Free Classification of Dysarthric Speech:

A Taxonomical Approach

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved March 2012 by the
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ARIZONA STATE UNIVERSITY

May 2012

ABSTRACT

Often termed the "gold standard" in the differential diagnosis of dysarthria, the etiology-based Mayo Clinic classification approach has been used nearly exclusively by clinicians since the early 1970s. However, the current descriptive method results in a distinct overlap of perceptual features across various etiologies, thus limiting the clinical utility of such a system for differential diagnosis. Acoustic analysis may provide a more objective measure for improvement in overall reliability (Guerra & Lovely, 2003) of classification. The following paper investigates the potential use of a taxonomical approach to dysarthria. The purpose of this study was to identify a set of acoustic correlates of perceptual dimensions used to group similarly sounding speakers with dysarthria, irrespective of disease etiology. The present study utilized a free classification auditory perceptual task in order to identify a set of salient speech characteristics displayed by speakers with varying dysarthria types and perceived by listeners, which was then analyzed using multidimensional scaling (MDS), correlation analysis, and cluster analysis. In addition, discriminant function analysis (DFA) was conducted to establish the feasibility of using the dimensions underlying perceptual similarity in dysarthria to classify speakers into both listener-derived clusters and etiology-based categories. The following hypothesis was identified: Because of the presumed predictive link between the acoustic correlates and listener-derived clusters, the DFA classification results should resemble the perceptual clusters more closely than the etiology-based (Mayo System) classifications. Results of the present investigation's MDS revealed three dimensions, which were significantly correlated with 1) metrics capturing rate and rhythm, 2) intelligibility, and 3) all of the long-term average spectrum metrics in the 8000 Hz band, which has been linked to degree of phonemic distinctiveness (Utianski et al., February 2012). A qualitative examination of listener notes supported the MDS and correlation results, with listeners overwhelmingly making reference to speaking rate/rhythm, intelligibility, and articulatory precision while participating in the free classification task. Additionally, acoustic correlates revealed by the MDS and subjected to DFA indeed predicted listener group classification. These results beget acoustic measurement as representative of listener perception, and represent the first phase in supporting the use of a perceptually relevant taxonomy of dysarthria.

ACKNOWLEDGMENTS

This research was supported by NIH Grants No. 1 F31 DC010093 (K. Lansford) and NIH/NIDCD2R01 DC006859 (J. Liss) from the National Institute on Deafness and Other Communication Disorders. The following paper is a portion of a larger ongoing project in the Motor Speech Disorders Lab at Arizona State University, led by Julie M. Liss and Kaitlin L. Lansford, with significant contributions from Rene L. Utianski. It is with sincere gratitude that I thank the above women for their time, talent, and guidance through this journey. A special thanks to Angela Davis, Dena Berg, & Cynthia Hensley for their contributions.

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Motor Speech Disorders: Dysarthria

The term *dysarthria* is used to describe a group of speech disorders resulting in abnormalities in the strength, speed, range, steadiness, tone, or accuracy of movements, which also affects control of the respiratory muscular control, and arise from disorders of neurological processing (Darley, Aronson, & Brown, 1975; Duffy, 1995; Duffy, 2005). Dysarthria can be further divided into types, which generally share the same underlying disease. Darley, Aronson, and Brown (1969a, b) first provided a conceptual framework for the various etiologies and perceptual features of speakers with dysarthria with their pivotal investigations, which will be referred to as the Mayo Clinic System throughout this paper.

The Mayo Clinic System

Often termed the "gold standard" in the differential diagnosis of dysarthria, the Mayo Clinic classification approach has been used nearly exclusively by clinicians since the early 1970s. In the first of two papers, Darley, Aronson, and Brown (1969a) based their classification matrix on the notion that "…patterns of dysarthria can be differentiated; they sound different" (p. 246). At the time of their first investigation, dysarthria was believed to be solely the result of poor articulation, and was described using non-descript terminology such as "slurred," "labored," "explosive," and "slobbery" (1969a, p. 247). The authors sought evidence for the diagnostic value of speech symptomology, and to better describe those speech aspects that "…are clinically differentiable" (p.247). Darley et al. posited that accurate differential diagnosis could facilitate the identification of neurological lesions and/or dysfunctions, based on the characteristics of speech. In their study, the authors described the perceptual characteristics of 212 speech samples from patients diagnosed with one of the following neurological conditions: pseudobulbar palsy, amyotrophic lateral sclerosis (ALS), bulbar palsy, cerebellar lesions, parkinsonism, dystonia, or choreoathetosis. Using a seven-point scale, authors assigned ratings for each of the previously described 38 perceptual dimensions that authors considered salient, pertaining to pitch, loudness, vocal quality, respiration, prosody, articulation, and overall intelligibility or bizarreness. Results ranked speakers by neurologic group as well as by rank of each of the 38 dimensions (see Table 1). Based on these results authors formed two conclusions: 1) perceived speech differences are a consequence of the underlying neurologic etiology, and 2) groups of speech deviations correlated with cite of lesion. Additionally, these groups were delineated into five types of dysarthria: flaccid, spastic, ataxic, hypokinetic, and hyperkinetic, with an additional mixed flaccid-spastic type specific to patients with ALS. The fourth and most influential result of this study was the use of these dimensions as a diagnostic tool for neurologic disorders (Darley, et al., 1969a, b).

Universal Acceptance

Research by Darley, Aronson, and Brown (1969a, b) laid the groundwork for future investigation of motor speech disorders, providing a novel vocabulary in the description of dysarthria (Duffy, 2007) and proposing the notion of a plural dysarthrias (Duffy & Kent, 2001). Since that time, researchers have attempted to replicate the original study or its findings (Bunton, Kent, Duffy, Rosenbek, & Kent 2007; Southwood & Weismer, 1993), test its applicability with speech-language pathologists and medical professionals (Fonville, et al., 2008; Van der Graaff, et al., 2009; Zyski & Weisiger, 1987), and have used this gold standard as a jumping-off point simply because it is so widely used (Dykstra, Hakel, & Adams, 2007). Virtually every dysarthria book written since the publication of the Mayo work has used their classification system as an organizing feature (e.g. see Darley, et al., 1975, Duffy, 2005, etc.). The clinical practice community has also embraced the Mayo Clinic System as its foundation, with approaches to treatment varying between clinicians (Jones & Lorman, 2002). Currently the *Frenchay Dysarthria Assessment* is the only published test for dysarthria diagnosis; however, in practice clinicians rely heavily on descriptive measures (Duffy, 2007), which stem from those described by Darley, Aronson, and Brown (1969a, b).

Limitations within the Mayo Clinic System

The study investigating speech deviations by Darley et al. (1969a) was the first of its kind and brought significance to the perception of dysarthria; however, the results, as can be seen in Table 1, were not distinct enough to allow for a unique differentiation between etiology-based dysarthria types. The current descriptive method results in a distinct *overlap* of perceptual features, thus limiting the clinical utility of such a system for differential diagnosis. Indeed all speakers with a given etiology do not necessarily present with the same speech features, particularly at differing levels of severity (Weismer & Kim, 2010). It also does not support etiology-based treatment strategies, with the exception of hypokinetic dysarthria (Baumgartner, Sapir, & Ramig, 2001; Fox et al., 2006; Spielman et al., 2011; Yorkston, Hakel, Beukelman, & Fager, 2007). Furthermore, etiology rarely results in pure dysarthria types (Duffy & Kent, 2001). Rather, patients, even with similar etiology, present with a mix of perceptual characteristics leading to overall degraded, sometimes unintelligible speech.

At the heart of the issue is that Darley, Aronson, and Brown (1969a, b) performed perceptual assessments of audiotaped samples of dysarthric speech without being blinded to each patient's medical diagnosis. This was, for their purposes, an appropriate design strategy. However, this does not mirror clinical practice, in which clinicians frequently do not have diagnostic information upon which to bias their listening. Additionally, due to the advancement of imaging since the 1960's, practicing clinicians generally utilize the results of differential diagnosis in order to formulate treatment, rather than in the identification of lesion cite. Bunton and her colleagues (2007) investigated interrater agreement for the Mayo Clinic System's perceptual indicators and found limitations in the use of over-lapping perceptual characteristics of dysarthria. Authors suggested that while agreement ratings falling between 32.8% and 100% may indicate the potential utility of auditory-perceptual ratings, further research would be necessary to account for the differing agreement ratings for each specific perceptual feature, and may not support the use of perceptual features as a *clinical tool* in the differential diagnosis of dysarthria. Indeed, Fonville, et al. (2008) demonstrated that among trained neurologists the accuracy in dysarthria classification when blinded to diagnosis and case history was a mere 35%. In a similar study, Van der Graaff, et al. (2009) found neurologists to correctly differentially diagnose dysarthria type only 40% of the time, residents, 41%, and speech-language pathologists 37% when blinded to past medical history. Overall interrater agreement was only fair among the three groups. Zyski and Weisiger (1987) found both experienced speech-language pathologists (SLP) and graduate students to perform with overall poor accuracy in the differentiation of dysarthria type using perception alone, with accuracy between 19 and 56%. In a survey examining the clinical use of the Mayo Clinic System, practicing SLPs reported the primary factor contributing to the difficulty of differential diagnosis of dysarthria was “lack of ‘clean’ diagnosis (i.e. mixed dysarthrias, multiple etiologies, etc.)” (Simmons & Mayo, 1997, p. 125). The results of these studies suggest the current dysarthria diagnostic practice is limited by an overlapping perceptual classification system that has yet to be replicated since it was first described.

Another limitation, and perhaps the most fundamental problem with the Mayo Clinic System, is its poor mapping to the resulting communication disorder, which, in turn, prevents informed treatment decisions. In a survey of 100 SLPs, Simmons and Mayo (1997) found sixty percent of respondents reported clinical use of the Mayo Clinic System. Authors indicated these low rates may have been related to the prevalence of mixed perceptual characteristics and etiologies in a clinical setting. Researchers indicate an improvement in the current system is warranted (Simmons & Mayo, 1997).

In addition to limitations in perceptual feature overlap and poor treatment relevance, there is lack of evidence supporting a strict tie between underlying etiology and resulting speech deficit. Kent, Duffy, Slama, Kent, and Clift (2001) reviewed current literature in search of evidence supporting the claim that speech deficits illustrate the underlying neurologic lesion. Results of the review indicated that while it may be possible to correlate an affected pathway with dysarthria, the authors caution that due to the limited availability of speech descriptions along with imaging, the results may be inconclusive. Indeed the original intent of Darley, Aronson, and Brown (1969a, b) may have been more an effort to focus on the diagnosis of disease, rather than the speech production deficit (Weismer & Kim, 2010). Additionally, some would caution that the link between etiology and speech-motor deficits has actually impeded both research and practice, and has led to a focus on oromotor non-speech tasks (Weismer, 2006; Weismer & Kim, 2010).

The limitations of the current system justify continued research into alternative methodology. A method that accounts for severity, considers perception, and utilizes the degraded acoustic signal would provide an objective, reliable, and relevant system for describing dysarthria.

What is the Alternative?

An alternative methodology warranting further investigation is one that does *not* rely on etiology. While etiology may be of prime importance when differentially diagnosing an unknown neurological impairment, it does little in the way of describing aspects of degraded speech—two patients with the same underlying etiology may present with very different speech characteristics. A system that identifies relevant speech characteristics impacting intelligibility and which of those characteristics may make the greatest impact on intelligibility would, no doubt, be of great clinical use. Additionally, acoustic analysis may provide a more objective measure that may improve overall reliability (Guerra & Lovely, 2003). Previous work by Liss et al. (2009) revealed the ability of rhythm metrics to distinguish among dysarthria subtypes, paving the way for use as an objective clinical tool. Work by Kim, Weismer, Kent, and Duffy (2009) as well as by Kent and Kim (2008) have revealed evidence in support of the use acoustic variables to develop a quantitative method of describing speech motor control deficits in individuals with dysarthria. Using acoustic metrics, Kim, Kent, and Weismer (2011) found greater than 60% of dysarthric speakers were correctly classified by severity versus by etiology (56.1%).

Taxonomy. Inherent in a classification scheme, and specifically within the Mayo Clinic System, is differential diagnosis. Diagnosis describes what is different (Balint, Buchanan, & Dequeker, 2006). An alternative to differential diagnosis is *taxonomy*, a “classification according to general laws or principles” (IBID, 2006, p.133), or a system that depends on similarities rather than differences. A taxonomical approach to dysarthria as described by Weismer and Kim (2010), focuses on the overarching commonalities, defining dysarthria as a whole rather than 38 perceptual parts. In this system, speakers across classification types present with a shared set of deficits, which represent the motor speech dysfunction. A focus on these commonalities could potentially provide a well-developed theory of dysarthria, one that may be useful in predictions and in selecting relevant treatment targets (IBID, 2010).

It is apparent that a taxonomical approach would require the identification of groups of dysarthric speakers who sound similar. As has already been presented, research into the perceptual groupings of dysarthric speakers does not match the groups delineated within the Mayo Clinic System (Bunton, et al., 2007; Fonville et al., 2008; Zeplin & Kent, 1996; Zyski & Weisiger, 1987). A functional system would identify a set of similar acoustic correlates (Guerra & Lovely, 2003; Kim, Kent, & Weismer, 2011; Kim, Weismer, Kent, & Duffy, 2009; Weismer & Kim, 2010) representative of degraded speech. This would then allow for the reliable detection of acoustic differences in order to distinguish between dysarthria types. Indeed acoustic measurements of articulation rate and voiceless interval duration have partitioned speakers with hypokinetic dysarthria from other types (Kim, Kent, & Weismer, 2011). As perception drives successful communication, only when it is addressed can meaningful and effective treatment targets be identified.

Present Study

The present project addresses the dysarthrias from the perspective that they are “communication disorders,” wherein listeners have difficulty recovering the speaker’s intended message. As described above, limitations of the Mayo Clinic System include overlapping perceptual characteristics, inconsistencies among and between perceptual features and underlying etiology, and the disregard of severity when classifying dysarthria. The present project aims to overcome these problems by linking groupings based on perceptual similarity to acoustic measurement and mapping, thereby outlining challenges encountered by listeners in understanding the degraded speech signal. This will lay the groundwork for the further development and refinement of a perceptually-relevant classification scheme or taxonomical approach that reflects the source(s) of communication deficit, and may point directly to intervention targets. In this way, we can begin to develop relevant targets for intervention, whether they may be modifications to the acoustic signal or optimizing listener performance.

The purpose of this study was to identify a set of acoustic correlates of perceptual dimensions used to group similarly sounding speakers with dysarthria. This first step in the development of a taxonomical approach will uncover the perceptual dimensions (and their acoustic correlates) that underlie judgments of similarity among speakers with dysarthria.

Method

Speakers. Productions from 33 speakers were collected from a larger corpus of research in the Arizona State University Motor Speech Disorders lab. Speakers were diagnosed with dysarthria by neurologists at the Mayo Clinic secondary to one of the following medical etiologies: cerebellar degeneration (11), amyotrophic lateral sclerosis (10), Huntington's disease (4), and Parkinson's disease (8). In order to be representative of previous research (Darley et al., 1969a, b), speakers were selected based on the presence of hallmark characteristics found within the Mayo Clinic classification system (see Table 1 to review characteristics). Dysarthria diagnoses were confirmed by two speech-language pathologists, and severity was rated to be mild to severe (Table 2). All speaker stimuli had been recorded and edited for use in a larger study conducted in the Arizona State University Motor Speech Disorders Lab. Each speaker read stimuli from visual prompts presented on a computer screen, and was recorded saying the phrase "*The standards committee met this afternoon in an open meeting.*" All recordings utilized a head-mounted microphone (Plantronics DSP-100), and participants were seated in a sound-attenuating booth. Recordings were made using a custom script in TF32 (Milenkovic, 2004; 16-bit, 44kHz), and saved directly to disc for subsequent editing using commercially available software (SoundForge; Sony Corporation, Palo Alto, CA) to remove any noise or extraneous articulations before or after target utterances.

Listeners. Twenty-six graduate students in Communication Disorders were recruited for this project. Participants were enrolled in the Motor Speech Disorders class and had received basic training in both dysarthria and the use of the Mayo Clinic System. Listeners were native English speakers, passed a threshold hearing screening, and self-reported normal cognitive skills. Data collected from three participants were not analyzed due to failure to meet inclusionary criteria.

Stimuli. The 33 speaker phrases were randomly assigned a two-letter code, and a static image of these initials was placed on a black background. Based on methodology outlined by Clopper (2008), this static image was paired with a corresponding sound file to aid listeners in completion of the free classification task. Stimuli were between 2.60 seconds and 13.544 seconds in duration with a mean duration of 6.486 seconds. Images were placed neatly and randomly in 3 rows next to a 16x16 cell grid using PowerPoint (see Figure 1). Each static image was sized to fit into one cell of the grid.

Acoustic measurements. A series of segmental and suprasegmental acoustic metrics were calculated to allow for the assessment of a relationship with perceptual characteristics. Toward that end, sixteen rhythm metrics were used to quantify the rate and rhythmic structure of dysarthric speech (Liss et al., 2009). Fundamental frequency mean, standard deviation, and range were calculated for each speaker (IBID, 2009). Long-term average spectra (LTAS) (Utianski et al., February 2012), and a series of metrics that capture vowel identity and distinctiveness, as described by Lansford et al. (May 2011; 2012) were also calculated. Sound files were analyzed using Praat software (Boersma & Weenik, 2006, available from http://www.fon.hum.uva.nl/praat/) and followed methodology as described by Liss et al., 2009. Table 3 lists the most significant metrics with descriptions. Inter- and intra-rater reliability for these measures were conducted and deemed to be high and acceptable (Liss et al., 2009).

Procedure

An auditory free classification task, as described by Clopper (2008), was used for collecting the similarity data. Free classification allows for the examination of perceptual similarity while avoiding experimenter-imposed categories, and without naming distinctive perceptual characteristics. Free classification is a perceptual sorting task, in which listeners are asked to group stimuli according to similarity, and is described by Gygi, Kidd, and Watson (2007) in the investigation of auditory similarity. Gygi et al. (2007) compared a free classification methodology to a paired comparisons method (wherein every sound is paired with all possible sounds and listeners rate similarity using a scale of one, not similar, to seven, very similar). Significantly, while authors noted similarity was more directly gauged using the paired comparisons method with the free classification method measuring similarity indirectly via categorization of stimuli, results of the two methodologies were similar (Gygi, Kidd, & Watson, 2007). The free classification method was also used by Guastavino (2007) to investigate classification of environmental sounds. Clopper and Pisoni (2007) found that in using free classification, listeners were able to make finer distinctions between dialectal speech patterns when specific labels were not experimenter-imposed. Clopper, Levi, and Pisoni (2006) found that a paired comparison similarity-rating task required approximately 50-60 minutes to complete. In comparison, the free classification task required 10-15 minutes to complete (Clopper and Pisoni's 2007, as cited in Clopper, 2008). In the present study, the use of free classification offered a faster, more concise listener task.

In the present project, listeners were seated in cubicles in a quiet environment using Dell Optiplex GX620 computers outfitted with Sennheiser HD 280 Silver headphones. All computers were calibrated using a Radio Shack digital sound level meter and a flat plate coupler. Volume was set individually on each computer and participants did not adjust the volume. While listeners were told all speakers were men and women with dysarthria, listeners were blind to etiology and classification type. Listeners were instructed to listen to the sound files and to group the files by dragging them into the grid depending on how similar they sounded. They were told that the icons speakers perceived as sounding similar were to be placed next to (touching) one another. They were permitted to make as many groups as needed with as many speakers in each group as needed (see Figure 2). There was no time limit imposed on either task and listeners were permitted to listen to and re-arrange the speaker files as many times as necessary. Results of a five-participant pilot study to assess methodology led to the inclusion of informal descriptive opportunities for listeners, wherein they were permitted to take notes below the PowerPoint slide.

Analyses. The similarity data were treated both quantitatively and qualitatively. First, descriptive statistics were calculated to determine the mean number of listener-derived groups and the mean number of speakers per group. Second, the similarity data were subjected to an additive similarity tree cluster analysis as described by Corter (1998) and used by Clopper (2008), in order to determine the number and composition of clusters of perceptually-similar speakers. Next, multidimensional scaling (MDS) of the similarity data was conducted in order to determine the salient perceptual dimensions underlying speaker similarity. Correlation analyses were conducted to facilitate interpretation of the perceptual dimensions revealed by the MDS analysis, by relating the dimensions to the acoustic and perceptual measurements described above. Finally, discriminant function analyses (DFA) were conducted to establish the feasibility of using the dimensions salient to perceptual similarity to reliably classify dysarthric speakers into both listener-derived clusters and etiology-based categories. In a qualitative analysis, listener notes were examined to determine if the results of the quantitative analyses described above tracked to the acoustic and perceptual characteristics reported by the listeners to underlie speaker similarity in dysarthria.

Results

Descriptive analysis. Descriptive statistics revealed a mean number of listener-derived groups as 7.7 (SD 2.85), with the mean number of speakers in each group equal to five (SD 2.1).

Cluster analysis. A dendogram output of the data (see Figure 3) suggested either a six or eight cluster solution, with one speaker not fitting into either solution. Due to the relatively small number of speakers belonging to groups within the eight-cluster solution, a six-cluster solution was selected. Crucially, the composition of the clusters was not limited to a single etiology-based category (see Table 4 for cluster member distribution). This finding suggests the perceptual and acoustic dimensions underlying similarity in dysarthria transcend underlying medical etiology.

Multi-dimensional scaling and correlation analysis. The similarity data from the cluster analysis were subjected to multidimensional scaling analysis in order to visualize the clusters of similar-sounding speakers in n-dimensions. Evaluation of two- to five-dimensional solutions led to the decision to analyze the results from the three-dimensional solution. This solution was selected, in part, due to the low stress of the model (.067; $R^2 = .98181$) and the ease of visualizing the clusters of similar-sounding speakers in three-dimensional space. In order to interpret the abstract dimensions derived by the MDS, a series of correlation analyses were conducted. Table 5 provides results from the correlation analysis for the acoustic metrics and three dimensions revealed by the MDS. As can be seen in Table 5, the first dimension was significantly correlated with many segmental and LTAS metrics capturing rate and rhythm, with the highest correlation with speaking rate ($r = -.919$). This dimension was also significantly correlated with a single vowel metric capturing mean dispersion ($r = .419$). Of interest, Cluster 1 speakers were separated from the remaining five clusters along this dimension (see Figure 4). The second dimension also was correlated with a number of metrics capturing speaking rhythm, albeit a different subset than those correlated with the first dimension (see Table 5), but was most highly correlated with intelligibility ($r = -.792$). Clusters 2-5 were delimited along this dimension (see Figure 4). The third dimension correlated significantly with all of the LTAS (RMS, SD, Range, and PV; see Table 5) metrics in the 8000 Hz band (r ranges from -.543 to -.605). Metrics in this high frequency band have been linked to degree of phonemic distinctiveness (Utianski et al., February 2012). While the third dimension was significantly correlated with a number of acoustic metrics, it does not appear to be as important a dimension to delineating the clusters as the first two dimensions (see Figures 5 and 6).

Discriminant function analysis. Discriminant function analysis (DFA) was conducted in order to verify the validity of the dimensions derived by the

MDS analysis as predictors of cluster group membership. Thus, the scores (i.e., spatial distances) associated with each speaker along the dimensions derived by the MDS were used to classify the speakers into one of the six listener-derived cluster groups. Cluster classification accuracy was 87.5% (See Table 6). An additional DFA was completed to assess whether cluster-based classification exceeded that of etiology-based. As can be seen in Table 7, the dimension scores classified the dysarthric speakers into one of the four etiology-based categories with 75.8% accuracy. Thus, cluster-based classification exceeded that of etiology-based.

Qualitative analysis. Because listeners were provided the opportunity to take notes during the free classification task, we were able to collect qualitative data regarding listener strategies and salient perceptual features. In examining the notes of the 21 listeners who elected to take them, we found that 100% of listeners mentioned the perceptual features of rate and rhythm of speech. This qualitative finding corresponds with the quantitative results that demonstrated metrics capturing rate and rhythm were significantly correlated with a primary dimension underlying similarity in dysarthria. Greater than 66% of listeners noted intelligibility within their speaker notations. Again, this qualitative finding supports the results of our quantitative approach that revealed intelligibility as being salient to similarity judgments. The third dimension revealed by MDS was correlated with all of the LTAS metrics in the 8000 Hz band, which has been linked to degree of phonemic distinctiveness (Utianski et al., February 2012). Therefore, it was not surprising to discover that 62% of listeners referenced articulatory precision within their notes. Additional perceptual features noted by listeners included severity (23.8%), resonance (23.8%), prosody (23.8%), respiratory differences (19%), variable loudness (14.3%), pitch breaks (9%), word boundary errors (4.7%), and overall oddness (4.7%). Of interest was the high frequency of vocal quality characteristics mentioned by this group of listeners (85.7%).

Discussion

The above results provide evidence to support the use of acoustic correlates of perceptually salient speech characteristics in describing and classifying speakers with dysarthria. The three dimensions revealed by MDS support the notion that there are similarities among speakers with dysarthria, which differentially influence listener perception. In fact, correlations between these dimensions and acoustic features offer insights as to what listeners perceive as the most salient and discriminant aspects of speech: rhythm and rate of speech, overall intelligibility, and phonemic distinctiveness. Vocal quality was the second most frequently mentioned perceptual characteristic within the listener notes. This motivates future investigation into how acoustic measurements can best capture this characteristic of the speech signal.

The present investigation offers both quantitative and qualitative evidence that supports the use of acoustic measurement in the classification of dysarthria. The above listener descriptors are particularly impressive given that no parameters other than to make judgments of similarity were placed upon the task. The perceptual features most frequently mentioned were also those that correlated to our acoustic measurements, suggesting the robustness of the relationship between the acoustic correlates to these perceptual features.

Most importantly, the above results suggest that the use of acoustic correlates may actually be a *better, more useful* system in describing dysarthria, offering an increase of 10% accuracy in classification. As can be seen in Table 4, many speakers with the same underlying etiologies (e.g. PD, HD, etc.) were grouped similarly. For example, Cluster 2 contained speakers with cerebellar degeneration (A) as well as ALS. More significantly however, is that not a single cluster was exclusive to etiology. This is even more powerful given the fact that only speakers displaying the hallmark characteristics of the Mayo Clinic System were selected as speakers in the current study, and that etiology-based classification was based on four groups, whereas cluster-based classification was based on six. This gives credence to the impact of overlapping perceptual features, which jeopardizes the efficacy of etiology-based models. This also supports the findings of previous research and clinical data stating that pure dysarthria classification, as described in the Mayo Clinic System, rarely exists (Duffy & Kent, 2001), as well as the notion that the speech mechanism can be affected in a constrained number of ways, thereby degrading the acoustic signal in similar ways (Kim, Kent, & Weismer, 2011).

Support for Taxonomy

As discussed above, a taxonomical approach to motor speech disorders, and specifically to dysarthria, would describe the most salient perceptual features that may be similar across dysarthria (Weismer & Kim, 2010). The above research results represent the first phase of exploration supporting the use of taxonomy rather than classification. Weismer and Kim (2010) outlined the need for the identification of core speech characteristics for those individuals with different disease and dysarthria types to facilitate effective intervention. Indeed the above results revealed a set of common perceptual features, regardless of underlying etiology. What is perhaps most significant is the ability of the acoustic metrics described above to correctly classify dysarthria (via DFA) in the same way as listeners (via free classification task), with 87.5% accuracy. Evenso, by examining listeners' perceptual groupings, it can be seen that acoustic metrics demonstrated superior skill over etiology in capturing perceived similarities and differences leading to listener classification.

Clinical Significance

The discipline-wide push for evidence-based practice (EBP) asserts that speech-language pathologists must pair clinical expertise with past and present research evidence. While it is important to consider the etiology-based Mayo Clinic System in enhancing diagnosis of underlying disease, its use as a "gold standard" stymies differential diagnostics of dysarthria, and does not map to a set of relevant treatment targets for the rehabilitation of degraded speech. Instead, treatment has taken a common sense approach, wherein behavioral management focuses on improving speech intelligibility and providing compensation strategies to patients. While clinical judgment is one piece of evidence, it is not sufficient to effectively direct treatment. Alternatively, by providing an objective measure of speech degradation (acoustic measurement), clinicians may be better informed as to the effect of certain perceptual characteristics on the overall speaker message. Behavioral interventions which are already being implemented, such as increased loudness (Baumgartner, Sapir, & Ramig, 2001; Spencer, Yorkston, & Duffy, 2003; Spielman et al., 2011), pacing (McHenry, 2003), rate control (Blanchet & Snyder, 2010), voice therapy (Baumgartner et al., 2001), strengthening of articulators (Kamhi, 2008), and speech supplementation strategies (Hustad, Jones, & Dailey, 2003), may be objectively measured through investigation of changes in the speech signal.

Future Directions

The above results support the plausibility of therapeutic intervention that targets the perceptual challenges posed by different patterns of acoustic degradation (Lansford, Liss, Caviness, & Utianski, 2011). As this work represents only trained graduate students, the investigation into the perceptions of experienced listeners is warranted. Moving forward, perceptual data from a larger corpus of speakers will be collected from experienced speech-language pathologists to test the validity of these preliminary data.

Additionally, ratings of perceived breathiness, hypernasality, vocal quality, and severity (as mentioned in graduate student listener notes) will be collected from SLPs to be considered by subsequent analyses of perceptual similarity.

Conclusion

While the classification method outlined by Darley, Aronson, and Brown (1969a, b) and referred to as the Mayo Clinic System provides a basis for the understanding of motor speech disorders, there is not adequate support for its use as a gold standard in dysarthria classification. Instead, the above results provide evidence for a proposed taxonomical approach to dysarthria, exploiting the use of acoustic metrics for quantifying and qualifying the perceptual similarities of speech degradation patterns. More importantly, by identifying the subset of acoustic and perceptual variables salient to speaker similarity judgments, we may begin to investigate how such similarities extend to the nature of the perceptual challenge.

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APPENDIX A

TABLES AND FIGURES

Table 1

Ranked Speaker Results

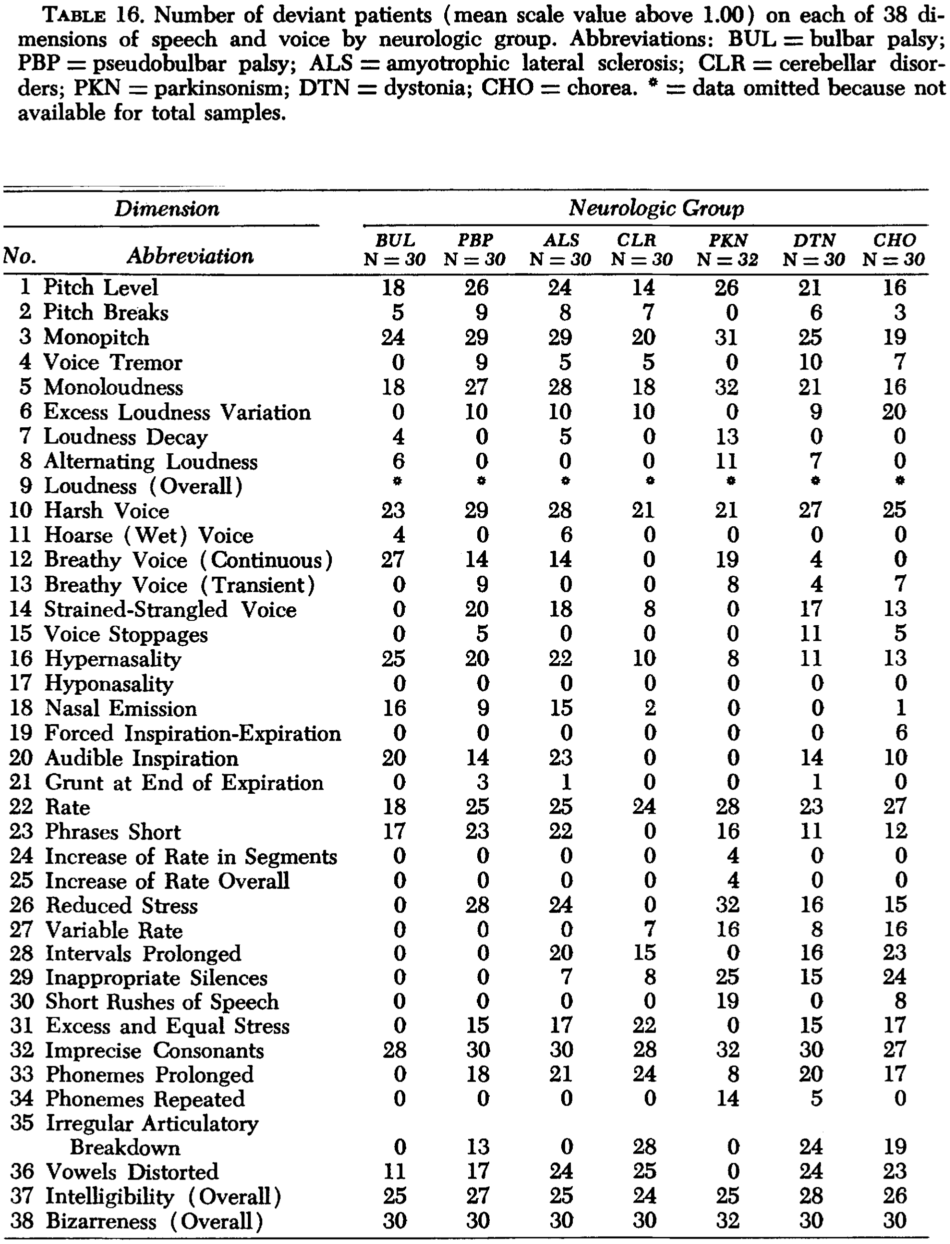


Table 16. Number of deviant patients (mean scale value above 1.00) on each of 38 dimensions of speech and voice by neurologic group. Abbreviations: BUL = bulbar palsy; PBP = pseudobulbar palsy; ALS = amyotrophic lateral sclerosis; CLR = cerebellar disorders; PKN = parkinsonism; DTN = dystonia; CHO = chorea. * = data omitted because not available for total samples.

Dimension		*Neurologic Group*						
No.	*Abbreviation*	*BUL* N = *30*	*PBP* N = *30*	*ALS* N = *30*	*CLR* N = *30*	*PKN* N = *32*	*DTN* N = *30*	*CHO* N = *30*
1	Pitch Level	18	26	24	14	26	21	16
2	Pitch Breaks	5	9	8	7	0	6	3
3	Monopitch	24	29	29	20	31	25	19
4	Voice Tremor	0	9	5	5	0	10	7
5	Monoloudness	18	27	28	18	32	21	16
6	Excess Loudness Variation	0	10	10	10	0	9	20
7	Loudness Decay	4	0	5	0	13	0	0
8	Alternating Loudness	6	0	0	0	11	7	0
9	Loudness (Overall)	*	*	*	*	*	*	*
10	Harsh Voice	23	29	28	21	21	27	25
11	Hoarse (Wet) Voice	4	0	6	0	0	0	0
12	Breathy Voice (Continuous)	27	14	14	0	19	4	0
13	Breathy Voice (Transient)	0	9	0	0	8	4	7
14	Strained-Strangled Voice	0	20	18	8	0	17	13
15	Voice Stoppages	0	5	0	0	0	11	5
16	Hypernasality	25	20	22	10	8	11	13
17	Hyponasality	0	0	0	0	0	0	0
18	Nasal Emission	16	9	15	2	0	0	1
19	Forced Inspiration-Expiration	0	0	0	0	0	0	6
20	Audible Inspiration	20	14	23	0	0	14	10
21	Grunt at End of Expiration	0	3	1	0	0	1	0
22	Rate	18	25	25	24	28	23	27
23	Phrases Short	17	23	22	0	16	11	12
24	Increase of Rate in Segments	0	0	0	0	4	0	0
25	Increase of Rate Overall	0	0	0	0	4	0	0
26	Reduced Stress	0	28	24	0	32	16	15
27	Variable Rate	0	0	0	7	16	8	16
28	Intervals Prolonged	0	0	20	15	0	16	23
29	Inappropriate Silences	0	0	7	8	25	15	24
30	Short Rushes of Speech	0	0	0	0	19	0	8
31	Excess and Equal Stress	0	15	17	22	0	15	17
32	Imprecise Consonants	28	30	30	28	32	30	27
33	Phonemes Prolonged	0	18	21	24	8	20	17
34	Phonemes Repeated	0	0	0	0	14	5	0
35	Irregular Articulatory Breakdown	0	13	0	28	0	24	19
36	Vowels Distorted	11	17	24	25	0	24	23
37	Intelligibility (Overall)	25	27	25	24	25	28	26
38	Bizarreness (Overall)	30	30	30	30	32	30	30

Note. Darley, Aronson, & Brown, (1969a)

Table 2

Speaker Information

Speaker Code	Gender	Age	Etiology	Severity
AF1	F	72	Cerebellar ataxia	Moderate
Af2	F	57	Multiple sclerosis / ataxia	Severe
Af6	F	57	Friedrich's ataxia	Moderate
AF7	F	48	Cerebellar ataxia	Moderate
AF8	F	65	Cerebellar ataxia	Moderate
AF9	F	86	Amyotrophic lateral sclerosis	Severe
AM1	M	73	Cerebellar ataxia	Severe
AM3	M	79	Cerebellar ataxia	Moderate - severe
AM4	M	46	Cerebellar ataxia	Moderate
AM5	M	84	Cerebellar ataxia	Moderate
AM6	M	46	Cerebellar ataxia	Moderate
AM8	M	63	Cerebellar ataxia	Moderate
ALSf2	F	75	Amyotrophic lateral sclerosis	Severe
ALSf5	F	73	Amyotrophic lateral sclerosis	Severe
ALSf6	F		Amyotrophic lateral sclerosis	Severe
ALSf7	F	54	Amyotrophic lateral sclerosis	Moderate
ALSf8	F	63	Amyotrophic lateral sclerosis	Moderate
ALSf9	F	86	Amyotrophic lateral sclerosis	Severe
ALSm1	M	56	Amyotrophic lateral sclerosis	Moderate
ALSm4	M	64	Amyotrophic lateral sclerosis	Moderate
ALSm7	M	60	Amyotrophic lateral sclerosis	Severe
ALSm8	M	46	Amyotrophic lateral sclerosis	Moderate
HDm8	M	43	Huntington's disease	Severe
HDm10	M	50	Huntington's disease	Severe
HDm11	M	56	Huntington's disease	Moderate
HDm12	M	76	Huntington's disease	Moderate
PDf5	F	54	Parkinson disease	Moderate
PDf7	F	58	Parkinson disease	Moderate
PDm8	M	77	Parkinson disease	Moderate
PDm9	M	76	Parkinson disease	Moderate
PDm10	M	80	Parkinson disease	Moderate
PDm12	M	66	Parkinson disease	Severe
PDm13	M	81	Parkinson disease	Moderate
PDm15	M	57	Parkinson disease	Moderate

Note. Ataxia (A), amyotrophic lateral sclerosis (ALS), Parkinson's Disease (PD), Huntington's Disease (HD). M = Male F = Female

Table 3

Acoustic and Perceptual Metrics Descriptions

Metrics	Description
Perceptual Measures	
Intelligibility	Percent words correct; may represent severity
Rhythm Metrics (Liss et al., 2009)	
SD Vocalic	Standard deviation of vocalic intervals
SD Consonantal	Standard deviation of consonantal intervals
Proportion Vocalic	Percent of utterance duration composed of vocalic intervals
nPVI- V	Normalized pairwise variability index for vocalic intervals. Mean of the differences between successive vocalic intervals divided by their sum.
rPVI- C	Pairwise variability index for consonantal intervals. Mean of the differences between successive consonantal intervals.
Speaking Rate (sp. rate)	Number of (orthographic) syllables produced per second, excluding pauses.
rPVI- VC	Pairwise variability index for vocalic and consonantal intervals. Mean of the differences between successive vocalic and consonantal intervals.
nPVI VC	Normalized pairwise variability index for vocalic + consonantal intervals. Mean of differences between successive vocalic + consonantal intervals divided by their sum.
SD VC	Standard deviation of successive vocalic and consonantal segments
LTAS Metrics (Utianski et al., February 2012)	* All normalized to Root Mean Square (RMS) energy of entire signal
All derived for 7 octave bands with center frequencies ranging from 125Hz- 8000 Hz	
RMS energy	RMS Energy
St. Dev. RMS energy	Standard deviation RMS energy (for 20ms windows)
Range RMS energy	Range RMS energy (for 20ms windows)
PVI RMS energy	Pairwise variability of RMS energy: mean difference between successive 20ms windows Range RMS energy
Vowel Metrics (Lansford, 2012)	
Disp_Mean	This metric captures the overall dispersion (or distance) of each pair of the ten vowels, as indexed by the Euclidean distance between each pair in the F1 X F2 space.

Table 4

Listener Derived Clusters with Members

Cluster	Speakers
Cluster 1	PDF5, PDF7, PDM8, PDM9, PDM10, PDM12, PDM13, PDM15, HDM11
Cluster 2	AF8, AM5, AM8, ALSF8, ALSM4, ALSM8,
Cluster 3	AF1, AF7, AM4, AM6, HDM12
Cluster 4	AF2, HDM8, HDM10
Cluster 5	ALSF6, ALSF7, ALSF9, ALSM1, AM1
Cluster 6	AF9, ALSF2, ALSF5, ALSM7

Note. Ataxia (A), amyotrophic lateral sclerosis (ALS), Parkinson's Disease (PD), Huntington's Disease (HD). M = Male F = Female

Table 5

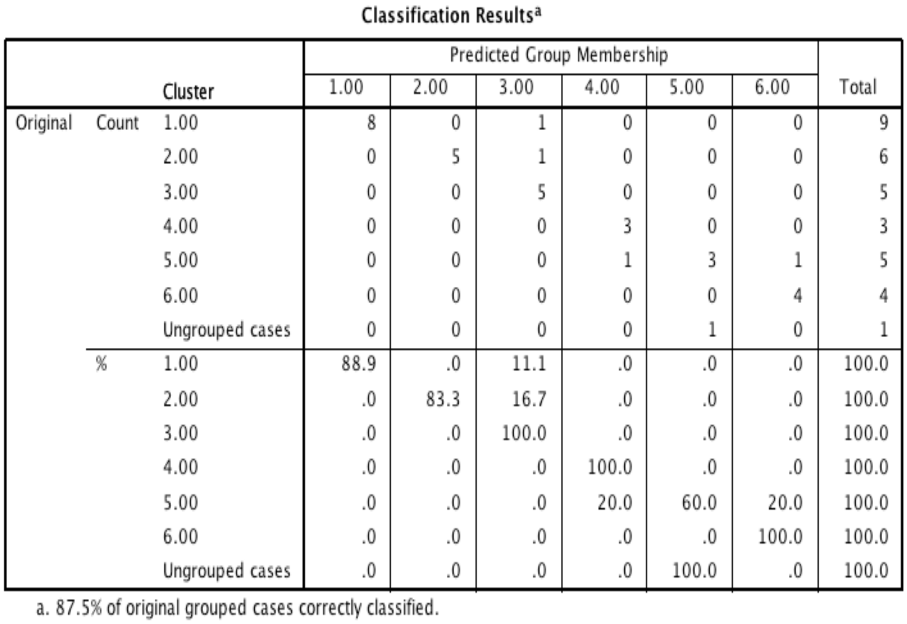
Correlation Matrix: MDS and Acoustic Metrics r Values

Metrics	Dimension1	Dimension2	Dimension3
Perceptual Measures			
Intelligibility		-.790**	
Rhythm Metrics			
SD Vocalic	.595**		
SD Consonantal	.467**		
Proportion Vocalic		.516**	
nPVI V		-.552**	
rPVI C			
Speaking Rate	-.921**		
rPVI VC	.503**		
nPVI VC		-.472**	
SD VC	.462**		
LTAS Metrics			
RMS 1000	.476**		
RMS 8000			.523**
St. Dev.1000	.491**		
St. Dev. 8000			.519**
Range 1000	.488**		
Range 4000	-.469**		
Range 8000			.494**
PVI 8000			.554**

Note. See Table 3 for metric descriptions. Above metrics included in table due to significance level. Original data set included 89 metrics of rhythm, vowel space, fundamental frequency, LTAS, etc.
**Pearson's Correlation < .01

Table 6

DFA Results -- Cluster Classification



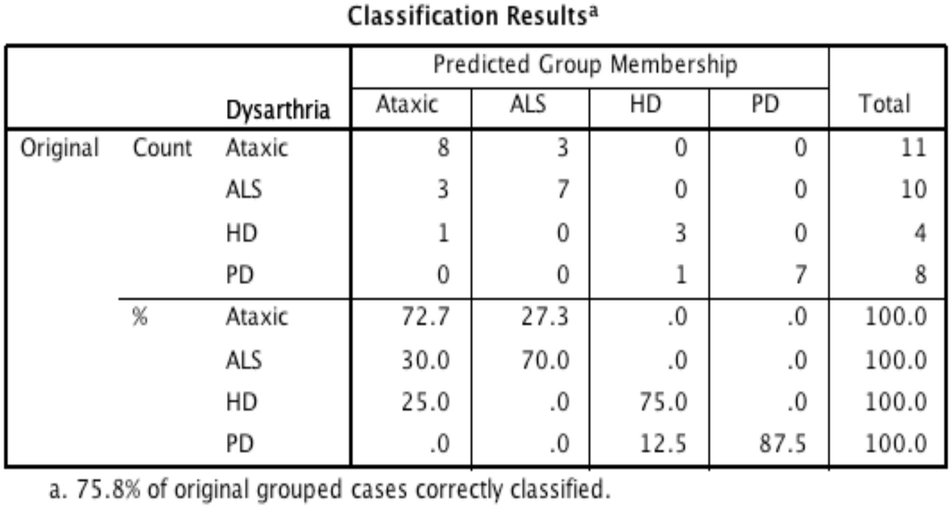
Classification Results[a]

			Predicted Group Membership						
		Cluster	1.00	2.00	3.00	4.00	5.00	6.00	Total
Original	Count	1.00	8	0	1	0	0	0	9
		2.00	0	5	1	0	0	0	6
		3.00	0	0	5	0	0	0	5
		4.00	0	0	0	3	0	0	3
		5.00	0	0	0	1	3	1	5
		6.00	0	0	0	0	0	4	4
		Ungrouped cases	0	0	0	0	1	0	1
	%	1.00	88.9	.0	11.1	.0	.0	.0	100.0
		2.00	.0	83.3	16.7	.0	.0	.0	100.0
		3.00	.0	.0	100.0	.0	.0	.0	100.0
		4.00	.0	.0	.0	100.0	.0	.0	100.0
		5.00	.0	.0	.0	20.0	60.0	20.0	100.0
		6.00	.0	.0	.0	.0	.0	100.0	100.0
		Ungrouped cases	.0	.0	.0	.0	100.0	.0	100.0

a. 87.5% of original grouped cases correctly classified.

Table 7

DFA Results -- Etiology-Based Classification



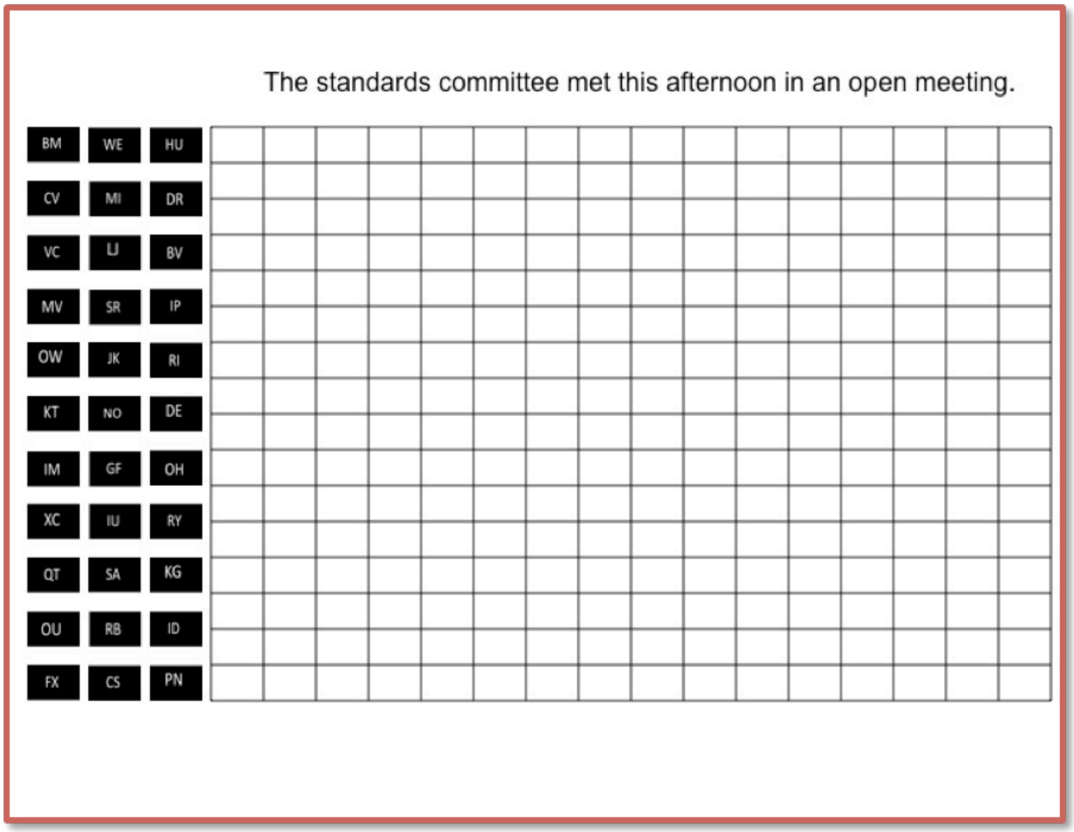
Classification Results[a]

			Predicted Group Membership				Total
		Dysarthria	Ataxic	ALS	HD	PD	
Original	Count	Ataxic	8	3	0	0	11
		ALS	3	7	0	0	10
		HD	1	0	3	0	4
		PD	0	0	1	7	8
	%	Ataxic	72.7	27.3	.0	.0	100.0
		ALS	30.0	70.0	.0	.0	100.0
		HD	25.0	.0	75.0	.0	100.0
		PD	.0	.0	12.5	87.5	100.0

a. 75.8% of original grouped cases correctly classified.

Figure 1

PowerPoint Stimulus

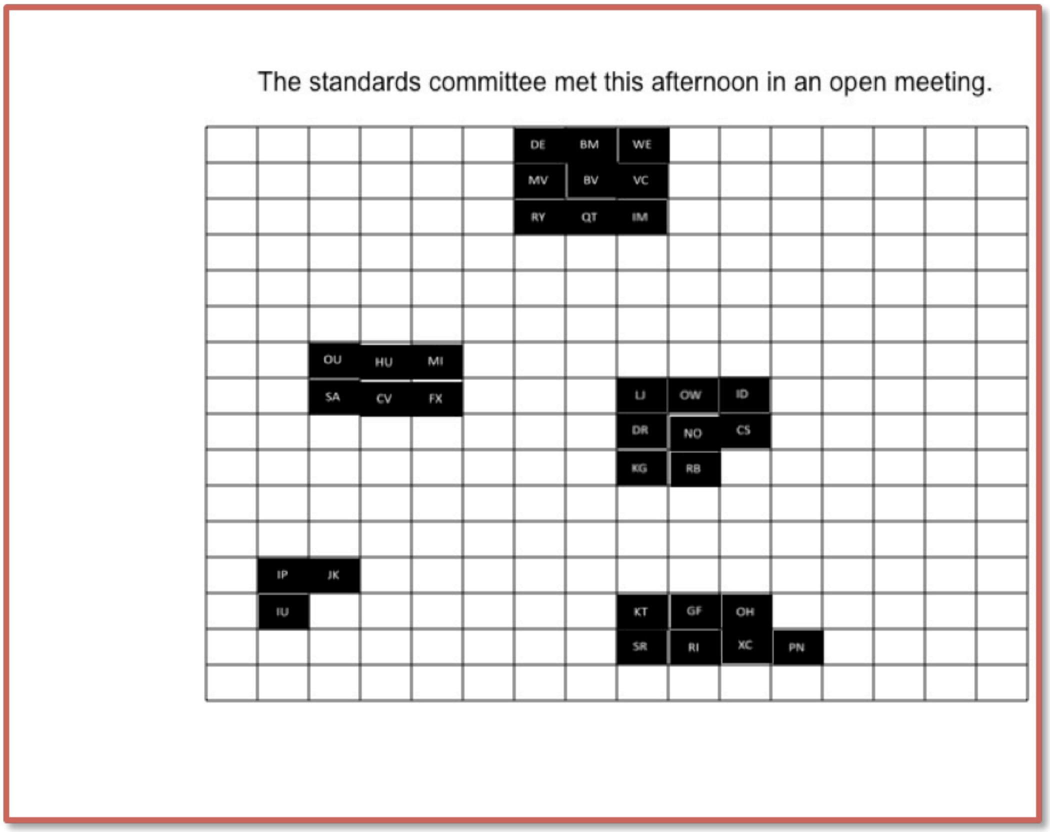


The standards committee met this afternoon in an open meeting.

Note. Static image of stimuli for free classification task. Actual stimuli contained sound file of recorded speakers.

Figure 2

Listener Derived Clusters example in Free Classification Task



The standards committee met this afternoon in an open meeting.

Figure 3

Dendogram Derived from Cluster Analysis

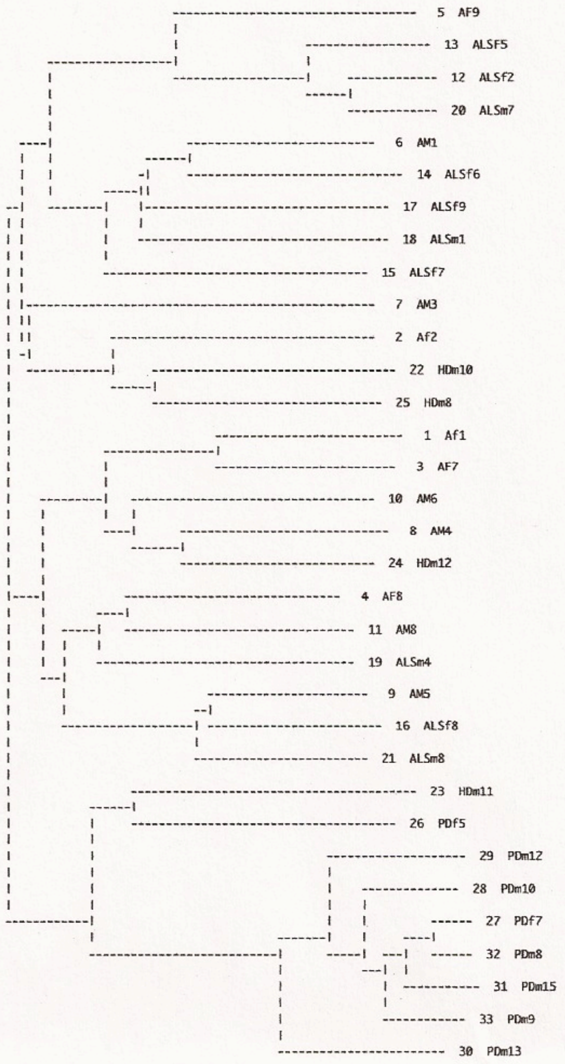


Figure 4

MDS Scatterplot Dimension 1 x 2

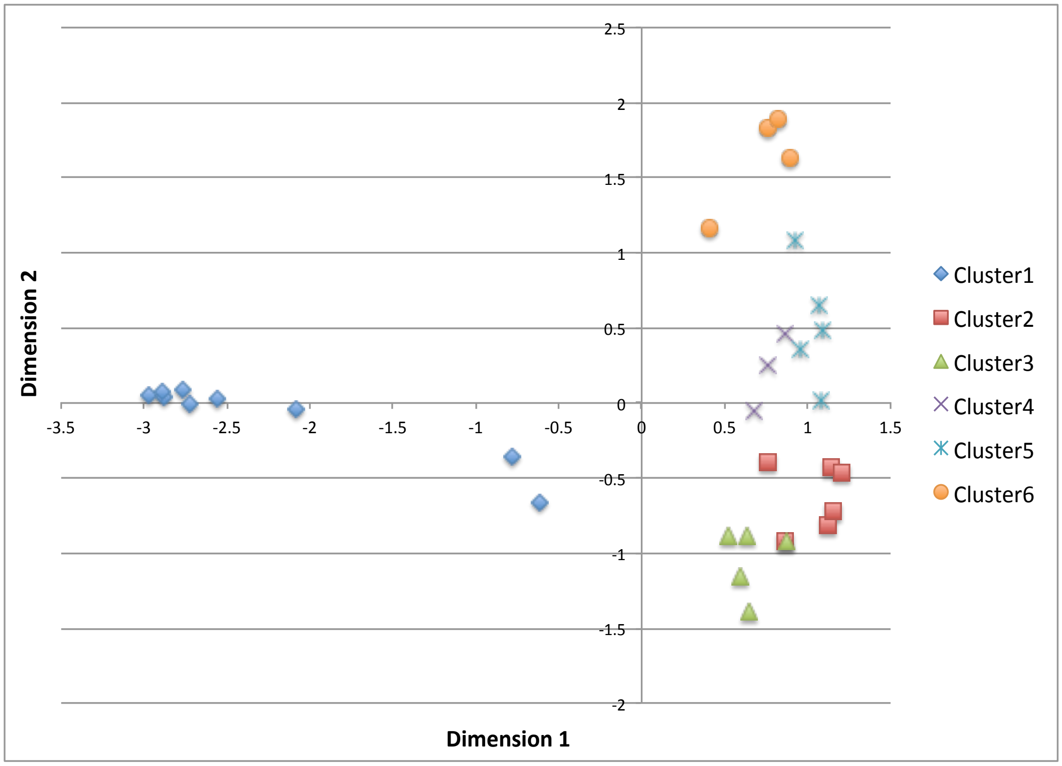


Figure 5

MDS Scatterplot Dimension 1 x 3

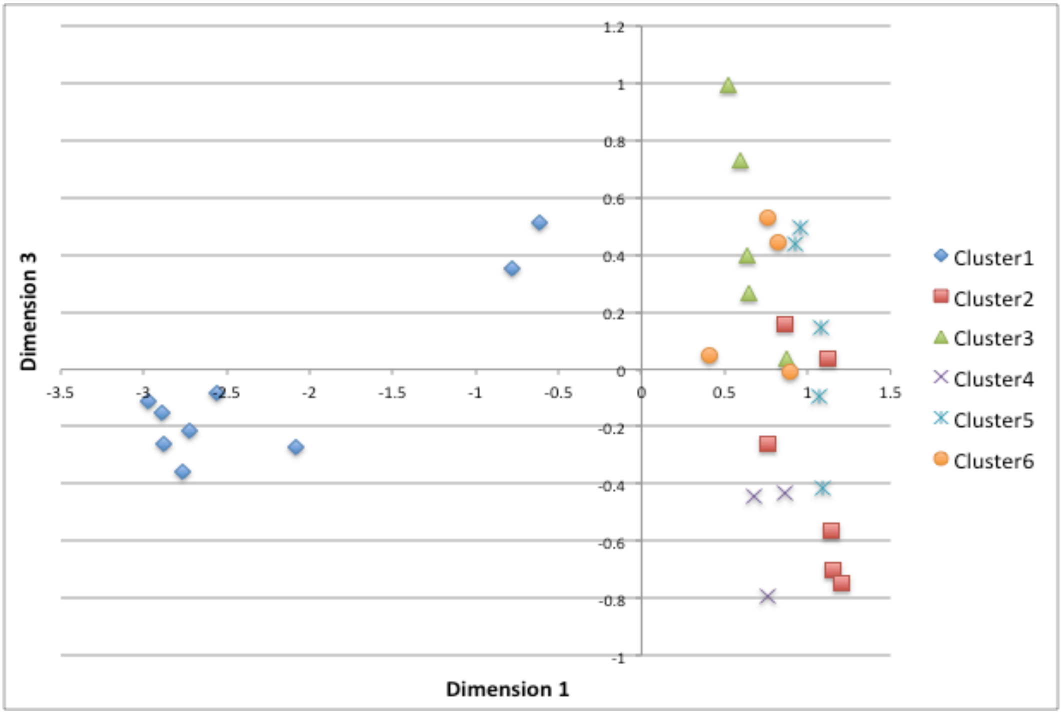
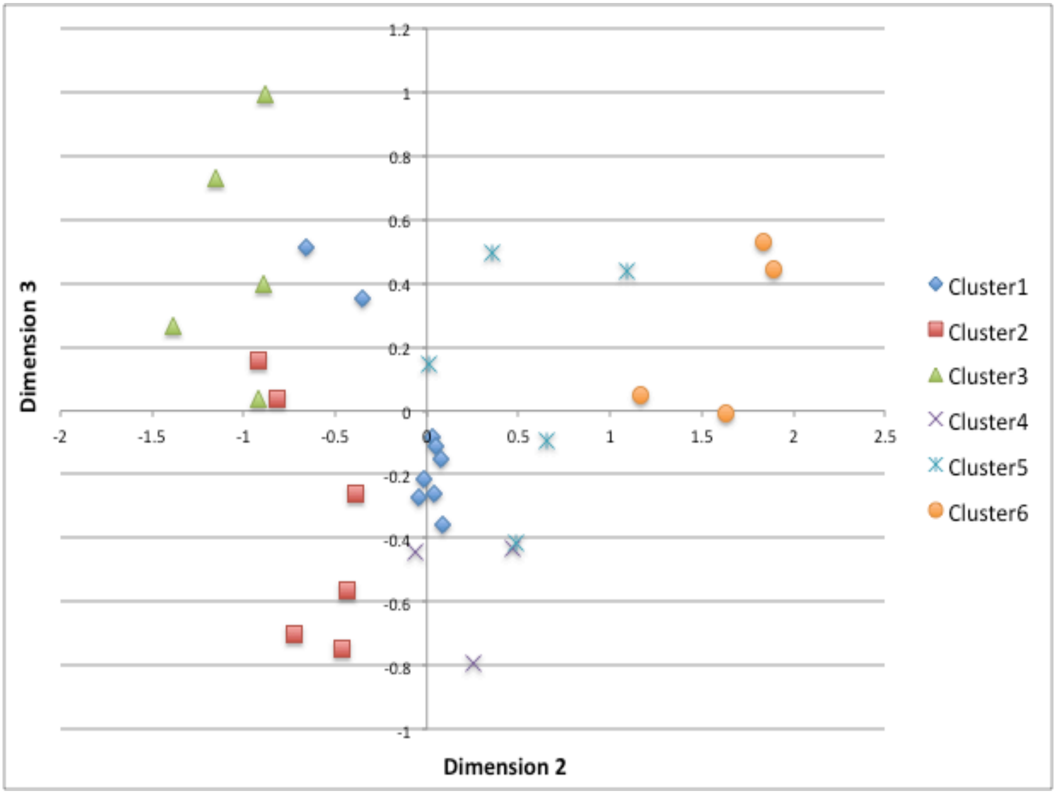


Figure 6

MDS Scatterplot Dimension 2 x 3



APPENDIX B

IRB APPROVAL

ARIZONA STATE UNIVERSITY
Knowledge Enterprise Development
Office of Research Integrity and Assurance

To: Julie Liss
COOR

From: Mark Roosa, Chair
Soc Beh IRB

Date: 12/07/2011

Committee Action: **Renewal**

Renewal Date: 12/07/2011

Review Type: Expedited F7

IRB Protocol #: 0310001421

Study Title: PERCEPTION OF DYSARTHRIC SPEECH

Expiration Date: 12/08/2012

The above-referenced protocol was given renewed approval following Expedited Review by the Institutional Review Board.

It is the Principal Investigator's responsibility to obtain review and continued approval of ongoing research before the expiration noted above. Please allow sufficient time for reapproval. Research activity of any sort may not continue beyond the expiration date without committee approval. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol on the expiration date. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study termination.

This approval by the Soc Beh IRB does not replace or supersede any departmental or oversight committee review that may be required by institutional policy.

Adverse Reactions: If any untoward incidents or severe reactions should develop as a result of this study, you are required to notify the Soc Beh IRB immediately. If necessary a member of the IRB will be assigned to look into the matter. If the problem is serious, approval may be withdrawn pending IRB review.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, or the investigators, please communicate your requested changes to the Soc Beh IRB. The new procedure is not to be initiated until the IRB approval has been given.

Please retain a copy of this letter with your approved protocol.