Title: The effect of singing training on voice quality for people with quadriplegia

Abstract (250 words max)

Objectives: Despite anecdotal reports of voice impairment in quadriplegia, the exact nature of these impairments is not well described in the literature. This paper details objective and subjective voice assessments for people with quadriplegia at baseline and after a respiratory-targeted singing intervention.

Study Design: Randomized controlled trial

Methods: Twenty-four participants with quadriplegia were randomly assigned to a 12-week program of either a singing intervention or active music therapy control. Recordings of singing and speech were made at baseline, 6 weeks, 12 weeks, and 6 months post intervention. These de-identified recordings were used to measure sound pressure levels and assess voice quality using the Multidimensional Voice Profile, and the Perceptual Voice Profile.

Results: Baseline voice quality data indicated deviation from normality in the areas of breathiness, strain, and roughness. A greater percentage of intervention participants moved toward more normal voice quality in terms of jitter, shimmer and noise-to-harmonic ratio, however the improvements failed to achieve statistical significance.

Conclusions: Subjective and objective assessments of voice quality indicate that quadriplegia may have a detrimental effect on voice quality; in particular causing a perception of roughness and breathiness in the voice. The results of this study suggest that singing training may have a role in ameliorating these voice impairments.

Keywords: voice quality, intensity, singing, music therapy, quadriplegia, spinal cord injury

Introduction

Despite the well-known detrimental effect of quadriplegia on respiration,[1, 2] there is a surprising lack of research on the effect of cervical spinal cord injury on voice and speech production. Subjective assessments have suggested some common speech characteristics when diaphragm function is spared following spinal cord injury (SCI). These include reduced loudness, short phrases and longer inspiratory durations,[3-6] as well as deviations in prosody, articulatory precision, and voice quality.[7] In addition, laryngeal dysfunction associated with intubation and tracheostomy insertion during acute medical management of cervical SCI can range from mild dysmobility to complete paralysis of the vocal folds and the growth of polyps and/or nodules.[5, 8] There is a relatively high rate of breathlessness during talking, found in motorised-wheelchair users, which may be caused by difficulty organising breathing to manipulate phrasing and speech loudness.[9, 10]

The relationship between impaired respiratory function and abnormal phonation and prosody in speech has been described previously in dysarthria.[11-14] Reduced breath support is also associated with reduced overall loudness levels and reduced variation in loudness and pitch,[15-18] unusual stress patterns and poor use of intonation;[14, 18] and abnormal breathing patterning resulting in short phrasing and reduced length of utterance.[13]

Quadriplegia is associated with decrements in voice volume and quality.[5, 19] A recent study examining the experience of decreased lung function for people with quadriplegia found that post-injury breathing and voice function were perceived as impaired by most participants.[20] In particular, decreases in vocal strength and endurance were reported, especially in social situations. However, this impairment was predominantly not perceived as a disability by the study participants. Most individuals adapted to their changed vocal capacities and developed their own strategies for handling these limitations, such that their vocal limitations were not perceived to be particularly problematic.

The speech characteristics of inadequate loudness, monoloudness, and reduced stress contrasts form a cluster of factors influenced by volume compression difficulties related to muscular weakness. People with quadriplegia compensate for expiratory muscle impairment by speaking at large lung volumes (taking advantage of higher recoil pressures) to increase loudness.[4] However this diminishes speech naturalness by reducing utterance duration, increasing pause time and decreasing number of syllables per breath.[7] MacBean et al.[5] reported prosodic and phonatory disturbances, and physical impairments in the respiratory and laryngeal subsystems of speech production. They also reported a high degree of variation between participants, with no clear relationship between lesion type and impairments. According to Hixon et al.[21] only 20% of vital capacity is used in speech breathing by healthy individuals. The typical 30-50% reduction in vital capacity observed following cervical SCI[22] should provide sufficient respiratory function to maintain adequate speech. However, although basic speech production may be preserved, the quality of speech in terms of phonation, articulation and prosody may be compromised. Although most people with quadriplegia are able to maintain an adequate level of loudness during conversational speech in a quiet room, they often encounter difficulties in increasing intensity to project over high levels of background noise.[5, 23] People with quadriplegia also make use of unusual respiratory muscle recruitment patterns for speech.[19] Published interventions to treat speech and voice dysfunction post SCI are limited to the use of abdominal binders to hold the abdomen in place when seated and increase lung volumes.[6, 7, 24]

Method

Participants

This paper describes in detail the voice quality outcomes that form a sub-set of a larger study of the effect of 12 weeks of singing training on respiratory function, voice and mood (Author, 2013). The full methods are published elsewhere (Author, 2013), but briefly a randomized, controlled trial design was used to examine the effect of singing training on a range of outcomes for participants with C4-C8 quadriplegia. The experimental group participated in group singing training using oral motor and respiratory exercises and therapeutic singing[25] three times per week. The control group participated in group music therapy including music sharing, song lyric discussion, musical games, and music-assisted relaxation. Group size for both conditions was limited to 3-4 participants and all sessions were 1 hour in length. The therapeutic singing intervention consisted of carefully selected exercises and well-known songs designed to increase respiratory and vocal strength and control (this protocol has been published previously) (Author, 2011). Assessments were conducted pre, mid, post, and 6-month following the 12-week intervention period.

English speaking participants at least one year post SCI who were in good health and able to travel were recruited from the Victorian Spinal Cord Service (Victoria, Australia). Exclusion criteria included a pre-existing history of speech disorder, respiratory disease, psychiatric disorder, or neurological impairment. Randomization was performed (using a computer-generated sequence) and stratified by previous tracheostomy history, due to research linking impaired laryngeal function with abnormal phonation for this population.[5] Group allocation was concealed (using sealed, opaque envelopes) from all persons involved in recruitment, data collection and analysis. The institutional Human Research Ethics Committee approved the project and all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed.

Recording procedure and instrumentation

Digital audio recordings of the voice assessments were made by an acoustic engineer in a soundproofed room to ensure minimal external noise interference. An Ono Sokki MI-1211 Type 1 omni-directional condenser microphone was positioned at a distance of 30cm from the mouth of each participant. All data was collected at 16-bit resolution and 44.1kHz sampling rates through a Fireface 400 data acquisition interface (RME) and Wavelab software platform (Steinberg). Real-time analysis was conducted simultaneously using the Ono-Sokki 5570 and an EASERA software analyser (SDA). Prior to each participant recording, the instrumentation chain was calibrated in a Bruel & Kjaer 4230 calibrator with a 94dB tone at 1kHz.

Each participant was directed through a sequence of phonatory exercises including sustained vowels (at normal, soft and loud intensities), the "Rainbow Passage"[26] with and without background noise, and reading and then singing the lyrics to a well-known song (Happy Birthday). In order to standardize the level of background noise provided via headphones to the participants, the signal feed level was set at the average vocal input signal level recorded during initial reading of the Rainbow passage. That is, each participant received a noise signal equal to the amplitude of their own voice signal during normal speaking conditions (signal-to-noise-ratio = 0).

Sound recordings from the vocal assessment were used to measure sound pressure level (SPL) and assess voice quality, both subjectively using the Perceptual Voice Profile[27] and objectively using computer analysis (Multidimensional Voice Profile).

Acoustic analysis

The Multidimensional Voice Profile (MDVP™) was chosen as a commonly used, robust, and accurate software tool for quantitative acoustic assessment of voice quality[28]. It extracts objective values on sustained phonation, which are displayed graphically and numerically in comparison to a built-in normative database. The MDVP™ parameters assessed in this study were measures of perturbation, including jitter and shimmer, and noise-related measures, including noise-to-harmonic ratio and voice turbulence index. Jitter and shimmer represent, respectively, period-to-period irregularities in frequency and in amplitude[29]. When either jitter or shimmer measurement is considerably higher than normal, the voice is frequently perceived as rough. Shimmer has also been correlated with a perception of breathiness.[30] Noise-to harmonics ratio and voice turbulence index are measures of the relative amounts of periodic and aperiodic energy in the voice. Noise-to-harmonics ratio is the ratio of the sound frequencies to the noise energy in the voice. This correlates with a perception of roughness in the voice when this value is lower than normal. Voice turbulence index measures the relative energy level of high-frequency noise. It mostly correlates with the turbulence caused by incomplete or loose adduction of the vocal folds. In this study, a sustained vowel “ee” at normal intensity was used for the acoustic analysis.

Computer-based voice analysis was used in addition to auditory-perceptual analysis for several reasons. Perceptual (subjective) assessments of voice have the advantages of convenience, economy, and robustness, but are also susceptible to a variety of sources of error and bias.[31] Inter- and intra-rater reliability of perceptual assessments reported in the literature fluctuate significantly[32] and normative, reliability, and validity data for perceptual assessments are rare.[33]

Perceptual analysis

The Perceptual Voice Profile (PVP) is a subjective rating of voice quality, pitch and intensity by a trained listener.[27] The PVP is a valid and reliable scale for rating dimensions of voice.[34] This tool provided a subjective, but informed rating of voice in terms of pitch (high, low, monotone), loudness (soft, loud, monoloud) and quality (breathy, strained, rough, glottal fry, pitch breaks, phonation breaks, voice arrests, falsetto, tremor, diplophonia). A 6-point Likert scale (1 indicates normal voice and 6 severe impairment) is used to rate parameters of voice. A senior speech pathologist with more than 30 years experience in voice analysis completed these auditory-perceptual voice evaluations of the Rainbow passage. Speech samples were de-identified and presented in randomized order so that the rater was blinded to both group allocation and order of assessment. Ten randomly selected speech samples were repeated and randomly distributed on the audio CD and rated again. Intra-rater reliability of the evaluations was examined using percentage agreement calculations. Scores within ±1 point of each other on the PVP rating scale were taken as an acceptable level of agreement.[34]

The Voice Handicap Index (VHI) is a 30-item instrument (divided into three content domains: functional, emotional, and physical) designed to quantify the psychosocial consequences of voice disorders. As a statistically robust tool with high internal consistency, reliability and strong test-retest stability,[35] the VHI was selected to measure any subjective changes in voice from the participant's perspective. Previous research[19] has reported significantly higher VHI scores for people with C5-C7 complete quadriplegia than able-bodied, age-matched controls.

Statistical Analysis

Normally distributed data are summarized as mean (standard deviation) and analysed using repeated measures ANOVAs. McNemar's Test was used to analyse any relationship between the numbers of participants from each group within normative limits from pre to post assessments on each MDVP™ outcome variable. SPSS Statistics Version 17.0 was used for statistical analysis.

Results

Demographics

The cohort of 24 participants was predominantly male (80%) with an average age of 45 (95% CI 39-51, range 27-70). The five women participants were all randomly assigned to the control condition. History of tracheostomy (n=12) was evenly distributed between invention (n=6) and control (n=6) conditions as per stratification in the randomisation process.

Acoustic Analyses

The vocal intensity (SPL) results have been published previously[36] and thus will not be presented in detail in this paper (Table 1). In summary, when compared with the control group, the group that received singing training became able to achieve significantly louder voice (SPL) when speaking over background crowd noise. Baseline decibel range during normal speech (the Rainbow passage) was 62-75dBA (mean 68.5dBA). When speaking over background noise, the baseline decibel range was 68-85dBA (mean 75dBA), which is below the normal range for loud speech.[37] The mean maximum phonation length at baseline was 12.4 seconds. This is below normal maximum phonation length values of 15-30 seconds.[38] Following the 12-week singing intervention, the intervention group achieved a significant increase in mean maximum phonation of five seconds (p=0.012).

Insert Table 1 around here

Multidimensional voice profile (MDVP) software analysis of voice was conducted on a sustained vocalization performed by participants. This software extracted data from the voice recordings including frequency and amplitude perturbation measurements (jitter and shimmer) as well as noise-related measurements (noise-to-harmonic ratio and voice turbulence index) and displayed them on a graph incorporating normative reference values (Figure 1). The shaded circle in Figure 1 represents normative data against which the profile for an individual voice can be compared.

Insert Figure 1 around here

Baseline MDVP data for the study cohort illustrate the effects of quadriplegia on voice quality (Table 2). In particular, jitter and shimmer were considerably outside normal thresholds. There was no effect of tracheostomy history on these baseline voice parameters (data not shown).

Insert Table 2 around here

The MDVP data were then analyzed to capture within-subject (percentage change from baseline) and between-subject (threshold-normalized) differences. For each of the MDVP variables, higher scores equal greater vocal dysfunction. To enable comparison between groups, threshold normality figures were used to determine movement towards or away from normality. On all voice parameters the percentage of intervention participants within normal ranges increased over time or remained stable. For the control group the percentage of participants within normal ranges decreased over time for jitter, shimmer and noise-harmonic ratio and increased for voice turbulence index (Table 3).

Insert Table 3 around here

Using McNemar's Test, no significant differences between groups were found. The numbers of participants from each group who improved (moved towards the threshold limits) from pre to post assessment were then calculated. A significantly greater number of intervention participants improved on jitter (n=9, vs n=4, p=0.019, McNemar's Test). There were no significant differences between groups for the other measures.

A similar pattern was seen when examining within-subject percentage change from baseline scores (Table 4). The intervention group improved their performance on the jitter, shimmer and noise-harmonic ratio while voice turbulence index got worse. Again, the reverse was true for the control group. These participants increased from baseline on jitter and shimmer scores and decreased voice turbulence index scores. Noise-harmonic ratio scores changed the least, but, as shown in Table 3, these scores were close to being within normal limits.

Insert Table 4 around here

Effect size calculations to determine the size of any clinically significant changes in acoustic voice parameters are presented in Table 5. These calculations revealed a large effect for the between-group difference in mean change for jitter over time, where the intervention group scores decreased (improved) over time from baseline, whereas the control group scores increased (got worse). A small effect was seen for noise-harmonic ratio. A medium negative effect was seen for voice turbulence index; intervention group scores increased (got worse) while control group scores decreased (improved).

Insert Table 5 around here

Perceptual Analysis

The Perceptual Voice Profile (PVP) results suggested that as an overall cohort the participant's voices were within normal limits for pitch and intensity. In terms of voice quality, there was some deviation from normality particularly in the areas of breathiness, strain, and roughness. For both intervention and control group, approximately a third of participants scored 2 or higher on these parameters. There was no clear pattern of improvement or deterioration in scores over time for either group. In terms of intra-rater reliability, scores within ±1 of each other on the 6-point PVP rating scale were taken as an acceptable level of agreement. Using this benchmark, intra-rater reliability for PVP scoring was 100%. Only 8.75% of the scores differed by ±1 point.

Higher scores on the Voice Handicap Index (VHI) indicate greater handicap. The maximum score for each subscale is 40 points, with a total maximum score of 120. A change of 18 points between two administrations of the VHI represents a significant shift in psychosocial function.[35] As can be seen from the group mean scores presented in Table 6, the largest shift in scores was 5 points. Correspondingly, there were no statistically significant results from the ANOVA analyses.

Insert Table 6 around here

Effect size calculations were conducted to determine the size of any clinically significant changes in VHI scores and are presented in Table 7.

Insert Table 7 around here

These calculations revealed small and medium negative effects[39] for the between-group difference in mean decrease in VHI scores over time. This was because the control group scores decreased more than the intervention group. The control group scores decreased slightly from pre to post assessment scores whereas the intervention group scores changed little.

Discussion

In addition to the negative effects on voice projection related to respiratory dysfunction, quadriplegia also appears to have a detrimental effect on voice quality; in particular causing a perception of roughness and breathiness in the voice. This was demonstrated through higher than normal baseline scores for jitter and shimmer for the entire cohort. These objective measurements from the Multidimensional Voice Profile (MDVP) were supported by the subjective Perceptual Voice Profile (PVP) results and also confirmed previous perceptual voice findings for this population.[5, 40] The study cohort did not have difficulty with conversational speech but had difficulty with projecting their voices over background noise and with sustained phonation.

For the MDVP data, threshold figures for normality were used as a yardstick to measure movement towards or away from normal vocal parameters. A significantly greater number of intervention group participants moved towards normal ranges on jitter over the intervention period. On the other parameters, the intervention group figures were either stable or fluctuating. The proportion of control participants within normal limits decreased for most parameters except for the voice turbulence index. The within-subjects measure (percentage change from baseline) indicated that participants in the intervention group showed an overall improvement (decrease from baseline) in all parameters but the voice turbulence index. The control group showed the reverse; an overall increase from baseline in all parameters but the voice turbulence index which improved. This apparent 'improvement' voice turbulence for control participants and 'decline' for intervention participants in is difficult to explain. It is possible that participants in the intervention group were shouting to a degree, in an attempt to increase intensity for vocal projection, and this is why voice quality deteriorated for this group. This explanation is consistent with the intervention group's significant increase in SPL when projecting over background noise.

Several concerns about the use of multi-dimensional acoustic voice analysis have been raised previously concerning test-retest reliability[41] and the usefulness of measuring perturbation for quantifying vocal quality.[42] Kent and colleagues[30] also queried whether any voice be adequately summarized as a table of values or a multi-dimensional graph, and whether normal voice quality can be represented by a normal distribution where means and standard deviations for each parameter are a sufficient normative standard by which clinical problems can be identified. The advantages of the MDVP analysis lie primarily in the rapid, nearly automatic measurement of multiple acoustic parameters for a selected voice sample. Thus, if used with due caution, as one component of a comprehensive voice analysis, multi-parameter acoustic analysis can contribute important information and complement other forms of voice analysis, such as perceptual analysis.

In a large study of voice following traumatic brain injury (TBI), McHenry[43] found the most frequent abnormal values were shimmer, voice turbulence index, and noise-to-harmonics ratio, which are consistent with laryngeal hypofunction. Laryngeal hypofunction and breathiness were the most common types of laryngeal impairment in this TBI cohort. Given the similarities in abnormal voice quality between these two populations (TBI and SCI), it may follow that people with quadriplegia also experience laryngeal impairment to some degree. This notion is supported by MacBean's[5] perceptual analysis of speech post SCI which suggested a pattern of impairment in the physical function of the laryngeal and respiratory subsystems of speech production. As indicated in our results we found no effect of tracheostomy on voice parameters, although our sample size was small for such a comparison.

Overall, the PVP results suggested that participants' voices were within normal limits for pitch and intensity. This supports the acoustic assessment results;[36]; sound pressure level of participants' speaking voices were within normal limits. The deviation from normality in breathiness, strain, and roughness for a third of the overall cohort supports findings from previous perceptual analysis of speech post SCI.[5] It is possible that participants compensated for the lack of respiratory support with increased laryngeal muscular activity. An increase in laryngeal activity could cause a perception of roughness and strain in vocal quality. Such vocal behavior would, in part, explain some participants' experience of excessive vocal effort and worsening of voice quality over the course of the day captured by the Voice Handicap Index (VHI).

The self-perception of vocal impairment as measured by the VHI did not change significantly for either group over the course of the study. Although there were small and medium negative effect sizes for the VHI data, these were calculated on small absolute mean changes and thus the clinical significance of these effect sizes is uncertain. This lack of significant change has two plausible explanations. First, the study was underpowered, thus with a larger sample size different results may have been obtained. Second, the baseline scores on this measure were already relatively low and thus a floor effect may have occurred where there was less room for scores to decrease significantly. The mean total VHI scores in the current study (ranging from 22-27) were all well below the mild category (mean score – 33) presented in Jacobsen et al.'s[35] initial paper. This supports previous research by Nygren-Bonnier and colleagues[20] who found that participants with cervical SCI did not perceive their vocal limitations to be problematic or socially restricting. They found that participants had adapted to and worked within their respiratory and vocal constraints and experienced these as a part of life rather than a problem. Thus, although previous research indicates that people with cervical SCI perceive greater voice difficulties than matched, able-bodied controls,[19] the level of vocal handicap reported in this study was still relatively mild when compared with other clinical populations. For example, Rosen and colleagues[44] reported a total VHI mean score of 73 for participants with functional dysphonia and a mean score of 60 for participants with neurological voice impairments.

Limitations

The primary study limitation is the limited statistical power due to random baseline demographic differences, small participant numbers, and large between-subject variability. In addition, there was a possible floor effect on the VHI assessment, where the baseline scores were already low and thus had less opportunity to decrease significantly. Although the group data are helpful for a general description of the voice impairment, it is important to note that many different MDVP voice profiles were observed within the study cohort. It would be valuable to determine such profiles for a larger group of participants with quadriplegia.

Conclusions

Quadriplegia has a detrimental effect on voice in terms of quality, strength and endurance. In particular, we found a perception of vocal roughness and breathiness. Previously presented results suggested that the singing training had a positive effect on voice projection and phonation length.[36] Voice quality (both objective and subjective measures) and perceived vocal handicap did not change significantly for either group. This may indicate that singing training does not affect these variables for people with quadriplegia or, as discussed previously, it could be a function of the small sample size or a floor effect due to low baseline scores on these measures.

Acknowledgements

This project was supported by the Victorian Neurotrauma Initiative. The authors also wish to acknowledge the technical assistance of Darren Tardio (Acoustic Engineer).

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