The Effect of Singing Training on Voice Quality for People With Quadriplegia

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Summary: Objectives. Despite anecdotal reports of voice impairment in quadriplegia, the exact nature of these impairments is not well described in the literature. This article 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 postintervention. These deidentified 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.

Key Words: 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 motorized-wheelchair users, which may be caused by difficulty organizing 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 pattern 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 postinjury 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

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treat speech and voice dysfunction after 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 article describes in detail the voice quality outcomes that form a subset of a larger study of the effect of 12 weeks of singing training on respiratory function, voice, and mood.[25] The full methods are published elsewhere,[25] 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[26] 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 three to four 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).[27] Assessments were conducted pre, mid, post, and 6-months after the 12-week intervention period.

English-speaking participants at least 1 year after SCI who were in good health and able to travel were recruited from the Victorian Spinal Cord Service (Victoria, Australia). Exclusion criteria included a preexisting history of speech disorder, respiratory disease, psychiatric disorder, or neurologic 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 soundproof room to ensure minimal external noise interference. An Ono Sokki MI-1211 Type 1 omni-directional condenser microphone (Ono Sokki Technology Inc., Yokohama, Japan) was positioned at a distance of 30 cm from the mouth of each participant. All data were collected at 16-bit resolution and 44.1 kHz sampling rates through a Fireface 400 data acquisition interface (RME, Haimhausen, Germany) and *Wavelab* software platform (Steinberg, Hamburg, Germany). Real-time analysis was conducted simultaneously using the Ono Sokki 5570 and an *EASERA* software analyser (Software Design Ahnert GmbH, Berlin, Germany). Before each participant recording, the instrumentation chain was calibrated in a Bruel & Kjaer 4230 calibrator (Brüel & Kjær Sound & Vibration Measurement A/S, Nærum, Denmark) with a 94 dB tone at 1 kHz.

Each participant was directed through a sequence of phonatory exercises including sustained vowels (at normal, soft, and loud intensities), the "Rainbow Passage"[28] with and without background noise and reading and then singing the lyrics to a well-known song (Happy Birthday). 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 (PVP)[29] and objectively using computer analysis (*Multidimensional Voice Profile* [*MDVP*]; KayPENTAX, Montvale, NJ).

Acoustic analysis

The *MDVP* was chosen as a commonly used, robust, and accurate software tool for quantitative acoustic assessment of voice quality.[30] 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.[31] 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.[32] 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.[33] Inter- and intrarater reliability of perceptual assessments reported in the literature fluctuate significantly[34] and normative, reliability, and validity data for perceptual assessments are rare.[35]

Perceptual analysis

The PVP is a subjective rating of voice quality, pitch, and intensity by a trained listener.[29] The PVP is a valid and reliable scale for rating dimensions of voice.[36] 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,