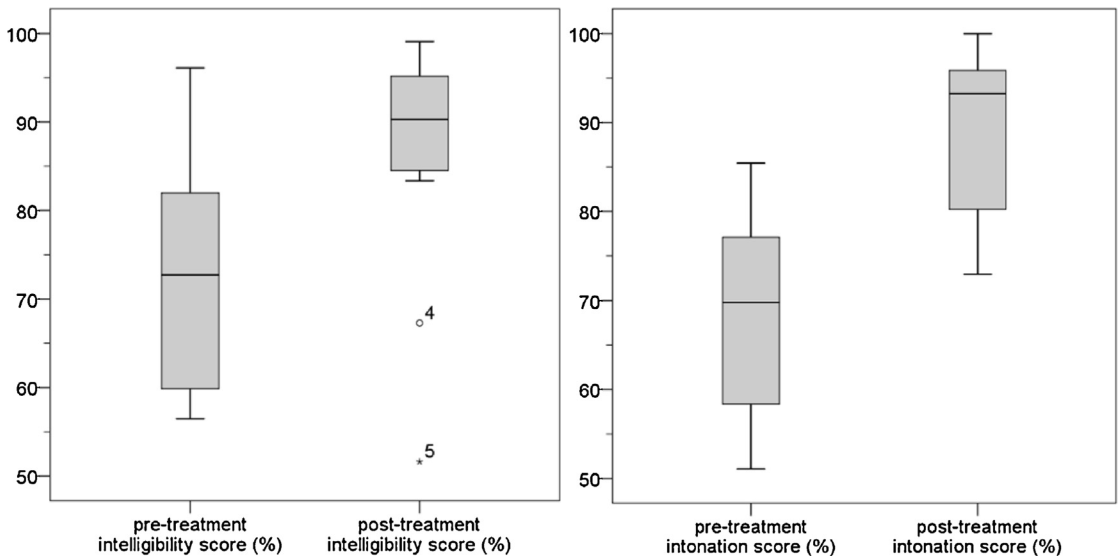

Fig. 2 and 3. Box and whiskers plots indicate the distribution of pre-treatment versus post-treatment group results for intelligibility (Fig. 2 at the left) and intonation (Fig. 3 at the right). The edges of a box represent the first (Q1) and third (Q3) quartiles, the horizontal line inside each box represents the median. In Fig. 2, the circle represents an outlier for participant 4 (see Table 4), and the asterisk represents an extreme value for participant 5 (see Table 4).

Table 3
Pre-treatment versus post-treatment maximum fundamental frequency (F_0-max) values in semitones for statements and questions: group results.

Stimulus	Parameter	Pre-treatment median (Q1–Q3)[a]		Post-treatment median (Q1–Q3)[a]		P-value[b]
Statements	F_0-max (median)					
	Sentence reading	85.98	(85.14–89.05)	86.18	(84.37–90.29)	0.386
	Sentence repetition	87.06	(85.88–89.18)	86.69	(84.26–90.47)	0.878
	F_0-max (final syllable)					
	Sentence reading	84.96	(82.80–87.39)	83.89	(82.19–88.33)	0.386
	Sentence repetition	84.84	(82.48–87.69)	83.72	(81.23–88.48)	0.959
Questions	F_0-max (median)					
	Sentence reading	86.80	(85.70–89.49)	88.71	(85.70–92.07)	0.074
	Sentence repetition	87.70	(86.42–90.25)	88.38	(85.01–91.24)	0.386
	F_0-max (final syllable)					
	Sentence reading	86.89	(83.00–88.17)	91.67	(89.01–95.80)	0.005*
	Sentence repetition	90.26	(88.07–91.67)	91.87	(89.44–95.92)	0.028*

[a] Because of the non-normal distribution of the data, medians are reported instead of means, and first quartile (Q1) and third quartile (Q3) values instead of standard deviations. Values are expressed in semitones (ST) to rule out interspeaker F_0 variations; $ST = 12 \times (\log2 \text{ (value in Hz)})$.
[b] P-value resulting from the Wilcoxon matched pairs signed ranks test. Significant results ($P < 0.05$) are marked with an asterisk.

Table 4
Pre-treatment versus post-treatment intelligibility and intonation: individual results. The results for intonation represent the conflated results for the sentence reading and sentence repetition tasks.

No.	Intelligibility (%)			Intonation (%)			
	Pre-treatment	Post-treatment	Δ[a]	No.	Pre-treatment	Post-treatment	Δ
1	72.70	83.37	+10.67	1	71.88	93.75	+21.87
2	56.50	90.57	+34.07	2	58.37	95.87	+37.50
3	96.10	98.20	+2.10	3	85.42	95.85	+10.43
4	58.57	67.30	+8.73	4	51.07	75.02	+23.95
5	58.90	51.63	−7.27	5	53.15	84.40	+31.25
6	82.10	90.30	+8.20	6	75.02	92.72	+17.70
7	60.87	95.33	+34.46	7	67.73	100.00	+32.27
8	89.93	99.10	+9.17	8	77.10	100.00	+22.90
9	81.87	95.00	+13.13	9	NA[b]	NA	NA
10	71.03	86.83	+15.80	10	80.22	80.23	+0.01
11	77.67	85.67	+8.00	11	64.63	72.93	+8.30

[a] Δ, pre-treatment to post-treatment difference.
[b] NA, results not available.

test after SPRINT therapy. This seems to corroborate on a larger scale the findings of the case study by Le Dorze et al. (1992), who argued that an individual with PD can learn to improve the statement-question contrast within a relatively short time span during which therapy is specifically directed at this particular speech characteristic. As listeners predominantly rely on F_0 cues at the final syllable in discriminating questions and statements, Ma et al. (2010) proposed targeting F_0 in speech treatment of speakers with PD in order to improve the statement-question contrast. Our results suggest that such a treatment strategy indeed leads to better post-treatment statement/question identification by the listeners, due to better post-treatment speaker control of the intonation characteristics that contrast statements and questions.

When splitting up the results per sentence mode, the perceptual data seem to indicate that post-treatment intonational changes were caused primarily by a better intonation of questions, as speakers were already relatively able to intone statements properly before treatment (*Mdn* = 94.90%; Q1–Q3 = 89.64–98.16%), a finding that is consistent with the outcome of the study by Ma et al. (2010). The perceptual data are supported by the results of the acoustic analysis, which revealed that, while F_0-max values for the final syllable of questions were post-treatment significantly higher, there was no significant post-treatment change in the F_0-max values for the final syllable of statements. The differences between F_0-max values of question and statement were greater post-treatment across tasks and measures, although they were most notable for the final syllable in sentence reading (1.93 ST versus 7.78 ST) and sentence repetition (5.42 ST versus 8.15 ST) comparisons (see Table 3).

When splitting up the results per task type, a significant improvement of intonation skills could only be observed during the sentence reading task, and not during the sentence repetition task. In an earlier study by Martens et al. (2011) no significant differences could be found between sentence reading and sentence repetition task results of speakers with PD uttering statements and declarative questions. In the present study, on the other hand, speakers with PD were controlled for good receptive prosodic skills (see Section 2.1), which may help to explain why, already during the pre-treatment condition, auditory external models (audio samples) seemed to help these speakers relatively well in producing adequate intonation patterns (*Mdn* = 85.45%; Q1–Q3 = 56.80–94.28%). Especially for questions, the outcome of the acoustic analysis lends credence to this hypothesis, because already in the pre-treatment condition, F_0-max values in the final syllable proved to be

Table 5
Pre-treatment versus post-treatment global speech timing parameters: individual results.

No.	Passage reading			Storytelling			Intelligibility test[e]		
	Pre[a]	Post[b]	Δ[c]	Pre	Post	Δ	Pre	Post	Δ
Speech rate (syll/s)									
1	2.78	1.78	−1.00	2.01	1.41	−0.60	2.06	1.62	−0.44
2	2.95	1.81	−1.14	2.07	2.37	+0.30	2.90	3.04	+0.14
3	2.68	1.83	−0.85	2.82	1.78	−1.04	3.38	2.63	−0.75
4	2.78	3.32	+0.56	0.99	2.26	+1.27	3.24	2.95	−0.29
5	1.79	1.41	−0.38	1.21	1.87	+0.66	2.27	2.41	+0.14
6	2.65	1.77	−0.88	2.26	1.68	−0.58	2.74	2.56	−0.18
7	3.04	3.16	+0.12	2.45	2.21	−0.24	3.77	3.99	+0.22
8	2.68	1.81	−0.87	2.78	2.22	−0.56	3.29	1.93	−1.36
9	NA[d]	NA	NA	NA	NA	NA	3.62	2.81	−0.81
10	2.30	2.08	−0.22	1.61	1.26	−0.35	2.26	2.53	+0.27
11	2.64	2.79	+0.15	3.03	2.93	−0.10	3.66	3.21	−0.45
Articulation rate (syll/s)									
1	3.46	2.83	−0.63	3.23	2.76	−0.47	2.35	2.24	−0.11
2	3.93	2.93	−1.00	3.45	4.03	+0.58	3.30	3.33	+0.03
3	3.39	2.79	−0.60	4.02	2.73	−1.29	3.38	2.74	−0.64
4	4.37	3.84	−0.53	1.17	2.73	+1.56	3.28	3.07	−0.21
5	2.62	2.25	−0.37	2.51	2.68	+0.17	2.62	2.61	−0.01
6	3.88	2.32	−1.56	3.18	3.01	−0.17	2.99	2.70	−0.29
7	3.54	4.84	+1.30	3.83	4.45	+0.62	3.77	3.99	+0.22
8	4.52	3.06	−1.46	4.67	3.73	−0.94	3.78	2.45	−1.33
9	NA	NA	NA	NA	NA	NA	3.62	3.10	−0.52
10	2.83	2.91	+0.08	2.81	2.74	−0.07	2.37	2.53	+0.16
11	3.78	3.97	+0.19	3.70	3.64	−0.06	3.66	3.21	−0.45
Mean pause time (s)									
1	0.67	1.21	+0.54	2.00	2.12	+0.12	0.41	0.54	+0.13
2	0.58	1.04	+0.46	1.60	1.55	−0.05	0.10	0.00	−0.10
3	0.66	1.50	+0.84	1.10	1.70	+0.60	0.00	0.00	0.00
4	1.00	0.56	−0.44	0.42	0.80	+0.38	0.00	0.00	0.00
5	1.44	1.42	−0.02	2.48	1.21	−1.27	0.30	0.50	+0.20
6	0.99	0.74	−0.25	0.65	1.35	+0.70	0.00	0.00	0.00
7	0.71	0.94	+0.23	1.39	1.60	+0.21	0.00	0.00	0.00
8	1.03	1.06	+0.03	0.99	1.39	+0.40	0.10	0.45	+0.35
9	NA	NA	NA	NA	NA	NA	0.00	0.00	0.00
10	0.64	0.79	+0.15	1.31	2.42	+1.11	0.00	0.00	0.00
11	0.94	0.82	−0.12	0.80	0.66	−0.14	0.00	0.00	0.00
Pause frequency (number)									
1	16	23	+7	8	12	+4	1.50	1.00	−0.50
2	16	23	+7	13	12	−1	0.50	0.00	−0.50
3	14	18	+4	9	27	+18	0.00	0.00	0.00
4	14	11	−3	9	8	−1	0.00	0.00	0.00
5	12	20	+8	10	8	−2	1.00	1.00	0.00
6	13	14	+1	13	13	0	0.00	0.00	0.00
7	6	13	+7	6	13	+7	0.00	0.00	0.00
8	18	25	+7	11	14	+3	0.50	2.00	+1.50
9	NA	NA	NA	NA	NA	NA	0.00	0.00	0.00
10	13	22	+9	10	22	+12	0.00	0.00	0.00
11	14	16	+2	6	11	+5	0.00	0.00	0.00

[a] Pre, pre-treatment.
[b] Post, post-treatment.
[c] Δ, pre-treatment to post-treatment difference.
[d] NA, results not available.
[e] Each pre-treatment or post-treatment intelligibility test result represents the median of the eighteen samples constituting a sentence intelligibility test. This explains why the pause frequency numbers for the intelligibility test have decimals, as opposed to the pause frequency numbers for passage reading and storytelling, which represent a single sample.

substantially higher during the sentence repetition task (*Mdn* = 90.26 ST; Q1–Q3 = 88.07–91.67 ST) when compared to the sentence reading task (*Mdn* = 86.89 ST; Q1–Q3 = 83.00–88.17 ST).

The relationship between the observed intonation changes during the intonation test on the one hand and the observed improvement of intelligibility during the intelligibility test on the other hand is not yet fully understood. An additional analysis of the intelligibility samples in terms of pre-treatment to post-treatment intonation changes would be warranted in order to establish whether or not post-treatment increased intelligibility could be ascribed to a better statement-question intonation contrast. However, the way in which the Dutch Sentence Intelligibility Assessment (Martens et al., 2010a) is conceived, does not allow for a good pre-treatment to post-treatment comparison of the intonation contrast, because the randomly generated lists contain more statements than questions, and do not contain minimal prosodic pairs of statements and declarative questions. Possibly, the increased focus on intonation during SPRINT therapy contributed to a heightened awareness of clear prosody during the post-treatment intelligibility test, an assumption which needs further investigation. At any rate, if after treatment individuals with PD are better able to produce questions and statements with a clearly distinguishable intonation, this in itself is certainly an important step in daily communication. The negative impact of loss of pragmatic communication skills on daily life in PD has already been pointed out by Pell et al. (2006) and Hall, Ouyang, Lonnquist, & Newcombe (2011). Because individuals with PD run a risk at becoming more and more dependent as their disease progresses, it is in their direct interest to be able to communicate a need for help or information to the people surrounding them by means of an unmistakable question.

In answer to the third research question, a significant post-treatment decrease in speech characteristics such as speech rate or articulation rate could not be demonstrated during the speech rate test, although most speakers did manage to slow down SR and AR to some extent. Especially during the passage reading task, SR was considerably lower (between 0.85 and 1.14 syllables per second) in Speakers 1, 2, 3, 6, and 8, while AR was considerably lower (between 1.00 and 1.56 syllables per second) in Speakers 2, 6, and 8. Adjusting pause characteristics, on the other hand, seems to have been an essential rate control strategy adopted by the speakers in the present study: mean pause time did not change much post-treatment, but during the passage reading task, an increase in pause frequency could be observed. In their study on speech and pause characteristics associated with voluntary rate reduction, Tjaden and Wilding (2011) also found that speakers with PD tend to rely more on pause time adjustments (by inserting longer and more frequent pauses) when asked to read a passage at a rate half as fast as the habitual one. The increase in pause frequency, however, was associated with an increase in grammatically inappropriate pause locations. Therefore, Tjaden and Wilding (2011) underlined the importance of correct pause placement training during therapy programmes focusing on voluntary rate reduction, a point certainly to be taken into account by therapists who are planning to use the Prosodietrainer (Martens, Latacz, et al., 2013) with individuals with PD. During the storytelling task, speakers generally seemed less able to control rate than during the passage reading task. It has already been put forward that speech tasks may differ in the demands they make on basal ganglia processing (Kempler & Van Lancker, 2002; Van Lancker Sidtis, Rogers, Godier, Tagliati, & Sidtis, 2010; Van Lancker Sidtis, Cameron, & Sidtis, 2012). These authors suggested that damage to the subcortical system can lead to more difficulties in the execution of speech tasks requiring an internal model (e.g. spontaneous speech) versus speech tasks in which an external model is provided (e.g. reading or repetition). Supposedly, this mechanism may render the self-monitoring of speech rate more difficult during a ‘high burden’ spontaneous speech task than during a ‘low burden’ reading task.

To shed light on the relationship between the observed pause frequency changes during the speech rate test on the one hand and the observed improvement of intelligibility during the intelligibility test on the other hand, an additional analysis of the intelligibility samples was conducted in terms of pre-treatment to post-treatment changes in global speech timing parameters. However, speakers inserted very few pauses during the sentence intelligibility test both before and after therapy, which can be related to the fact that the test was made up of relatively short sentence items between 5 and 15 syllables. The speech rate test, on the other hand, consisted of reading and retelling a passage item. Consequently, it is difficult to compare pause characteristics outcomes of both tests. As to speech characteristics, no significant pre-treatment to post-treatment differences could be established, although the median SR and AR were more than half a syllable per second lower following therapy (SR: pre-treatment $Mdn = 3.24$; post-treatment $Mdn = 2.64$; AR: pre-treatment $Mdn = 3.30$; post-treatment $Mdn = 2.74$). We hypothesize that in some speakers (Speakers 3, 8, and 9, and to a lesser extent Speakers 1 and 11), the lower SR and AR in the post-treatment condition may have been clinically relevant enough to result in a twofold effect as described by Liss (2007): speakers reaching a better articulatory accuracy on the one hand, and listeners receiving more time to process the acoustic stream on the other hand. However, as there were also speakers who showed improved intelligibility combined with an increase of SR and AR (e.g. Speakers 2,7, and 10), we cannot unequivocally claim that intelligibility improved after SPRINT therapy as a result of decreased rate.

As far as individual treatment differences are concerned (see Tables 4 and 5), Speakers 2 and 7 made a major post-treatment improvement in terms of intelligibility (an increase of 34.07% and 34.46% respectively) in comparison with the other participants. We hypothesize that the results of Speaker 2 may be related to the fact that this participant also exhibited the most notable post-treatment improvement of all participants in terms of intonation (an increase of 37.50%) as well as rate control during the passage reading task (a speech rate reduction of 1.14 syllables per second). Speaker 7 showed a comparable major post-treatment improvement in intonation (an increase of 32.27%) and achieved post-treatment rate control by inserting about twice as many pauses during both the passage reading and storytelling tasks. The fact that Speakers 2 and 7 had already participated in speech therapy prior to the present study may also have contributed to this result, although the magnitude of the changes in the other participants who had already received speech therapy before (Speakers 3, 9, and 11) is comparable to that in participants who had not been involved in speech therapy before (Speakers 1, 4, 6, 8, and 10). Speaker 5, the only participant showing a post-treatment decline in intelligibility, made a substantial post-treatment progress in terms of intonation (an increase of 31.25%), but reducing rate apparently did not lead to satisfactory post-treatment results: during the passage reading task, this speaker inserted quite lengthy pauses pre-treatment as well as post-treatment (mean pause time 1.44 s and 1.42 s respectively), and did so even more frequently post-treatment. Listening once again to the speech samples of Speaker 5 further revealed that this participant did not suppress belches, made a couple of reading mistakes, and sometimes articulated the final sound of words in an awkward, affected manner. We hypothesize that, despite the partial success for intonation, neuropsychological deficits that were perhaps too subtle to detect during the screening may have been responsible for the fact that Speaker 5 did not seem to respond well to SPRINT therapy as a whole.

A final remark concerns the cost-effectiveness of the proposed training programme, or to put it differently: does the obtained progress in intelligibility justify a sustained intensive three-week treatment regimen? In line with Scott and Caird (1983), Johnson and Pring (1990), Robertson and Thomson (1984), and Ramig, Fox, and Sapir (2008), the present study provides arguments in favour of a short-lasting intensive speech therapy programme for individuals with PD, provided they are able and ready to make the effort. Moreover, the perspective that progress may be possible in a relatively short time span can further enhance motivation and adherence. Obviously, clinical judgement will remain necessary to decide on candidacy for the proposed treatment type. The individual intelligibility scores in Table 4 show that ten out of eleven participants made progress. At least five of them seem to have made significant progress from a clinical point of view: according to Martens et al. (2010a), stipulating a normal intelligibility of at least 96.0% in adults under 70, and at least 93.1% in adults aged 70 or older, post-treatment normal sentence intelligibility is approximated in Speakers 2, 6, 7, and 9, and achieved in Speaker 8. Taking into account the small sample size and the limited speaker characteristics set (see Table 1), it is hard to draw any conclusions regarding what Yorkston et al. (2007) referred to as candidacy criteria, as the aforementioned five speakers seemed to make substantial progress regardless of gender, age, years post diagnosis, medical treatment, or severity.

Ramig et al. (2008) admitted that speech treatment regimens incorporating principles such as intensity and multiple repetitions pose some practical challenges: there is a shortage of therapists who can deliver intensive treatment to the growing population of individuals with PD in need, there is a need for continued exercise after treatment termination, and, finally, intensive treatment can be costly. The authors argued that this will require going beyond the classic one-to-one (patient-to-clinician) treatment delivery model. The design of the Prosodietrainer (Martens, Latacz, et al., 2013) allows for an alternative way of organizing treatment delivery: during the intensive treatment phase, the therapist version can be used in the classic patient-therapist setting; after this phase, the patient can continue exercise by means of the patient version meant for independent use at home; finally, periodical booster sessions can be conducted in order to maintain and generalize the new style of speaking. This approach may eventually provide a cheaper, more effective, and more motivating alternative to a continuing but less intensive patient-to-clinician treatment delivery model, a treatment regimen still very much common practice in the Belgian health care setting.

4.2. Limitations

The present study has a number of limitations. For a start, a one group pretest–posttest design by nature lacks control for extraneous factors, and is known to produce an upward bias in effect size (Carlson & Schmidt, 1999). As a result, we cannot fully claim but only hypothesize that pre-treatment to post-treatment changes were actually due to SPRINT therapy. Another shortcoming pertains to the fact that intelligibility was only tested by means of a low-burden reading task. We can only speculate about the outcome in the case of a high-burden spontaneous speech task, which is closer to the reality of everyday communication. A third limitation is that no intrarater reliability data are available for the perceptual assessment, and no interrater reliability data are available for the acoustic analysis. A final drawback is that intelligibility, intonation, and speech rate were tested in separate samples. A single sample combining all three aspects would have allowed for a more unequivocal assessment of which variables actually contributed to improved intelligibility.

4.3. Future research

Future extensions of this research could include a rerun of the current pilot study in the format of a truly experimental group design or single case design, including long-term follow-up measures, to find out whether improved intelligibility after treatment can be maintained, as well as self-evaluation measures, to find out whether participants experience any difference in communicative interactions after treatment. Additionally, it would be interesting to investigate the effect of supplementing the treatment programme with other communicative functions of prosody (e.g. boundary marking, focus, emotional prosody) next to the sentence modality function (the statement-question contrast) already contained within the Prosodietrainer (Martens, Latacz, et al., 2013).

5. Conclusion

This study has endeavoured to expand the knowledge on treatment designed to address prosodic aspects of speech in individuals with dysarthria due to Parkinson's disease, by investigating the effect of intensive speech rate and intonation therapy, and by formulating treatment outcomes in terms of acoustic measures (such as global speech timing and fundamental frequency parameters) as well as functional measures (such as prosodic efficacy and intelligibility). After treatment, participants were more able to control their rate during a reading task through inserting more pauses, and to realize a clear phrase final intonation contrast between statements and questions. Although it is not yet fully understood whether intelligibility increased as a result of these changes in speech rate and intonation, a substantial improvement of intelligibility could nevertheless be demonstrated in spite of the participants' degenerative condition, the advanced mean number of years post-diagnosis, the relatively high mean age, and the predominance of moderate dysarthria. We therefore advance the treatment protocol introduced in this study as a promising alternative to loudness-based treatment particularly if vocal loudness is not the sole or main issue to address in speech therapy. Individuals of various ages with mildly or moderately reduced intelligibility due to Parkinson's disease may benefit from the proposed therapy. A major candidacy criterion to take into account is motivation, because individuals have to be willing and able to adhere to an intensive treatment schedule.

Acknowledgements

This research is part of a larger project called 'Computerized Assessment and Treatment of Rate, Intonation, and Stress' (CATRIS), supported by a fund (TBM-080662) from the Flemish Agency for Innovation by Science and Technology (IWT). We thank all the participants, speech and language therapists, and institutions who made this research possible. We are much indebted to Kim De Keyser, Tatjana De Meyer, Astrid Vandriessche, and Beatrijs Wille for their contribution to the testing and training of the participants. We are also grateful to Kristien Wouters for her advice on statistics. Finally, we thank Rahul Shrivastav and two anonymous reviewers for their constructive feedback on this study.

References

Adams, S. C., & Dykstra, A. (2009). Hypokinetic dysarthria. In M. R. McNeil (Ed.), *Clinical management of sensorimotor speech disorders* (2nd ed., pp. 166–186). New-York/Stuttgart: Thieme.

Anand, S., & Stepp, C. (2015). Listener perception of monopitch, naturalness, and intelligibility for speakers with Parkinson's disease. *Journal of Speech, Language, and Hearing Research, 58*, 1134–1144.

Atkinson-Clement, C., Sadat, J., & Pinto, S. (2015). Behavioral treatments for speech in Parkinson's disease: Meta-analyses and review of the literature. *Neurodegenerative Disease Management, 5*(3), 233–248.

Audacity Team (2012). *Audacity [Computer programme]. Version 2.0.1.*. http://audacity.sourceforge.net/ (accessed 01.08.12).

Baylor, C. R., Burns, M., Eadie, T. L., Britton, D., & Yorkston, K. M. (2011). A qualitative study of interference with communicative participation across communication disorders in adults. *American Journal of Speech-Language Pathology, 20*, 269–287. http://dx.doi.org/10.1044/1058-0360(2011/10-0084)

Blanchet, P. G., & Snyder, G. J. (2009). Speech rate deficits in individuals with Parkinson's disease: A review of the literature. *Journal of Medical Speech-Language Pathology, 17*, 1–7.

Cannito, M. P., Suiter, D. M., Beverly, D., Chorna, L., Wolf, T., & Pfeiffer, R. M. (2012). Sentence intelligibility before and after voice treatment in speakers with idiopathic Parkinson's disease. *Journal of Voice, 26*(2), 214–219.

Carlson, K. D., & Schmidt, F. L. (1999). Impact of experimental design on effect size: Findings from the research literature on training. *Journal of Applied Psychology, 84*(6), 851–862.

Dagenais, P. A., Southwood, M. H., & Lee, T. L. (1998). Rate reduction methods for improving speech intelligibility of dysarthric speakers with Parkinson's disease. *Journal of Medical Speech-Language Pathology, 6*(3), 143–157.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1975). *Motor speech disorders*. Philadelphia: W B Saunders.

De Bodt, M. S., Hernández-Díaz Huici, M. E., & Van De Heyning, P. H. (2002). Intelligibility as a linear combination of dimensions in dysarthric speech. *Journal of Communication Disorders, 35*, 283–292.

Dekens, T., & Verhelst, W. (2011). On noise robust voice activity detection. *Proceedings of the 12th Annual Conference of the International Speech Communication Association* (pp. 2660–2663). Florence, Italy: International Speech Communication Association.

Dekens, T., Martens, H., Van Nuffelen, G., De Bodt, M., & Verhelst, W. (2014). Speech rate determination by vowel detection on the modulated energy envelope. *Proceedings of the 22nd European Signal Processing Conference* (pp. 1252–1256) Retrieved from: http://www.eurasip.org/Proceedings/Eusipco/Eusipco2014/HTML/papers/1569922087.pdf

de Swart, B. J. M., Willemse, S. C., Maassen, B. A., & Horstink, M. W. (2003). Improvement of voicing in patients with Parkinson's disease by speech therapy. *Neurology, 60*(3), 498–500.

Duffy, J. R. (2005). *Motor speech disorders. Substrates, differential diagnosis, and management* (2nd ed.). St-Louis, MO: Elsevier Mosby.

Fox, C., Ebersbach, G., Ramig, L., & Sapir, S. (2012). LSVT LOUD and LSVT BIG: Behavioral treatment programs for speech and body movement in Parkinson disease. *Parkinson's Disease*. http://dx.doi.org/10.1155/2012/391946 12 p. (Article ID 391946)

Gonzalez-Moreira, E., Torres-Boza, D., Kairuz, H. A., Ferrer, C., Garcia-Zamora, M., Espinoza-Cuadros, F., et al. (2015). Automatic prosodic analysis to identify mild dementia. *BioMed Research International* (Article ID 916356).

Hall, D., Ouyang, B., Lonnquist, E., & Newcombe, J. (2011). Pragmatic communication is impaired in Parkinson disease. *International Journal of Neuroscience, 121*(5), 254–256.

Hammen, V. L., Yorkston, K. M., & Minifie, F. D. (1994). Effects of temporal alterations on speech intelligibility in parkinsonian dysarthria. *Journal of Speech & Hearing Research, 37*(2), 244–253.

Hanson, W., & Metter, E. (1983). DAF speech rate modification in Parkinson's disease: A report of two cases. In W. Berry (Ed.), *Clinical dysarthria* (pp. 231–254). Austin, TX: Pro-Ed.

Hargrove, P., Anderson, A., & Jones, J. (2009). A critical review of interventions targeting prosody. *International Journal of Speech-Language Pathology, 11*(4), 298–304.

Herd, C. P., Tomlinson, C. L., Deane, K. H. O., Brady, M. C., Smith, C. H., Sackley, C. M., et al. (2012). Comparison of speech and language therapy techniques for speech problems in Parkinson's disease. *Cochrane Database of Systematic Reviews*, (8) http://dx.doi.org/10.1002/14651858.CD002814.pub2. (Art. No. CD002814)

Johnson, J. A., & Pring, T. R. (1990). Speech therapy and Parkinson's disease: A review and further data. *British Journal of Disorders of Communication, 25*, 183–194.

Kempler, D., & Van Lancker, D. (2002). Effect of speech task on intelligibility in dysarthria: A case study of Parkinson's disease. *Brain and Language, 80*, 449–464.

Kleim, J. A., & Jones, T. A. (2008). Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. *Journal of Speech Language, and Hearing Research, 51*(1), S225–S239.

Kleim, J. A., Jones, T. A., & Schallert, T. (2003). Motor enrichment and the induction of plasticity before or after brain injury. *Neurochemical Research, 28*(11), 1757–1769.

Le Dorze, G., Dionne, L., Rialls, J., Julien, M., & Ouellet, L. (1992). The effects of speech and language therapy for a case of dysarthria associated with Parkinson's disease. *European Journal of Disorders of Communication, 27*, 313–324.

Liss, J. M. (2007). The role of speech perception in motor speech disorders. In G. Weismer (Ed.), *Motor speech disorders* (pp. 187–219). San Diego: Plural Publishing.

Lowit-Leuschel, A., & Docherty, G. J. (2001). Prosodic variation across sampling tasks in normal and dysarthric speakers. *Logopedics Phoniatrics Vocology, 26*, 151–164.

Lowit, A., Dobinson, C., Timmins, C., Howell, P., & Kröger, B. (2010). The effectiveness of traditional methods and altered auditory feedback in improving speech rate and intelligibility in speakers with Parkinson's disease. *International Journal of Speech-Language Pathology, 12*(5), 426–436.

Ludlow, C. L., & Bassich, C. J. (1984). Relationships between perceptual ratings and acoustic measures of hypokinetic speech. In M. R. McNeil, J. C. Rosenbek, & A. E. Aronson (Eds.), *The dysarthrias: Physiology, acoustics, perception, management* (pp. 163–192). San Diego: College-Hill.

Ma, J.K.-Y., Whitehill, T., & So, S.Y.-S. (2010). Intonation contrast in Cantonese speakers with hypokinetic dysarthria associated with Parkinson's disease. *Journal of Speech, Language, and Hearing Research, 53*(4), 836–849.

Maas, E., Robin, D. A., Austermann Hula, S. A., Freedman, S. E., Wulf, G., Ballard, K. J., et al. (2008). Principles of motor learning in treatment of motor speech disorders. *American Journal of Speech-Language Pathology, 17*, 277–298.

Martens, H., Dekens, T., Latacz, L., Van Nuffelen, G., Verhelst, W., & De Bodt, M. (2013). Automated assessment and treatment of speech rate and intonation in dysarthria. *Proceedings of Rehab 2013* http://dx.doi.org/10.4108/pervasivehealth.2013.252366

Martens, H., Latacz, L., Dekens, T., Van Nuffelen, G., Verhelst, W., & De Bodt, M. (2013). *Prosodietrainer [Computer programme]. Version 1.19 beta 1*. Retrieved 29.05.14 from: http://catris.etro.vub.ac.be/prosodietrainer_en.html

Martens, H., Van Nuffelen, G., Cras, P., Pickut, B., De Letter, M., & De Bodt, M. (2011). Assessment of prosodic communicative efficiency in Parkinson's disease as judged by professional listeners. *Parkinson's Disease*. http://dx.doi.org/10.4061/2011/129310 10 p. (Article ID 129310)

Martens, H., Van Nuffelen, G., & De Bodt, M. (2010a). *NSVO-Z: Nederlandstalig Spraakverstaanbaarheidsonderzoek – Zinsniveau [Dutch Sentence Intelligibility Assessment]*. Belsele: Vlaamse Vereniging voor Logopedisten.

Martens, H., Van Nuffelen, G., & De Bodt, M. (2010b). De ontwikkeling van een fonetisch gebalanceerde standaardtekst [Development of a phonetically balanced standard passage]. *Logopedie, 23*(5), 31–36.

Patel, R. (2011). Assessment of prosody. In A. Lowit & R. D. Kent (Eds.), *Assessment of motor speech disorders* (pp. 75–95). San Diego, CA: Plural Publishing.

Pell, M. D., Cheang, H. S., & Leonard, C. L. (2006). The impact of Parkinson's disease on vocal-prosodic communication from the perspective of listeners. *Brain and Language, 97*(2), 123–134.

Peppé, S., McCann, J., Gibbon, F., O'Hare, A., & Rutherford, M. (2007). Receptive and expressive prosodic ability in children with high-functioning autism. *Journal of Speech, Language, and Hearing Research, 50*(4), 1015–1028.

Ramig, L., Countryman, S., O'Brien, C., Hoehn, M., & Thompson, L. (1996). Intensive speech treatment for patients with Parkinson disease: Short and long-term comparison of two techniques. *Neurology, 47*, 1496–1504.

Ramig, L. O., Countryman, S., Thompson, L. L., & Horii, Y. (1995). Comparison of two forms of intensive speech treatment for Parkinson disease. *Journal of Speech and Hearing Research, 38*(6), 1232–1251.

Ramig, L. O., Fox, C., & Sapir, S. (2008). Speech treatment for Parkinson's disease. *Expert Review of Neurotherapeutics, 8*(2), 299–311.

Ramig, L. O., Sapir, S., Countryman, S., Pawlas, A. A., O'Brien, C., Hoehn, M., et al. (2001). Intensive voice treatment (LSVT®) for individuals with Parkinson's disease: A two-year follow-up. *Journal of Neurology, Neurosurgery, and Psychiatry, 71*, 493–498.

Ramig, L. O., Sapir, S., Fox, C., & Countryman, S. (2001). Changes in vocal loudness following intensive voice treatment (LSVT®) in individuals with Parkinson's disease: A comparison with untreated patients and normal age-matched controls. *Movement Disorders, 16*(1), 79–83.

Robertson, S. J., & Thomson, F. (1984). Speech therapy in Parkinson's disease: A study of the efficacy and long term effects of intensive treatment. *British Journal of Language and Communication Disorders, 19*(3), 213–224.

Scott, S., & Caird, F. I. (1983). Speech therapy for Parkinson's disease. *Journal of Neurology, Neurosurgery, and Psychiatry, 46*, 140–144.

Skodda, S., Rinsche, H., & Schlegel, U. (2009). Progression of dysprosody in Parkinson's disease over time – A longitudinal study. *Movement Disorders, 24*(5), 716–722.

't Hart, J., Collier, R., & Cohen, A. (1990). *A perceptual study of intonation: An experimental-phonetic approach to speech melody*. Cambridge, UK: Cambridge University Press.

Theodoros, D. G., Thompson-Ward, E. C., Murdoch, B. E., Lethlean, J., & Silburn, P. (1999). The effects of the Lee Silverman Voice Treatment program on motor speech function in Parkinson disease following thalamotomy and pallidotomy surgery: A case study. *Journal of Medical Speech-Language Pathology, 7*(2), 157–160.

Tjaden, K., & Wilding, G. (2011). Speech and pause characteristics associated with voluntary rate reduction in Parkinson's disease and multiple sclerosis. *Journal of Communication Disorders, 44*(6), 655–665. http://dx.doi.org/10.1016/j.jcomdis.2011.06.003

Turner, G. S., & Weismer, G. (1993). Characteristics of speaking rate in dysarthria associated with Amyotrophic Lateral Sclerosis. *Journal of Speech and Hearing Research, 36*(6), 1134–1144.

Van Lancker Sidtis, D., Cameron, K., & Sidtis, J. J. (2012). Dramatic effects of speech task on motor and linguistic planning in severely dysfluent parkinsonian speech. *Clinical Linguistics and Phonetics, 26*(8), 695–711.

Van Lancker Sidtis, D., Rogers, T., Godier, V., Tagliati, M., & Sidtis, J. J. (2010). Voice and fluency changes as a function of speech task and deep brain stimulation. *Journal of Speech, Language, and Hearing Research, 53*, 1167–1177.

Van Nuffelen, G., De Bodt, M., Vanderwegen, J., Van de Heyning, P., & Wuyts, F. (2010). Effect of rate control on speech production and intelligibility in dysarthria. *Folia Phoniatrica et Logopaedica, 62*(3), 110–119.

Wang, D., & Narayanan, S. S. (2007). Robust speech rate estimation for spontaneous speech. *IEEE Transactions on Audio, Speech, and Language Processing, 15*(8), 2190–2201.

Yorkston, K. M., Hakel, M., Beukelman, D. R., & Fager, S. (2007). Evidence for effectiveness of treatment of loudness, rate, or prosody in dysarthria: A systematic review. *Journal of Medical Speech-Language Pathology*, *15*(2).. xi–xxxvi.

Yorkston, K. M., Hammen, V. L., Beukelman, D. R., & Traynor, C. (1990). The effect of rate control on the intelligibility and naturalness of dysarthric speech. *Journal of Speech and Hearing Disorders, 55*, 550–560.