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Speech intelligibility by listening in Parkinson speech with and without deep brain stimulation: Task effects

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ABSTRACT

The effects of speech task (conversation versus conversation-repetition) and deep brain stimulation (DBS) on intelligibility in Parkinson's disease were examined. Speech samples in the two production modes (tasks) were matched by having subjects repeat their own utterance types previously obtained during spontaneously produced conversational speech. Intelligibility measures from listeners were augmented by difficulty ratings. Linguistic context in the experimental protocol was manipulated using the results of a written pre-test and segregation of auditory stimuli by difficulty and length. Comparisons of task and DBS state revealed significant effects of task, DBS, and stimulus length on intelligibility measures of speech. Difficulty ratings tracked accuracy measures. Overall repetition was more intelligible than conversation, especially for shorter stimuli, demonstrating that task demands and spoken context had strong effects on motor speech competence. The adverse effects of DBS on speech intelligibility were observed on conversational but not repeated speech. These results demonstrate a facilitative role of external models provided by repetition in motor speech performance, and a mildly disruptive role of DBS on internally modeled conversational speech.

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1. Introduction

While acoustic analyses reveal a great deal about the effect of cerebral disorders on speech, measures of intelligibility by listeners are of high practical value to patients and their clinicians (Weismer & Martin, 1992). It has been claimed that such measures can discriminate between dysarthrias (Tikofsky & Tikofsky, 1964). Intelligibility measures also cast a different kind of light on the effects of brain damage on speech. However, assessing intelligibility poses special challenges. Intelligibility differs in important ways from measures of comprehensibility (Yorkston, Strand, & Kennedy, 1996). It is well known that numerous factors may crucially affect speech intelligibility. These include ambient noise, distance between speakers, and, in the experimental environment, parameters of the recording and the auditory delivery system. Listeners' characteristics, such as attention or distraction, previous knowledge of the target samples, exposure and familiarity with the speech (Hustad & Cahill, 2003; Liss, Spitzer, Caviness, & Adler, 2002; Tjaden & Liss, 1995), contingencies of transcription of heard stimuli (Hustad, 2006a) and language background may affect subjective ratings or identification protocols (Hustad, 2006b, 2007). Properties of the stimuli are highly pertinent, including thematic content (which may be fragmentary or coherent through the sampled speech), lexical frequency (rare versus frequent words), predictability of the individual words in phrases (based on phrase structure or semantic plausibility; Carter, Yorkston, Strand, & Hammen, 1996; Hustad & Beukelman, 2001, 2002; Sitler, Schiavetti, & Metz, 1983), characteristics of neighboring words (Luce & Pisoni, 1998), semantic properties (Grosjean & Itzler, 1984) and phonetic contexts (Bard, Shillcock, & Altmann, 1988), and whether the target utterances are novel (newly created) or formulaic (known) expressions (Van Lancker Sidtis, 2011). Many of these properties can be summarized under the rubric *linguistic redundancy*, which refers to the influence of the properties of language and linguistic knowledge of these properties on comprehension of the utterance. It is important to take these properties into consideration as much as possible in order to have an independent, valid measure of the intelligibility of the speech itself, focusing on the physical signal arising from articulation and phonation (including prosody).

Another factor affecting intelligibility is speech task. It is well known that task conditions of various configurations affect motor speech performance (Bunton & Keintz, 2008; Hustad & Lee, 2008; Ziegler, 2003). Articulatory movements were shown to vary with speech task (Tasko & McClean, 2004). In dysarthric and normal speakers, increases in loudness were found to affect intelligibility more than changes in rate (Ramig et al., 2001; Tjaden & Wilding, 2004). Similarly, distance from speaker also affected intelligibility in dysarthria (Ho, Iansek, & Bradshaw, 1999).

Significant task differences were found previously in two single cases of Parkinsonian (PD) dysarthria (Canter and Van Lancker; 1985; Kempler & Van Lancker, 2002) and in two group studies (Van Lancker Sidtis et al., 2005; Van Lancker Sidtis, Rogers, Godier, Tagliati, & Sidtis, 2010), in which speech that was repeated or read aloud was more intelligible to listeners than matched spontaneous expressions. Other findings support this viewpoint (Frearson, 1985). Significant differences in association with reading or repetition samples, compared to other tasks, have been shown in acoustic (Brown & Docherty, 1995; Gentil, Chauvin, Pinto, Pollak, & Benabid, 2001; Kent, Kent, Rosenbek, Vorperian, & Weismer, 1997; Sidtis, Rogers, Godier, Tagliati, & Sidtis, 2010; Snidecor, 1943) or articulatory measures (Kent & Kent, 2000; Zeplin & Kent, 1996). These reports and an array of analogous results from gait and arm movement studies (Atchison, Thompson, Frackowiak, & Marsden, 1993; Burleigh, Norak, Nutt, & Obeso, 1997; Georgiou et al., 1993) suggest that, for the individual with basal ganglia disease, providing an external model before or during execution of a motor task, be it stepping, reaching, or speaking, constitutes a significantly facilitative boost (Morris, 2000). Several authors suggest that motor deficits in Parkinson's disease are more severe in "internally guided" than in "externally guided" motor tasks (Baev, 1995; Lewis et al., 2007; Schenk, Baur, Steude, & Bötzel, 2003) implying that, for speech, a deficient subcortical system can be expected to perform more poorly for conversational speech, when an internal model is required, than in repetition, where an external model is provided.

The opportunity to assess how acute changes in basal ganglia function affect internally versus externally modeled speech emerges due to a recent new therapy for movement disorders in Parkinson's disease. There is currently a cohort of Parkinson's subjects who have undergone implantation of stimulating electrodes in the subthalamic nucleus, a therapeutic procedure commonly referred to as deep brain stimulation (DBS). For these subjects, improvement in motor function, comparable to the positive

effects of levodopa (De Letter, Santens, & Van Borsel, 2005; De Letter et al., 2007), is offered by having the DBS in the ON state. In the OFF state, previous movement difficulties quickly reappear. Improvements in motor function (Kumar et al., 1998) are reported to last at least five years (Krack et al., 2003; Romito et al., 2003) with some overall decline in motor and language functions after 8 years (Fasano et al., 2010). A positive effect on gait has also been reported (Krystkowiak et al., 2003). The effects of DBS on a range of cognitive functions are under investigation. While neuropsychological testing has not revealed notable changes in cognition (Alegret et al., 2001; Dujardin, Defebvre, Krystkowiak, Blond, & Destée, 2001), there are some reports that verbal fluency (De Gaspari et al., 2006) and semantic processing were diminished (Whelan, Murdoch, Theodoros, Hall, & Silburn, 2003). In contrast, reports of linguistic improvements with DBS-STN have also appeared (Zanini et al., 2003).

The effects of DBS-ON on motor speech measures remain under investigation by several research groups (D'Alatri et al., 2008; Tripoli et al., 2008; Wang, Verhagen Metman, Bakay, Arzbaecker, & Bernard, 2003). Improvement of oral control (Gentil, Garcia-Ruiz, Pollak, & Benabid, 1999) and force or strength of articulators (Gentil, Pinto, Pollak, & Benabid, 2003; Pinto, Gentil, Fraix, Benabid, & Pollak, 2003) have been documented, and, similar to the effects of levodopa (Sanabria et al., 2001), improved voice quality in DBS-ON has been reported in several studies (e.g., Gentil et al., 2001; Sarr et al., 2009; Sung et al., 2004; Van Lancker Sidtis et al., 2010).

In this study, we examine speech intelligibility measures for speech obtained from PD subjects with and without DBS, and for those with DBS, subjects were tested with the stimulators ON and OFF. For all subjects, intelligibility was examined utilizing speech samples obtained from two different speech tasks, spontaneous and repeated speech, which were exactly matched for both structure and content. The rationale for using a spoken (rather than a visual, as in reading) cue to compare speech tasks is to replicate in mildly dysarthric subjects previous findings for severely dysarthric subjects; and to replicate previous findings using acoustic and clinical measures with performance by listeners on intelligibility of the speech. The study design endeavored to control an array of extraneous variables surrounding intelligibility testing, specifically pertinent details of stimulus context and characteristics of listeners.

2. Method

2.1. Subjects

Six PD subjects with DBS and 5 PD subjects without DBS were studied. All were right handed, native English speakers with normal hearing and no other confounding medical or neurological diagnoses. The DBS and non-DBS groups were comparable in years of education (16.1 and 16.7) and years post-PD diagnosis (11.2 and 10). The groups differed in age: mean age in the DBS group was 58.2 (range of 56–62) and 67.2 yrs (60–73) in the non-DBS group. Correspondingly, mean age at diagnosis for the two groups differed: 47 years for the DBS group (range of 41–50), and 57.2 for the non-DBS group (47–65). These differences arise from the clinical contingencies of patient selection for DBS surgery and the relative recency of the introduction of DBS treatment (See Table 1). The time since initial DBS programming, which in all cases targeted the subthalamic nucleus bilaterally, ranged in the surgical subjects from 2 to 56 months, with a mean of 20 months. All subjects had mildly dysarthric, hypokinetic speech as commonly seen in Parkinson's disease, including hypophonia, imprecise articulation, dysfluencies, and rate abnormalities. Two of the DBS subjects reported childhood speech disorders. Three of the DBS subjects reported post surgical worsening of their speech; 2 reported improvements, and 1 reported no change.

2.2. Speech samples

Speech intelligibility was examined in PD subjects with and without DBS and in PD subjects with DBS ON and OFF, utilizing matched spontaneous ("conversation") and repeated ("conversation-repetition") speech samples. Samples were obtained by having each subject talk about any topic, such as family, vacations, or hobbies, for 5 min. Subjects wore a Shure head-held microphone and responses were recorded simultaneously on a Marantz Professional CD recorder and a Marantz digital recorder to ensure that primary and backup recordings would be obtained. Phrases of 3–8 words were selected

Table 1
Patient information. PD refers to subjects with PD who were not treated with DBS. DBS-PD refers to PD subjects who were treated with DBS. Ages are in years. In all DBS subjects, the stimulation frequency was 185 Hz, pulse width 60 μs. The average amplitude was 2.9 V, bilaterally.

Subject	Age	Years of education	Age at diagnosis	Years since diagnosis	Months since DBS
PD-1	73	17	65	8	NA
PD-2	71	16	61	10	NA
PD-3	60	15	53	7	NA
PD-4	70	20	60	10	NA
PD-5	62	15	47	15	NA
Means	67.2	16.6	57.2	10	NA
DBS-PD-1	59	15	49	10	9
DBS-PD-2	62	18	47	15	2
DBS-PD-3	61	14	50	11	12
DBS-PD-4	49	16	40	9	4
DBS-PD-5	62	16	51	11	56
DBS-PD-6	56	18	45	11	37
Means	58.2	16.2	47.0	11.2	20.0

from their conversational sample and later on that same day presented to the subject in altered order in a repetition format (Table 2).

To obtain repeated versions of the utterances obtained in conversation, the examiner said each phrase or sentence as the subject had formerly spoken it in the conversational mode, and asked the subject to repeat the phrase or sentence. Ten utterances 3–8 words in length were excerpted from each subject in each DBS condition and from the PD subjects without DBS. Stimuli for the listening protocol were free of proper nouns, low frequency words, formulaic expressions, and specialty vocabulary. Stimulus items were captured and stored using PRAAT digital speech analysis software (Boersma & Wenink, 2009). Conversation and conversation-repetition stimuli were matched for each subject and for DBS ON and OFF on number of words (+/−1) and number of syllables (+/− 4). Paired conversation-repetition items were randomized into the listening set. Conversation and conversation-repetition exemplars were separated for listening; that is, to avoid exposure effects, the utterance-pairs were distributed onto two counterbalanced test versions (A & B), so that all utterances were presented an equal number of times overall to listeners, but no listener heard any utterance-type (conversation or conversation-repetition) in both modes. That is, if a stimulus type occurred in version A in conversation mode, that stimulus type occurred in version B in conversation-repetition mode, and vice versa. Linguistic context was provided in the listening protocol with one to five blank spaces (in a "cloze procedure") on the response sheet (See Table 3); these constitute the "short" (1–2 target words; 26.2%); (Table 4) and "long" (3–5 target words; 73.8% target stimuli). Response items in the written carrier sentence were balanced and distributed across stimulus items as discontinuous (23.5%) or adjacent at the beginning (25.8%), middle (25.8%) or end (24.7%) of the phrase. In addition, Table 4 shows how many items of each length contained one or two target words (versions combined).

Table 2
Examples of the listening stimuli. Conversation and conversation-repetition pairs were made up of the same linguistic material for direct comparison.

Conversation items from spontaneous speech sample:
My topic today is exercise as I lie here trying to be still and quiet. *I grew up the youngest of four girls* and went to all girl catholic schools and didn't know the first thing about exercise when till I was married. My idea of *a great afternoon* was to *read a really good book* and do nothing.
Conversation-repetition items:
My topic today is exercise
I grew up the youngest of four girls
A great afternoon
Read a really good book

Table 3
Sample portion of answer sheet.

	Utterance	Degree of Difficulty (1=least difficult, 5= most difficult) Easy Hard
1)	He _____ it	1 2 3 4 5
2)	I'm pretty happy _____	1 2 3 4 5
3)	_____ _____ my _____ to agree	1 2 3 4 5
4)	I didn't _____	1 2 3 4 5

Intelligibility protocol 1 (Text-only pre-test): To examine the role of linguistic context (as independent from the auditory signal), 15 native English speakers (7 females and 8 males), educated in the USA, ages 22–60 yrs (mean age of 41 yrs) with an average of 16 yrs education (ranging from 12 to 20 yrs) performed a text-only pre-test (without hearing the stimuli). Writers had not had any exposure to the speech of the PD study subjects. Instructions were to write words in the missing blanks of the answer sheets by guessing from the answer sheet text alone.

Intelligibility protocol 2 (Listening protocol): For the spoken material, 30 respondents (23 females and 7 males; different from participants in the written task) performed the listening study (mean age 41.5 yrs, range from 17 to 82; education mean 15.3 yrs, range from 10 to 22 yrs), 15 subjects for each of the two test versions (A & B). All were native speakers of English, born and educated in the USA. None of the participants performing the listening protocols had been exposed to the speech of the study PD subjects. Following the instructions, four practice items were administered. During the practice session, listeners were permitted to adjust the headphone volume to comfortable levels and then were told not to change that setting at any later time during the listening task. Participants were instructed to listen to each utterance, which could be heard only once, and to write down whatever he or she heard, guessing where necessary. The protocol was administered item by item by an examiner to 1–3 listeners at a time. There was no time constraint; the examiner advanced to the next stimulus when the listener was ready. After making written entries of words in the blanks of the answer sheet, listeners also rated the difficulty of understanding each spoken sample by circling a number from 1 (least difficult) to 5 (most difficult) (See Table 3). The total number of utterances per test version was 170. Data from a total number of 426 target items (blanks within the items) per test version were analyzed.

3. Results

3.1. Intelligibility protocol 1 (text-only pre-test)

Overall, participants were not able to identify a large number of target words on the text-only pre-test. Of the 426 target words utilized in the protocol, an average of 27.3 words (6.4%) per participant

Table 4
Number of stimulus items made of 3–8 words containing 1 or 2 target words (blanks) in combined test versions.

# of words	1 target word (blank)	2 target words (blanks)
Three	10	8
Four	12	26
Five	2	9
Six	0	18
Seven	0	4
Eight	0	0

was identified on the text-only pre-test. This indicated a very small role of linguistic redundancy – or "guess-ability" – inherent in the test items alone when bereft of the spoken signal. Most of the 27.3 target words identified in the written-only protocol were unevenly distributed across the writers. Twelve target items were uniformly identified by half of the writers. Based on the assumption that guessing from linguistic context alone may have generated these few correct responses, these 12 words were removed at the second level of the analysis process (see "Text-only edit" level of analysis below).

3.2. Intelligibility protocol 2 (listening protocol)

A total of 852 responses from listeners (426 from each test version, versions A & B) were scored. Intelligibility scores were averaged across listeners for each subject and condition. Results revealed that the speech samples obtained from the 11 PD subjects with DBS (both ON and OFF) and without DBS were relatively intelligible to listeners, with an overall intelligibility performance of 89.9%. Intelligibility did not differ between the two versions of the task (A & B), with version A resulting in a mean intelligibility accuracy of 90.0%, and version B mean intelligibility accuracy of 87.7%. Therefore, the data from the two listening test versions were merged for analysis. Analyses were designed to compare the effect of task (conversation versus conversation-repetition modes) and the context provided in the listening stimuli (all words, text-edited, sentence-edited, and one and two word stimuli), and the effects of DBS (OFF versus ON) on these factors. The levels of linguistic context in the listening stimuli are as follows:

1. All Stimuli: Performance on conversation items was compared with performance on repetition items for all of the stimuli.
2. Text-only edit: The 12 words identified at 50% across subjects in the written pre-test (see above) were eliminated from this listening set. This narrowed the listening set to items that were not "guessed" from the written record.
3. Sentence edit: We identified a subset of conversation items that had been identified by 100% of listeners (60 stimulus items on each version), and removed these, along with the conversation-repetition pair-mate of each. From the original set of 340 utterances, this left 220 utterances, representing increased difficulty through reduced predictable context presented to listeners.
4. 1–2 Words: Finally, items with only one or two targets (shorter stimuli providing the least spoken context) were analyzed.

3.3. Intelligibility scores

The first analysis evaluated the effects of task and listening set independent of DBS. PD and DBS-OFF intelligibility data were combined for this analysis. Because the intelligibility scores were negatively skewed, they were log transformed prior to analysis. A two-way, repeated-measures, analysis of variance (ANOVA) assessed the effects of task (conversation versus conversation-repetition) and listening set (four levels of difficulty described above). There was a significant effect of listening set [$F(3,30) = 6.498$; $p = 0.002$], with intelligibility scores declining as the spoken context was reduced. There was a trend toward a task effect [$F(1,10) = 3.609$; $p = 0.087$], with better intelligibility during repetition. However, task interacted with listening set [$F(3,30) = 6.942$; $p = 0.001$], with the improvement of intelligibility during repetition compared to conversation greatest in the listening set with the least supporting spoken context (1–2 words) Fig. 1.

The effects of DBS and listening set were addressed in separate analyses for conversation and conversation-repetition. During conversation, there was a significant effect of listening set [$F(3,15) = 3.473$; $p = 0.043$], with intelligibility declining with increasing difficulty and reduced listening context. There was a trend toward intelligibility being worse with DBS-ON compared to DBS-OFF [$F(1,5) = 4.13$; $p = 0.098$]. During repetition, there was a comparable effect of listening set [$F(3,15) = 3.437$; $p = 0.044$] with intelligibility declining with reduced listening context. There was also an interaction between listening set and DBS [$F(3,15) = 3.712$; $p = 0.035$], with the worst intelligibility

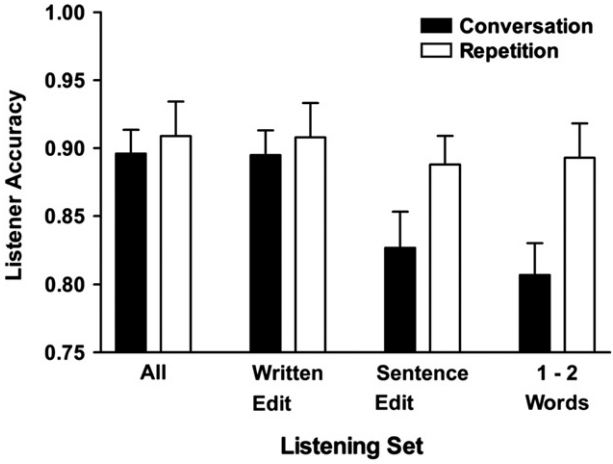

Fig. 1. Intelligibility scores for conversation and conversation-repetition with four levels of difficulty. Values are means ± 1 SEM for 11 subjects (5 PD and 6 PD with DBS-OFF).

for the listening set with the least linguistic context (1–2 words) with DBS-ON. There was no main effect of DBS on intelligibility. DBS ON and OFF data were also analyzed separately. With DBS off, there was a significant interaction between task and listening set [$F(3,15) = 7.037$; $p = 0.004$], with the poorest intelligibility for 1 or 2 word conversational stimuli. When DBS was ON, intelligibility also declined with decreasing linguistic context [$F(3,15) = 3.396$; $p = 0.046$]. These results are summarized in Table 5 and in Fig. 2.

3.4. Difficulty ratings

Ratings of difficulty provide a supplementary measure of intelligibility, probing how much effort is expended to process the stimuli. Difficulty ratings on a scale of 1–5 for conversation and conversation-repetition exemplars were averaged across listeners. In the combined group of PD and DBS-OFF subjects, intelligibility was rated as more difficult for conversation than for repetition [$t(10) = 2.557$; $p = 0.029$]. With respect to DBS, intelligibility was judged to be more difficult with DBS ON compared to DBS OFF for conversational speech [$t(5) = 2.744$; $p = 0.041$]. Fig. 3.

4. Discussion

In this sample of 11 PD subjects with mild hypokinetic dysarthria, speech intelligibility overall was relatively preserved as measured by this procedure. The high intelligibility is likely a function of our patient pool and our test protocol. The subjects were all only mildly dysarthric. Our interest was to replicate findings from severe dysarthria in subjects with mild dysathria. Secondly, our test protocol provided linguistic support of varying degrees to the listeners. Corresponding to the relatively good intelligibility of the speech samples, small but significant differences related to speech task (conversation versus conversation-repetition), the extent of linguistic context in which intelligibility was

Table 5
Summary of intelligibility effects as a function of task (conversation, conversation-repetition), DBS (on, off), and listening set.

Listening set	
Task	During both conversation and conversation-repetition, intelligibility declined with reduced listening context
DBS	DBS status interacted with listening set, with intelligibility declining with reduced listening context in both the DBS ON and OFF conditions.

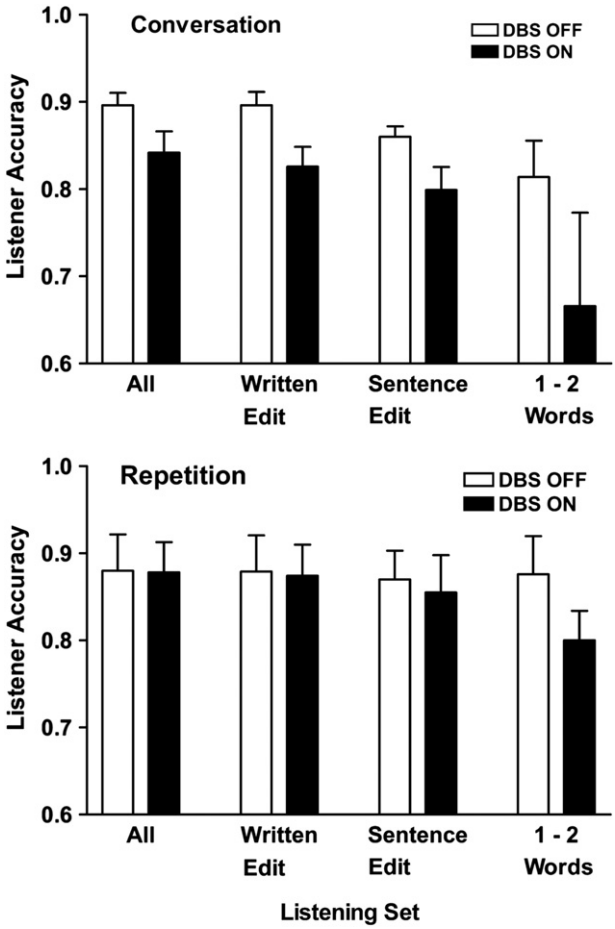

Fig. 2. Intelligibility scores for four levels of context as a function of DBS status for conversation (top) and repetition (bottom). Values are means ± 1 SEM for 6 DBS subjects.

judged, and to DBS (OFF, ON) emerged, indicating that intelligibility in mild Parkinsonian dysarthria is affected by each of these factors. Intelligibility was better for repeated speech than for conversational speech, and this was most pronounced for shorter speech samples. There were comparable spoken context effects on intelligibility with DBS ON and OFF. The reduction in intelligibility with DBS ON was greatest for the listening set with the least spoken context. Further, listeners rated intelligibility as more difficult for conversational speech than for repeated speech with both DBS ON and DBS OFF. Finally, intelligibility was judged to be most difficult for conversational speech with DBS ON.

The improved intelligibility in repetition is supported by acoustic and clinical rating studies. A higher harmonic-to-noise ratio (HNR, a voice quality measure) was obtained for repetition than for conversation samples (Van Lancker Sidtis et al., 2010). Further, in the Sidtis et al. study, fewer dysfluencies were noted overall for repeated speech and more than half the DBS subjects were more dysfluent in the ON than the OFF state (Sidtis, Katsnelson, Rogers, & Sidtis, 2008). In other studies in our laboratory, clinical ratings yielded lower ratings of vocal abnormalities (better voice quality) and lower rated dysfluencies for repetition (greater fluency) than conversation (Van Lancker Sidtis et al., 2010). However, the relationship of intelligibility results from listening and acoustic measures is likely to be complex (Weismer, Jenag, Laures, & Kent, 2001).

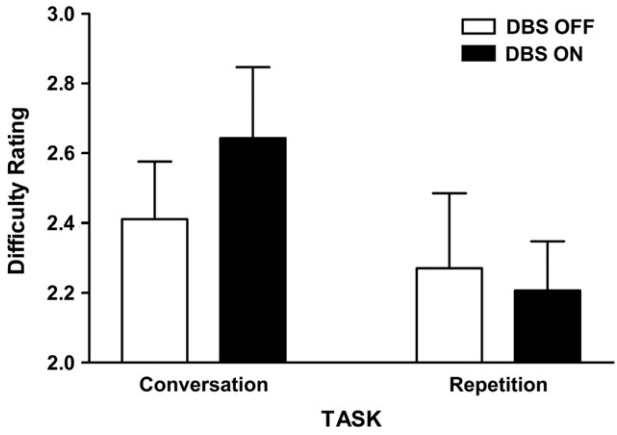

Fig. 3. Difficulty ratings for conversation and conversation-repetition with DBS OFF and ON. Values are means ± 1 SEM.

The study aimed to take task, DBS state, and spoken context into account in assessing intelligibility. Results revealed significant differences in intelligibility measures depending on length of target stimuli, implying a role of spoken context. Only a few items were discernable from the written material alone, indicating that linguistic redundancy played a small role in this study design. When these few correctly identified items were removed ("written edit"), little difference was seen. However, for conversation, an effect of spoken stimulus context (i.e., number of target words) was seen; listening samples with fewer target speech stimuli were less intelligible. For test stimuli with only 1–2 words left blank, accuracy was decreased for the conversational items. This result suggests that contextual support, where longer stretches of speech are provided, leads to more successful speech recognition, endorsing the roles of both top-down and bottom-up processing (Klasner & Yorkston, 2005). There may also be an advantage of vocal accommodation to the longer items (Nygaard, Sommers, & Pisoni, 1994) or, a related notion, an effect of familiarization (Spitzer, Liss, Cavines & Adler, 2000).

When comparing the effects of task and DBS therapy, the results for intelligibility measures reported here demonstrated that DBS reduces intelligibility during conversational speech, but not for repeated speech, except short target items (1–2 words; those with the least spoken context) (Fig. 2). These findings are consistent with studies of normal speech, comparing clear and conversational modes (Picheny, Durlach, & Braida, 1985) and contrasting hypospeech and hyperspeech forms (Lindblom, 1990). The results reported here support models of basal ganglia function that postulate a role for the basal ganglia in representing an internal model of motor function. For speech, repetition reduces the need for this function and consequently, repeated speech is less affected by basal ganglia pathology. On the other hand, while DBS improves some of the motor signs and symptoms of basal ganglia disease, it appears to interfere with the ways in which internal models are used in producing conversational speech.

Limitations of this study include the relatively small sample size. Number of study subjects was constrained in part by the labor-intensive use of spontaneous speech in the experimental design and the comparison of the subjects in two speaking states (ON and OFF DBS) and two speaking tasks. Further studies of intelligibility in DBS, and the effects of speech task, using a larger subject pool are desirable. A second limitation is the use of listener adjustment to amplitude at the onset of the study. Concerns arise naturally from utilizing hypophonic speech in a format that presents digitized samples to listeners. Overall, the speech is amplified, by nature of the presentation. The protocol, which instructed the listeners to set a comfortable listening level to practice items at the beginning of the test, was designed so that a relative range of hypophonic speech among the dysarthric talkers would be presented. To address some of these issues, we are designing a second experiment that provides no linguistic support and that presents all stimuli at a dB level consistently reduced from comfortable listening level.

In summary, this study used naturalistic speech directly comparing spontaneous with repeated production. These results support theories of motor behavior that contrast external with internal models as significantly affecting motor action competence. In repeated speech, a phrase produced by another speaker provides an external model, reducing the burden of effort for the basal ganglia. This does not appear to be adversely affected by DBS, except in situations in which the supporting linguistic context is severely reduced. In conversational speech, DBS reduces intelligibility and increases the difficulty experienced by listeners, consistent with the possibility that the basal ganglia's role in maintaining or generating an internal model for speech production is further compromised with this form of therapy.

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References

Alegret, M., Junqué, C., Valldeoriola, F., Vendrell, P., Pilleri, M., Rumia, J., et al. (2001). Effects of bilateral subthalamic stimulation on cognitive function in Parkinson disease. *Archives of Neurology, 58*(8), 1223–1227.

Atchison, P. R., Thompson, P. D., Frackowiak, R. S., & Marsden, C. D. (1993). The syndrome of gait ignition failure: a report of six cases. *Movement Disorders, 8*, 285–292.

Baev, K. V. (1995). Disturbances of learning processes in the basal ganglia in the pathogenesis of Parkinson's disease: a novel theory. *Neurological Research, 17*, 38–48.

Bard, E. G., Shillcock, R. C., & Altmann, G. T. M. (1988). The recognition of words after their acoustic offsets in spontaneous speech: effects of subsequent context. *Perception and Psychophysics, 44*(5), 395–408.

Boersma, P., & Wenink, D. (2009). *Praat: Doing phonetics by computer Computer program*. Version 5.0.46, Retrieved 7 January 2009 from http://www.praat.org/.

Brown, A., & Docherty, G. J. (1995). Phonetic variation in dysarthric speech as a function of sampling task. *European Journal of Disorders of Communication, 30*, 17–35.

Bunton, K., & Keintz, C. K. (2008). The use of a dual-task paradigm for assessing speech intelligibility in clients with Parkinson disease. *Journal of Medical Speech-Language Pathology, 16*(3), 141–155.

Burleigh, J. A., Norak, F. B., Nutt, J. G., & Obeso, J. A. (1997). Step initiation in Parkinson's disease: influence of levodopa and external sensory triggers. *Movement Disorders, 12*, 206–215.

Canter, G. J., & Van Lancker, D. (1985). Disturbances of the temporal organization of speech following bilateral thalamic surgery in a patient with Parkinson's disease. *Journal of Communication Disorders, 18*, 329–349.

Carter, C., Yorkston, K., Strand, E., & Hammen, V. (1996). Effects of semantic and syntactic context on actual and estimated sentence intelligibility of dysarthric speakers. In D. Robin, K. Yorkston, & D. Beukelman (Eds.), *Disorders of motor speech: Assessment, treatment, and clinical characterization* (pp. 100–108). Boston: College Hill Press.

D'Alatri, L., Paludetti, G., Contarino, M. F., Galla, S., Marchese, M. R., & Bentivoglio, A. R. (2008). Effects of bilateral subthalamic nucleus stimulation and medication on Parkinsonian speech impairment. *Journal of Voice, 22*(3), 365–373.

De Gaspari, D., Siri, C., Di Gioia, M., Antonini, A., Isella, V., Pizzolato, A., et al. (2006). Clinical correlates and cognitive underpinnings of verbal fluency impairment after chronic subthalamic stimulation in Parkinson's disease. *Parkinsonism and Related Disorders, 12*, 289–295.

De Letter, M., Santens, P., De Bodt, M., Van Maele, G., Van Borsel, J., & Boon, P. (2007). The effect of levodopa on respiration and word intelligibility in people with advanced Parkinson's disease. *Clinical Neurology and Neurosurgery, 109*, 495–500.

De Letter, M., Santens, P., & Van Borsel, J. (2005). The effects of levodopa on word intelligibility in Parkinson's disease. *Journal of Communication Disorders, 38*, 187–196.

Dujardin, K., Defebvre, L., Krystkowiak, P., Blond, S., & Destée, A. (2001). Influence of chronic bilateral stimulation of the subthalamic nucleus on cognitive function in Parkinson's disease. *Journal of Neurology, 248*, 603–611.

Fasano, A., Romito, L. M., Daniele, A., Piano, C., Zinno, M., Bentivoglio, A. R., et al. (2010). Motor and cognitive outcome in patients with Parkinson's disease 8 years after subthalamic implants. *Brain, 133*(9), 2664–2676.

Frearson, B. (1985). A comparison of the A.I.D.S. sentence list and spontaneous speech intelligibility scores for dysarthric speech. *Australian Journal of Human Communication Disorders, 13*, 5–21.

Gentil, M., Chauvin, P., Pinto, P., Pollak, P., & Benabid, A. L. (2001). Effect of bilateral stimulation of the subthalamic nucleus on Parkinsonian voice. *Brain & Language, 78*, 233–240.

Gentil, M., Garcia-Ruiz, P., Pollak, P., & Benabid, A. L. (1999). Effect of stimulation of the subthalamicnucleus on oral control of patients with Parkinsonism. *Journal of Neurology, Neurosurgery and Psychiatry, 67*, 329–333.

Gentil, M., Pinto, S., Pollak, P., & Benabid, A.-L. (2003). Effect of bilateral stimulation of the subthalamic nucleus on parkinsonian dysarthria. *Brain and Language, 85*, 190–196.

Georgiou, N., Bradshaw, J. L., Jansek, R., Phillips, J. G., Mattingley, J. B., & Bradshaw, J. A. (1993). An evaluation of the role of internal cues in the pathogenesis of Parkinsonian hypokinesia. *Brain, 116*, 1575–1587.

Grosjean, F., & Itzler, J. (1984). Can semantic constraint reduce the role of word frequency during spoken word recognition? *Bulletin of the Psychonomic Society, 22*, 180–182.

Ho, A. K., Iansek, R., & Bradshaw, J. L. (1999). Regulation of Parkinsonian speech volume: the effect of interlocutor distance. *Journal of Neurology, Neurosurgery and Psychiatry, 67*, 199–202.

Hustad, K. C. (2006a). A closer look at transcription intelligibility for speakers with dysarthria: evaluation of scoring paradigms and linguistic errors made by listeners. *American Journal of Speech-Language Pathology, 15*(3), 268–277.
Hustad, K. C. (2006b). Estimating the intelligibility of speakers with dysarthria. *Folia Phoniatrica et Logopaedica, 58*, 217–228.
Hustad, K. C. (2007). Effects of speech stimuli and dysarthria severity on intelligibility scores and listener confidence ratings for speakers with cerebral palsy. *Folia Phoniatric et Logopaedica, 59*, 206–317.
Hustad, K. C., & Beukelman, D. R. (2001). Effects of linguistic cues and stimulus cohesion on intelligibility of severely dysarthric speech. *Journal of Speech, Language, and Hearing Research, 44*, 497–510.
Hustad, K. C., & Beukelman, D. R. (2002). Listener comprehension of severely dysarthric speech: effects of linguistic cues and stimulus cohesion. *Journal of Speech, Language, and Hearing Research, 45*, 545–558.
Hustad, K. C., & Cahill, M. A. (2003). Effects of presentation mode and repeated familiarization on intelligibility of dysarthric speech. *American Journal of Speech-Language Pathology, 12*, 1–11.
Hustad, K. C., & Lee, J. (2008). Changes in speech production associated with alphabet supplementation. *Journal of Speech, Language, and Hearing Research, 51*, 1438–1450.
Kempler, D., & Van Lancker, D. (2002). The effect of speech task on intelligibility in dysarthria: case study of Parkinson's disease. *Brain and Language, 80*, 449–464.
Kent, R. D., & Kent, J. F. (2000). Task-based profiles of the dysarthrias. *Folia Phoniatrica et Logopaedica, 52*, 48–53.
Kent, R. D., Kent, J. F., Rosenbek, J. C., Vorperian, H. K., & Weismer, G. (1997). A speaking task analysis of the dysarthria in cerebellar disease. *Folia Phoniatrica et Logopaedica, 49*, 63–82.
Klasner, E. R., & Yorkston, K. M. (2005). Speech intelligibility in ALS and HD dysarthria: the everyday listener's perspective. *Journal of Medical Speech-Language Pathology, 13*(2), 127–139.
Krack, P., Batir, A., Van Blercom, N., Chabardes, S., Fraix, V., Ardouin, C., et al. (2003). Five-year follow-up of bilateral stimulation of the subthalamic nucleus in advanced Parkinson's disease. *New England Journal of Medicine, 349*, 1925–1934.
Krystkowiak, P., Blatt, J. L., Bourriez, J. L., Duhamel, A., Perina, M., Blond, S., et al. (2003). Effects of subthalamic nucleus stimulation and levodopa treatment on gait abnormalities in Parkinson. *Archives of Neurology, 60*, 80–84.
Kumar, R., Lozano, A. M., Kim, Y. J., Hutchison, W. D., Sime, E., Halket, E., et al. (1998). Double-blind evaluation of subthalamic nucleus deep brain stimulation in advanced Parkinson's disease. *Neurology, 51*, 850–855.
Lewis, M. M., Slagle, C. G., Smith, A. B., Truong, Y., Bai, P., McKeown, M. J., et al. (2007). Task specific influences of Parkinson's disease on the striato-thalamo-cortical and cerebello-thalamo-cortical motor circuitries. *Neuroscience, 147*(1), 224–235.
Lindblom, B. (1990). Explaining phonetic variation: a sketch of the H&H theory. In W. J. Hardcastle, & A. Marchal (Eds.), *Speech production and speech modeling* (pp. 403–439). Dordrecht: Kluwer Publishers.
Liss, J. M., Spitzer, S. M., Caviness, J. N., & Adler, C. (2002). The effects of familiarization on intelligibility and lexical segmentation in hypokinetic and ataxic dysarthria. *Journal of the Acoustic Society of America, 112*(6), 3022–3030.
Luce, P., & Pisoni, D. (1998). Recognizing spoken words: the neighborhood activation model. *Ear and Hearing, 19*, 1–36.
Morris, M. E. (2000). Movement disorders in people with Parkinson disease: a model for physical therapy. *Physical Therapy, 80*(6), 578–597.
Nygaard, L. C., Sommers, M. S., & Pisoni, D. B. (1994). Speech perception as a talker-contingent process. *Psychological Science, 5*(1), 42–46.
Picheny, M. A., Durlach, N. I., & Braida, L. D. (1985). Speaking clearly for the hard of hearing: intelligibility differences between clear and conversational speech. *Journal of Speech and Hearing Research, 28*, 96–103.
Pinto, S., Gentil, M., Fraix, V., Benabid, A., & Pollak, P. (2003). Effects of subthalamic nucleus stimulation on oral force control in Parkinson's disease. *Journal of Neurology, 250*, 179–187.
Ramig, L., Sapir, S., Countryman, S., Pawlas, A., O'Brien, C., Hoehn, M., et al. (2001). Intensive voice treatment (LSVT®) for individuals with Parkinson's disease: a two year followup. *Journal of Neurology, Neurosurgery & Psychiatry, 71*, 493–498.
Romito, L. M., Scerrati, M., Contarino, M. F., Iacoangeli, M., Bentivoglio, A. R., & Albanese, A. (2003). Bilateral high frequency subthalamic stimulation in Parkinson's disease: long-term neurological follow-up. *Journal of Neurosurgical Science, 47*, 119–128.
Sanabria, J., Ruiz, P. G., Gutierrez, R., Marquez, F., Escobar, P., Gentil, M., et al. (2001). The effect of levodopa on vocal function in Parkinson's disease. *Clinical Neuropharmacology, 24*(2), 99–102.
Sarr, M., Pinto, S., Jankowski, L., Purson, A., Ghio, A., Espesser, R., et al. (2009). *L-dopa and STN stimulation effects on pneumophonic coordination in parkinsonian dysarthria: Intra-oral pressure measurements*. Movement Disorders Society Conference, Paris, France, June, Abstract Th-240.
Schenk, T., Baur, B., Steude, U., & Bötzel, K. (2003). Effects of deep brain stimulation on prehensile movements in PD patients are less pronounced when external timing cues are provided. *Neuropsychologia, 41*, 783–794.
Sidtis, D., Katsnelson, D., Rogers, T., & Sidtis, J. (2008). Task effects on fluency and voice with ON and OFF DBS in Parkinson's subjects: evidence from acoustic measures and expert listeners. In *Paper presented at the Motor Speech Conference, Monterey, CA*.
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*(5), 1–11.
Sitler, R., Schiavetti, N., & Metz, D. E. (1983). Contextual effects in the measurement of hearing-impaired speakers' intelligibility. *Journal of Communication Disorders, 11*, 22–30.
Snidecor, J. (1943). A comparative study of the pitch and duration characteristics of impromptu speaking and oral reading. *Speech Monographs, 10*, 50–56.
Spitzer, S. M., Liss, J. M., Caviness, J. N., & Adler, C. (2000). An exploration of familiarization effects in the perception of hypokinetic and ataxic dysarthric speech. *Journal of Medical Speech-Language Pathology, 8*, 285–292.
Sung, J.-E., Kim, H., Kim, H.-S., Oh, S. H., Hong, J. M., & Lee, M. S. (2004). Effects of subthalamic nucleus deep brain stimulation on the phonation and articulation of the patients with Parkinson's disease. *Journal of Korean Neurological Association, 22*, 472–477.
Tasko, S. M., & McClean, M. D. (2004). Variations in articulatory movement with changes in speech. *Journal of Speech, Language, and Hearing Research, 47*, 85–100.
Tikofsky, R. S., & Tikofsky, R. P. (1964). Intelligibility as a measure of dysarthric speech. *Journal of Speech and Hearing Research, 7*, 325–333.

Tjaden, K., & Liss, J. M. (1995). The role of listener familiarity in the perception of dysarthric speech. *Clinical Linguistics and Phonetics, 9*(2), 139–154.

Tjaden, K., & Wilding, G. E. (2004). Rate and loudness manipulations in dysarthria: acoustic and perceptual findings. *Journal of Speech, Language and Hearing Research, 47*, 766–783.

Tripoli, E., Zrinzo, L., Martinez-Torres, I., Tisch, S., Frost, E., Borrell, E., et al. (2008). Effects of contact location and voltage amplitude on speech and movement in bilateral subthalamic nucleus deep brain stimulation. *Movement Disorders, 23*(16), 2377–2383.

Van Lancker Sidtis, D. (2011). Two track mind: formulaic and novel language support a dual process model. In Miriam Faust (Ed.), *Advances in the neural substrates of language: toward a synthesis of basic science and clinical research* (pp. 342–367). London: Wiley-Blackwell.

Van Lancker Sidtis, D., Hanson, W., Jackson, C., Lanto, A., Kempler, D., & Metter, E. J. (2005). Fundamental frequency (f0) measures comparing speech tasks in aphasia and Parkinson's disease. *Journal of Medical Speech-language Pathology, 12*(4), 207–212.

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.

Wang, E., VerhagenMetman, L., Bakay, R., Arzbaecher, J., & Bernard, B. (2003). The effect of unilateral electrostimulation of the subthalamic nucleus on respiratory/phonatory subsystems of speech production in Parkinson's disease: a preliminary report. *Clinical Linguistics and Phonetics, 17*(4-5), 283–289.

Weismer, G., Jeng, J., Laures, J. S., & Kent, R. D. (2001). Acoustic and intelligibility characteristics of sentence production in neurogenic speech disorders. *Folia Phoniatrica et Logopaedica, 53*, 1–18.

Weismer, G., & Martin, R. (1992). Acoustic and perceptual approaches to the study of intelligibility. In R. Kent (Ed.), *Intelligibility in speech disorders* (pp. 67–118). Philadelphia: John Benjamins.

Whelan, B. M., Murdoch, B. E., Theodoros, D. G., Hall, B., & Silburn, P. (2003). Defining a role for the subthalamic nucleus within operative theoretical models of subcortical participation in language. *Journal of Neurology, Neurosurgery, and Psychiatry, 74*, 1543–1550.

Yorkston, K., Strand, E., & Kennedy, M. (1996). Comprehensibility of dysarthric speech: implications for assessment and treatment planning. *American Journal of Speech-Language Pathology, 5*, 55–66.

Zanini, S., Melatini, A., Capus, L., Gioulis, M., Vassallo, A., & Bava, A. (2003). Language recovery following subthalamic nucleus stimulation in Parkinson's disease. *Cognitive Neuroscience & Neuropsychology, 14*, 511–516.

Zeplin, J., & Kent, R. D. (1996). Reliability of auditory–perceptual scaling of dysarthria. In D. Robin, K. Yorkston, & D. R. Beukelman (Eds.), *Disorders of motor speech: Recent advances in assessment treatment and clinical characterization* (pp. 145–154). Baltimore: Brokes.

Ziegler, W. (2003). Speech motor control is task-specific: Evidence from dysarthria and apraxia of speech. *Aphasiology, 17*, 3–36.