INTRODUCTION

Research into the language abilities of speakers with Down syndrome has primarily concentrated on linguistic comprehension and language and literacy skills in children with Down syndrome. Phonation and intonation within this client group remain underresearched in comparison to language and literacy. Nevertheless, it has been argued that the perceptual voice quality of children with Down syndrome differs significantly from that of typically developing children. A similar lack of attention can be observed with respect to various aspects of speech melody such as fundamental frequency (F0) and the structure of intonation patterns. Although there have been studies on intonation, the focus has mainly been on children, and the results are relatively outdated and inconsistent. The aim of this paper is therefore to investigate aspects of phonation and intonation of a group of young adult speakers with Down syndrome rather than children.

Phonation or vocal fold vibration is related to the speaker’s voice quality, ie, the perceptual impression caused by specific modes of vocal fold vibration in different laryngeal settings. There seems to be general agreement that the perceptual voice quality of speakers with Down syndrome is “raucous,” exhibits breathiness and roughness, and is generally “hoarse.” These perceptual impressions are to some extent confirmed by data from acoustic analyses that indicate increased frequency perturbations (jitter), amplitude perturbations (shimmer), and spectral noise-to-harmonic component ratios in Down syndrome children as compared to typically developing children.

Intonation refers to the linguistic use of speech melody variations in utterances. The study of intonation has mainly concentrated on a few aspects of F0 in both children and adults. These studies report conflicting evidence regarding the average pitch height in Down syndrome speakers as compared with a normal population: Moran and Gilbert found that the mean speaking F0 in adults with Down syndrome is significantly higher than that in matched controls, while research by Pentzs indicates that children with Down syndrome have “characteristically low pitched voices.” It has been hypothesized that the conflicting results may be linked to puberty and the development of secondary sexual characteristics: there may be reduced laryngeal growth in the Down syndrome group compared to the control group.

There is also conflicting evidence on the correlation between perceptual and acoustic data in the Down syndrome population. There appears to be high agreement between the acoustic and perceptual results in children. There were significant differences in the severity ratings between Down syndrome speakers and speakers with voice disorders, with a clear correlation between severity ratings and the acoustic measures obtained. However, adult data indicate that although listeners could accurately distinguish Down syndrome adult voices from voice disorder “normal” adults, there were no significant differences in the acoustic measures across both groups.

The difficulty of correlating acoustic and perceptual analysis is a persistent issue in the general voice literature. The main variable determining agreement in the perceptual and acoustic data appears to be the experience and training of the listener completing the perceptual ratings. Difficulties remain with inter- and intrarater reliability on the perceptual analysis alone and predictability of dysphonia using acoustic analysis alone. More recently, research has shown that reliable description of voice quality for diagnostic purposes requires both acoustic and perceptual data.

On examining the existing data on voice quality of people with Down syndrome, it is clear that there are limitations to the methodology used in data collection, which may account...
for at least some of the contradictory results. Issues relating to perceptual and acoustic analysis are only beginning to be understood. The data on voice quality in the adult Down syndrome population are old and drawn from mostly a pediatric population or an adult subject population who are in care.20 The results in many of these studies are conflicting, and although there seems to be agreement that there are differences in voice quality from “normal” adults,4 the perceptual data on defining the nature of these differences remain inconsistent.

Other factors that have an effect on the perceptual evaluation of the Down syndrome client group include the presence of anatomical and structural differences: people with Down syndrome have a typically high palatal vault, a larger than average tongue in relation to the oral cavity, and general hypotonicity in the facial musculature.21 Pryce3 hypothesizes that hypotonicity of the supralaryngeal tract may be linked to voice quality. Although there is little research into how exactly these features affect speech production and phonation, there is an established effect on phonology, indicating error patterns that are different from those found in typically developing children22 as well as a significant delay in acquisition.23 Early research in the perception of voice quality of Down syndrome focuses on distinguishing Down syndrome from “nonretarded” speakers.

Montague and Hollein4 in their study of 20 Down syndrome children focus on breathiness and disturbed resonance resulting in increased nasality. This altered nasal resonance, however, was not significant in Moran’s2 perceptual study of identifying Down syndrome adults from “nonretarded” adults with voice disorders. Skilled listeners from separate fields of special needs and speech pathology were able to correctly identify Down syndrome and voice disordered speakers, respectively, at a level of accuracy higher than that expected by chance from the prolonged vowels /a/, / i/, and /u/.22

There seems to be a reduced efficiency of upper respiratory function, which affects vocal production in people with Down syndrome. Pryce3 compared the voice quality of people with Down syndrome to normal controls, people with learning disabilities and adults with diagnosed functional dysphonia. His change results indicated that people with Down syndrome needed to make twice as much effort to initiate phonation as the control group: voice quality of adults with Down syndrome was compared with that of three other groups, a normal control, people with learning difficulties, and adults with diagnosed functional dysphonia. While Pryce’s research confirms the effect of a reduced level of respiratory function, it fails to establish a link between perceptive and acoustic voice quality.

The aim of this paper is to investigate acoustic measures of intonation and phonation in a group of young adults with Down syndrome as compared to a control group of typical speakers of Southern British English. Measures of phonation include aspects of F0, pitch range, jitter, and shimmer.

**DESIGN**

**Materials**

Nine young adults with Down syndrome and nine age- and gender-matched control group of typical speakers of Standard British English participated in a speech production task to provide different types of speech materials. First, speakers produced a sustained “ah” vowel at a constant pitch level. Second, they also provided an ascending and descending pitch glide on the same vowel. Third, they were required to read an extract of the “Rainbow Passage,” and fourth, each speaker provided at least one minute of spontaneous speech.

**Subjects**

The experimental group consisted of five females and four males with Down syndrome. The speakers were between 17 and 29 years old with a mean age of 24.7 years. All Down syndrome speakers were members of a theater group but had never had any formal voice therapy or coaching. The control group consisted of nine age- and gender-matched adults with normal voices drawn from a university population. Their mean age was 23.5 years. All subjects spoke British English and took part on a voluntary basis. Information on the hearing status of both groups was only collected informally. One Down syndrome subject reported “moderate” hearing loss, but none of the other subjects said they experienced any significant hearing problems.

**Recording procedure**

The Down syndrome speakers were recorded on location, either at their homes or at an agreed location. Control group samples were obtained in a university lab setting. A PC card recorder (Marantz PDM 660) and a condenser head-mounted microphone (AKG CL444) were used to collect the data.

**Analysis procedures**

Subjects’ deliveries of the sustained “ah” vowel were measured for maximum phonation time (MPT). The ascending and descending pitch glides on the sustained vowels were analyzed for minimum pitch and maximum pitch. The latter values give an indication of the speakers’ organic pitch range (OPR), ie, the “maximum range of which the speaker’s voice is physically capable, given the biologically determined factors of his or her laryngeal anatomy and physiology.”24

Furthermore, subjects’ deliveries of the “Rainbow Passage” were analyzed for intonation to obtain a number of acoustic measures that provide a general characterization of the speakers’ pitch contour framework. These measures included a specification of the speaker’s “linguistic pitch range,” “voice compass,” and “declination.” Subjects’ utterances were analyzed for F0 by means of the standard pitch analysis algorithm (autocorrelation method) in PRAAT.24 The obtained F0 values were subsequently corrected manually for octave jumps, which were occasionally observed in the transitions from voiced to voiceless speech segments.

Linguistic pitch range (LPR) can be defined as the “range within which the phonologically relevant pitch of the speaker’s voice habitually varies in paralinguistically unmarked, attitudinally neutral conversation.”26 The LPR of the speakers was established as the mean distance between the onset and offset of all the linguistically relevant pitch movements in the delivery of the text. Linguistically relevant pitch movements were taken
to be the rising and falling pitch movements associated with sentence accents and major syntactic boundaries.

Additionally, another representation of pitch range was measured, ie, voice compass. This can be defined as “the range of pitch stretching one standard deviation on either side of the mean pitch.”6 Besides the average speaking F0 level of the speakers, this value provides a general indication of the melodic variation in F0. Finally, the declination for each utterance was measured. Declination can be defined as the general downsloping trend of overall pitch in utterances.7

In the third instance, phonation was investigated for the two groups of subjects on the basis of an acoustic analysis of jitter and shimmer. “Jitter” provides an indication of the speakers’ frequency perturbations, while “shimmer” is a measure for amplitude perturbations. For this purpose all the vowels in the deliveries of the “Rainbow Passage” were manually selected on the basis of a broad-band spectrogram that was time-aligned with the analog waveform. For each vowel, jitter and shimmer were measured in the middle third portion of the segment. Although we are aware that measuring the jitter and shimmer of vowels in different phonetic contexts is to some extent compromised by natural variations in F0 and intensity, it can be argued that these natural variations apply equally to all the speakers and it is likely that systematic differences between speaker groups in terms of phonation will show up irrespective of natural variations applying to both groups.

RESULTS

Organic pitch range
As indicated earlier, OPR can be considered as the maximal range of which the speaker’s voice is capable.7 This range was established on the basis of the isolated vowel realizations with ascending and descending pitch glides. Maximum pitch was taken as the highest pitch (in Hz) each speaker achieved in the vowel with an ascending pitch glide, while minimum pitch was established as the lowest pitch (in Hz) in descending pitch glide. The difference between these two values is indicative of the speaker’s OPR, which is expressed here in semitones to perceptually normalize for anatomical differences between male and female speakers.25 The mean values for the OPR in the two groups of speakers are summarized in Figure 1.

In view of the small number of speakers in each group (N = 9), the statistical significance of OPR could not reliably be determined, and the OPR values presented here should be taken as exploratory measures requiring further confirmation in a larger-scale study.

Linguistic pitch range
LPR refers to the phonological pitch span in attitudinally neutral utterances. In order to define this range, all the individual utterances in the deliveries of the “Rainbow Passage” were analyzed for F0 by means of the standard pitch analysis algorithm in PRAAT.24 Subsequently, all the pitch movements (rises and falls) associated with sentence accents and phrase boundaries in each utterance were identified and their F0-onset and F0-offset were measured. Phonological pitch span was expressed as the difference in semitones between F0-onset and F0-offset in each pitch movement. In the analysis of LPR, a total number of 653 linguistically relevant pitch movements were measured. The results of these LPR measurements are summarized in Figure 2.

These LPR measurements were analyzed by means of a two-way analysis of variance with GENDER (2) and SPEAKER GROUP (2) as between-subject variables and pitch excursion (in semitones) as the dependent variable. This analysis revealed a significant effect of SPEAKER GROUP (F(1,652) = 19.58, P < 0.0001), which indicates that the excursion sizes associated with phonological events in the Down syndrome group (mean = 4.73 semitones (ST)) are smaller than those in the control group (mean = 5.62 ST). The effect of GENDER was not significant (F(1,652) = 0.0492, P = 0.8243), but there was a significant interaction between the two variables (F(3,650) = 55.9218, P < 0.0001). This interaction indicates that the LPR was bigger for men in the Down syndrome group, while the LPR was substantially bigger for women in the control group.

Voice compass and declination
The voice compass was defined as the pitch range stretching one standard deviation on either side of the mean pitch. Voice compass thus gives an indication of the speaker’s average speaking F0 as well as the melodic variation in F0. These values are different from the LPR in that they are based on all F0 values in the utterances, not only those associated with main phonological events such as sentence accents and markers of syntactic boundaries. In order to obtain voice compass information, each utterance in the text was analyzed for F0, and mean F0 and the standard deviation were computed. The results of the F0 measurements are summarized in Figure 3.

Mean F0 was analyzed using a two-way analysis of variance with SPEAKER GROUP (2) and GENDER (2) as between-subject variables, and mean F0 as the independent variable. The analysis revealed a significant main effect of SPEAKER GROUP (F(1,113) = 60.0997, P < 0.0001) and GENDER (F(1,113) = 94.6631, P < 0.0001). There was no significant interaction between the two effects. This is to say that average speaking F0 in the Down group is significantly higher than that in the control group and this applies to both males and females.
A similar two-way analysis of variance of the standard deviation around the mean revealed significant main effects of SPEAKER GROUP \((F(1,113) = 34.6597, P < 0.0001)\) and GENDER \((F(1,113) = 11.4905, P = 0.0010)\). The interaction between the two main effects was not significant. As shown in Figure 4, the standard deviation around the mean is significantly lower in the Down syndrome speakers, and in both groups the standard deviation is highest in male speakers.

In addition to voice compass, the declination in the utterances in the delivery of the text was measured. Declination is the general down-sloping trend of overall pitch in utterances,\(^7\) which is generally regarded as a language universal feature.\(^{25}\) Declination for the individual utterances was measured in semitones per second. In Figure 5, it can be seen that declination is shallower in speakers with Down syndrome. This difference was investigated by means of a two-way analysis of variance with the same between-subject variables as above. From this analysis it appears that only the difference between speaker groups is significant \((F(1,113) = 243.64, P < 0.0001)\).

Voice quality

Phonation was assessed in terms of MPT, jitter, and shimmer. MPT was measured on the sustained vowel productions in the nine speakers in each group. From these measurements it appears that the Down syndrome group only differs marginally from the control group. In both groups the females have a somewhat smaller MPT than male speakers. This is illustrated in Figure 6. As a result of the small number of observations, no statistical analysis was carried out on these results, and the validity of these measures requires further investigation in a larger-scale study.

In order to determine jitter and shimmer, the vowels in the delivery of the text were analyzed for both measures. For this purpose, the middle third portion of all 899 vowel realizations was selected and analyzed for jitter and shimmer by means of the voice analysis algorithm in PRAAT.\(^{24}\) The results of the jitter and shimmer measurements are summarized in Figure 7.

These results were analyzed in two separate analyses of variance with SPEAKER GROUP (2) and GENDER (2) as between-subject variables and jitter and shimmer as the respective dependent variables. From these analyses it appears that jitter is significantly lower in speakers with Down syndrome \((F(3,896) = 45.7941, P < 0.0001)\). There were no significant differences in shimmer between both groups. It should also be observed that for both groups it appears that jitter and shimmer are significantly lower in female speakers (jitter:
have a wider OPR than men.26 The absence of such difference is consistent with previous research indicating that females with a substantial difference between males and females, which the speakers in the control group is nearly 2.5 times as large, differenc between the male and female participants. The OPR of Down syndrome speakers is close to one octave, with little dif-
fraction in a read speech sample.

This study found that Down syndrome speakers have a con-
siderably smaller OPR than the control group. The OPR of Down syndrome speakers is close to one octave, with little difference between the male and female participants. The OPR of the speakers in the control group is nearly 2.5 times as large, with a substantial difference between males and females, which is consistent with previous research indicating that females have a wider OPR than men.26 The absence of such difference in Down syndrome speakers is interesting in that it points toward similar restrictions on the laryngeal mechanism in both sexes. As a result of the small sample size, this observation awaits further confirmation in a larger-scale study.

Analysis of LPR indicated that the excursion sizes of the pitch movements associated with phonological prosodic events (pitch accents and syntactic boundaries) were not significantly different in both speaker groups: the average excursion size in the Down syndrome group was smaller than that in the control group. The obtained values are slightly smaller than the 6.5 semitones reported in Willems.27 There was, however, a significant interaction between the experimental variables in that there were differences in excursion size between male and female Down syndrome groups, while this was not the case in the control. This difference in excursion size between males and females in Down syndrome speakers is consistent with that reported by Henton,26 who indicates that females typically have a narrower LPR than male speakers. This expectation, however, is not born out for the control group where the pitch range of females is slightly wider than that in males. This deviation from what is found in other studies can be explained by the fact that female speakers of Southern British English often mark syntactic boundaries by means of a creaky voice, which causes F0 to drop down to the very low end in their pitch range (often down to 70 Hz), which yields very big pitch excursions associated with these boundaries. This typical feature of Southern British English only occurs in female speakers, and this may have contributed to the difference in the control group.

In this study, analysis of the voice compass indicated that average speaking F0 is significantly higher in the Down syndrome speakers and this applies to both males and females. This finding is consistent with the results of Moran and Gilber,

This study investigated aspects of intonation and phonation in young adults with Down syndrome. OPR, LPR, and voice compass were measured in nine Down syndrome and nine age- and gender-matched speakers with a Southern British English background. Phonation was assessed in terms of MPT, jitter, and shimmer in a read speech sample.

This study found that Down syndrome speakers have a considerably smaller OPR than the control group. The OPR of Down syndrome speakers is close to one octave, with little difference between the male and female participants. The OPR of the speakers in the control group is nearly 2.5 times as large, with a substantial difference between males and females, which is consistent with previous research indicating that females have a wider OPR than men.26 The absence of such difference in Down syndrome speakers is interesting in that it points toward similar restrictions on the laryngeal mechanism in both sexes. As a result of the small sample size, this observation awaits further confirmation in a larger-scale study.

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In this study, analysis of the voice compass indicated that average speaking F0 is significantly higher in the Down syndrome speakers and this applies to both males and females. This finding is consistent with the results of Moran and Gilbert,10 who also report a higher mean F0, but is contradictory to the results of Pentz,17 who reports that children with Down syndrome have “characteristically low pitched voices.” The higher mean speaking F0 may be the reflection of physiological factors at the level of the larynx in that it may point toward generally shorter vocal folds in this client group. It should, however, not be excluded that the higher average speaking F0 may also have been acquired as an indicator of submissiveness in social interactions26 and may thus be related to personality characteristics of this client group.

Besides the higher speaking F0, it was found that the standard deviation around the mean is also significantly lower in the Down syndrome group, suggesting that their rendering of speech intonation is less melodious and more monotonous than that of the control group. This is further supported by the analysis of declination, which indicated a substantially shallower declination line in the Down syndrome group. This narrower LPR may also point to physiological factors, but it cannot be excluded either that this may be the result of using different markers to signal linguistic information. This may well reflect different processing strategies within this population. This clearly requires further investigation, but it is an interesting consideration in our increasing understanding of how people with Down syndrome process linguistic information at both the segmental and suprasegmental levels.

This study investigated MPT, jitter, and shimmer. MPT in the Down syndrome group only differs marginally from the control group. The differences between male and female speakers in both groups are consistent with earlier research in that MPT in male speakers is somewhat longer than that in female speakers.2 This normal MPT suggests that Down syndrome speakers use efficient vocal fold vibration, without wasteful air leakage that is characteristic in, for instance, breathy voice.
It should be noted though that this observation is not consistent with the observation of Pryce,5 who reports greatly reduced phonation time in Down syndrome speakers and takes this as evidence of increased respiratory effort for this client group. The results of this study seem to suggest the opposite.

Besides MPT, it was found that jitter and shimmer were significantly lower in females than in males. More of a surprise is the fact that jitter is significantly lower in the Down syndrome group than in the matched control group: ie, there are generally fewer frequency perturbations in the Down syndrome group. This is not consistent with earlier findings on voice quality within this group.5 This may be explained by the fact that data from the earlier studies were obtained from children, and the present data are from an adult population. As well, the current data came from a theater group. Although they had never received any formal voice therapy or coaching, they were more aware of voice production for the purposes of performance despite the fact that none engaged in any form of vocal exercise or warm-up.

From a perceptual point of view, the voice quality of Down syndrome has been judged as breathy and rough8 and as “hoarse.”3,9,10 The results of this study would suggest that these perceptual judgments on voice quality may not reflect laryngeal parameters, but may be more affected by supralaryngeal factors whereby particular patterns of articulation affect the resonance characteristics of the vocal tract.

Finally, it should be pointed out that there are limitations to the present study, particularly in relation to the small sample size and sample type. The limitations of using the “Rainbow Passage” for the connected speech sample were evident in the Down syndrome group. The sample was somewhat hampered by variables such as literacy and comprehension skills. Perhaps more useful would be to target the speech sample to meet the variable abilities of this group by using a more accessible passage with simple sentence structure and high-frequency words. This would also provide more linguistic information for analysis regarding the use of intonation contours as markers. However, results strongly suggest that there is more work to be done in the area of Down syndrome and voice from perceptual, acoustic, and possibly linguistic perspectives.

CONCLUSIONS
The results of an acoustic analysis of intonation and phonation in young adults with Down syndrome indicate that these speakers exhibit a reduced OPR and a somewhat reduced LPR. In terms of the melodic variation in the intonation patterns, a higher mean speaking F0 was found with a generally less melodic rendering of the intonation patterns and a shallower declination. The analysis of phonation in terms of jitter and shimmer indicated reduced jitter, while shimmer did not deviate significantly from the normal group. Although the observed differences between the Down syndrome and control groups are suggestive of a lack of laryngeal control at the physiological level, it cannot be excluded that they may reflect personality characteristics or the use of different linguistic strategies in implementing intonation contours.

REFERENCES