Impact of Abnormal Acoustic Properties on the Perceived Quality of Electrolaryngeal Speech

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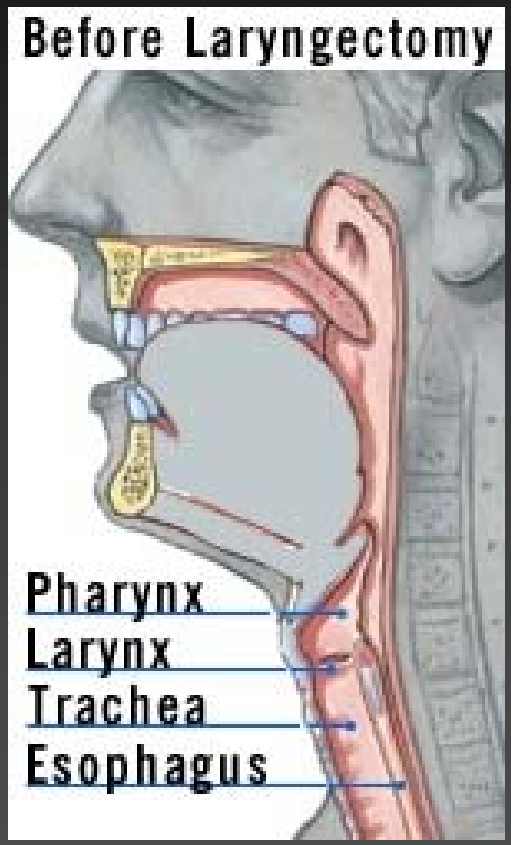
Outline of Talk

- The Electrolarynx (EL) and EL speech
  - Deficiencies of EL speech
- Perceptual Experiments
  - Methods
  - Analysis
  - Interpretation
- Summary and future work.

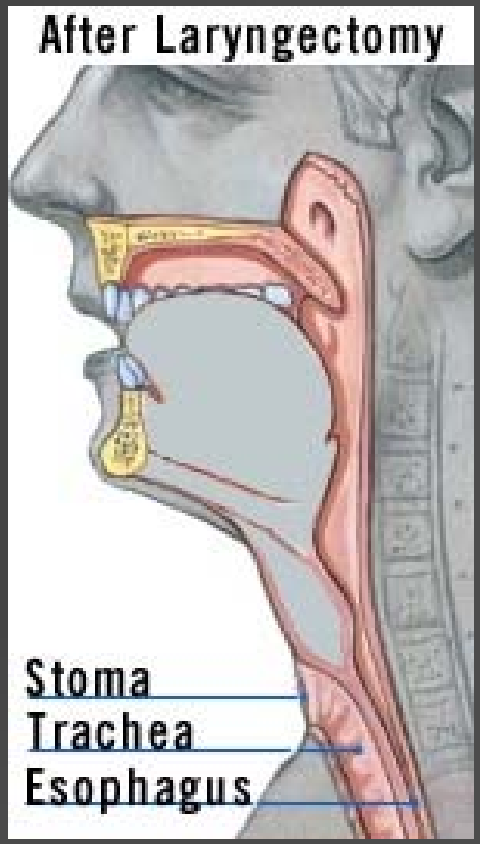
The need for Electrolaryngeal (EL) Speech

- Each year thousands of people in the US alone undergo laryngectomy surgery to treat laryngeal cancer.
- These people need to rely on an alternative means of communication: alaryngeal speech
- Most common form of alaryngeal speech is EL speech (Hillman *et al*.1998).

The Laryngectomy



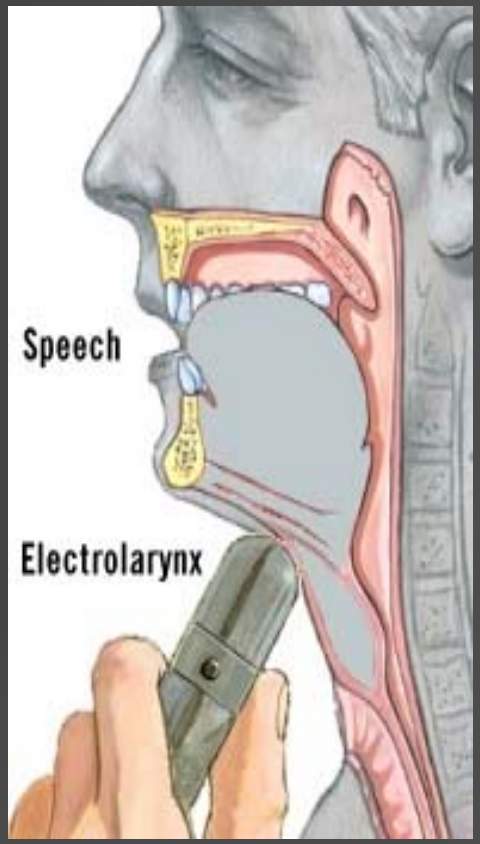
- The larynx and surrounding structures are removed
- Trachea is sewn into the neck to make breathing hole (stoma).
- Vocal tract decoupled from lower airway
- Articulators remain intact



Figures taken from http://www.inhealth.com/

How is an Electrolarynx used?

- User holds device against the neck (or just under the chin)
- Vibrations are transmitted through the neck wall into the vocal tract.
- User articulates normally



Graphic taken from http://www.inhealth.co

Inadequacies of EL Speech

- Artificial, mechanical quality
  - often draws unwanted attention to EL user
- Reduced loudness (relative to normal speech), especially in noisy environments
- Reduced intelligibility
  - Confusion between voiced and unvoiced consonants (Weiss *et al.*1979; Weiss & Basili 1985)
  - Vowel intelligibility ~ 80 % (Weiss & Basili 1985)

Reasons for poor EL speech quality

- Improper source spectrum. (Qi and Weinberg 1991, Weiss *et al.*1979)
- Interference of directly radiated sound
- Lack of fine control over pitch, amplitude and voice on/offset.
- Others?
  - e.g. distortions introduced to the vocal tract transfer function

Attempts at Improving EL Speech

- Source
  - Qi & Weinberg (1991): attempted to reduce the “low frequency deficit” in EL speech.
  - Ma (1999): replaced EL excitation signal with normal excitation signal
- Direct noise
  - Verdolini *et al.* (1979): amplified signal at lips to increase “SNR”
  - Cole *et al.*(1997): used a combination of noise reduction techniques to remove direct noise
  - Espy-Wilson *et al.* (1998): used adaptive filtering to reduce the directly radiated noise
- Pitch Control
  - Uemi *et al.* (1994) used air pressure from stoma to control the fundamental frequency of EL

Motivation for research

- Previous studies all reported some improvement, but:
  - All were done in isolation
  - No indication of their relative improvements
  - No measure of how much closer improved speech is to normal speech.

Research Goals

- Determine the relative contributions of the properties of EL speech to its artificial quality.
  - (Perceptual Experiments)

Perceptual Experiments

- **Goals:**
  - Establish the relative contributions of different EL speech properties to its unnatural quality.
- **Experimental Procedure:**
  - Create different enhanced versions of EL speech to be compared against each other.
  - Method of Paired Comparisons and Law of Comparative Judgment
    - Establish a ranking for differently enhanced versions of EL speech and normal speech based on how normal they are perceived to be.
  - Visual Analog Scale (VAS)
    - Listeners rate each speech token based on how they differ from normal natural speech

Perceptual Experiments - Methods

- **Experimental Procedure details:**
  - Two speakers (normal male and female)
  - Generate 10 speech tokens per sentence
    - One sentence consisting of all voiced phonemes
      - We were away a year ago where I wore Rollerblades.
    - One sentence with voiced and unvoiced phonemes
      - She tried the cap and fleece so she could pet the puck.
    - Spoken using normal voice and Servox EL
      - Subjects held breaths while using Servox
    - Three enhancements added to EL speech:
      - Low frequency enhancement (L)
      - Removal of direct noise (N)
      - Added pitch modulation (P)
    - Normal speech made monotonous.

Perceptual Experiments - Methods

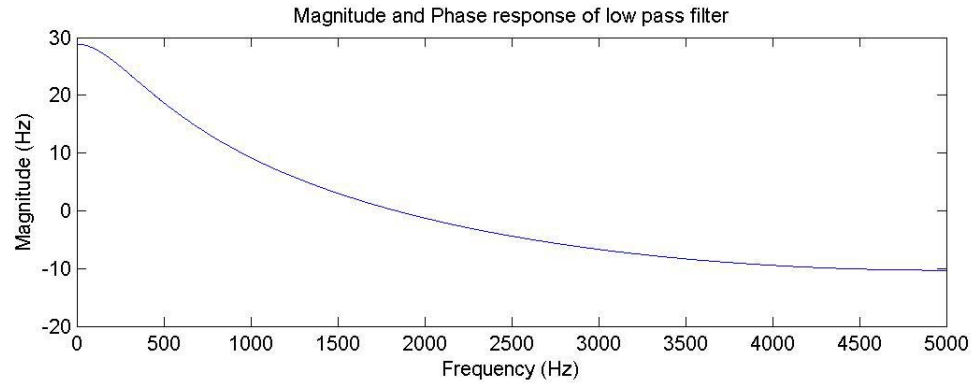
- **<u>Experimental Procedure details (cont):</u>**
  - Speech Tokens to be generated
    - (1) Raw EL Speech
    - (2) EL-L, (3) EL-P, (4) EL-N
    - (5) EL-LP, (6) EL-LN, (7) EL-NP
    - (8) EL-LNP
    - (9) Monotonous normal speech
    - (10) Normal speech

      - L – (Low frequency enhancement)
      - N – (Removal of direct noise)
      - P – (Added pitch modulation)

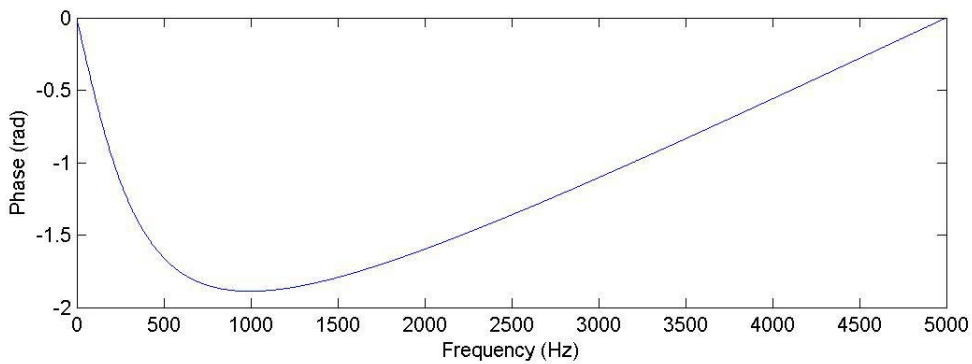
Implementing Enhancements - L

- Low frequency (L):
  - low pass filter speech as in Qi and Weinberg (1991)

$$H(z) = \frac{1}{\left[1 - az^{-1}\right]^2}$$



Before



After

Implementing Enhancements: The “Door”

- Remove direct noise (N):

- Before After

Implementing Enhancements - P

- Added pitch modulation (P):
  - Pitch contour extracted from normal speech and used to modulate EL speech using MELP vocoder
    - Before After
  - Shift monotone EL pitch
  - Flatten pitch contour in normal speech to make monotonous
    - Before After

MELP

- **M**ixed **E**xcitation **L**inear **P**redictive Vocoder
- Based on US Federal standard at 2.4 kbs
  - Modified to make it more perceptually invisible
- Allows for pitch modification without affecting speech quality

Perceptual Experiments

- Example of experimental sentences:
  - Normal
  - Normal – mono
  - EL-LNP
  - EL-NP
  - EL-LP
  - EL-LN
  - EL-P
  - EL-N
  - EL-L
  - EL-raw

Perceptual Experiments

- **Experimental Procedure details (cont):**
  - 45 total pairs presented
  - Pairs presented twice to establish intra-subject reliability
  - Repeated for each speaker/sentence condition
  - Prior to presentation of pairs:
    - The normal speech token presented as a standard.
    - All sentences presented to listener one by one.

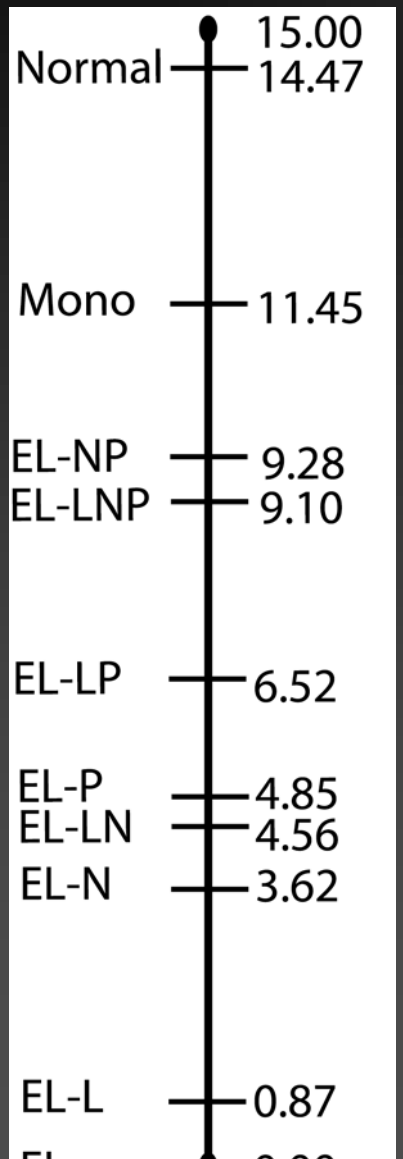
Perceptual Experiments - Analysis

- Law of Comparative Judgment
  - Compute the proportion of times each stimulus is judged "better" than the other stimuli
  - Convert proportions to scale vales on a psychological continuum

Perceptual Experiments – Analysis (cont.)

- Visual Analog Scale
  - The distance from the end of the VAS marked “Not at all different” used as estimate of how different speech token is from normal natural speech.
  - Mean and standard deviation of distances were computed
  - ANOVAs followed by post-hoc Bonferroni corrected *t*-tests were computed to test for significant differences

Perceptual Experiments: Ranking Results

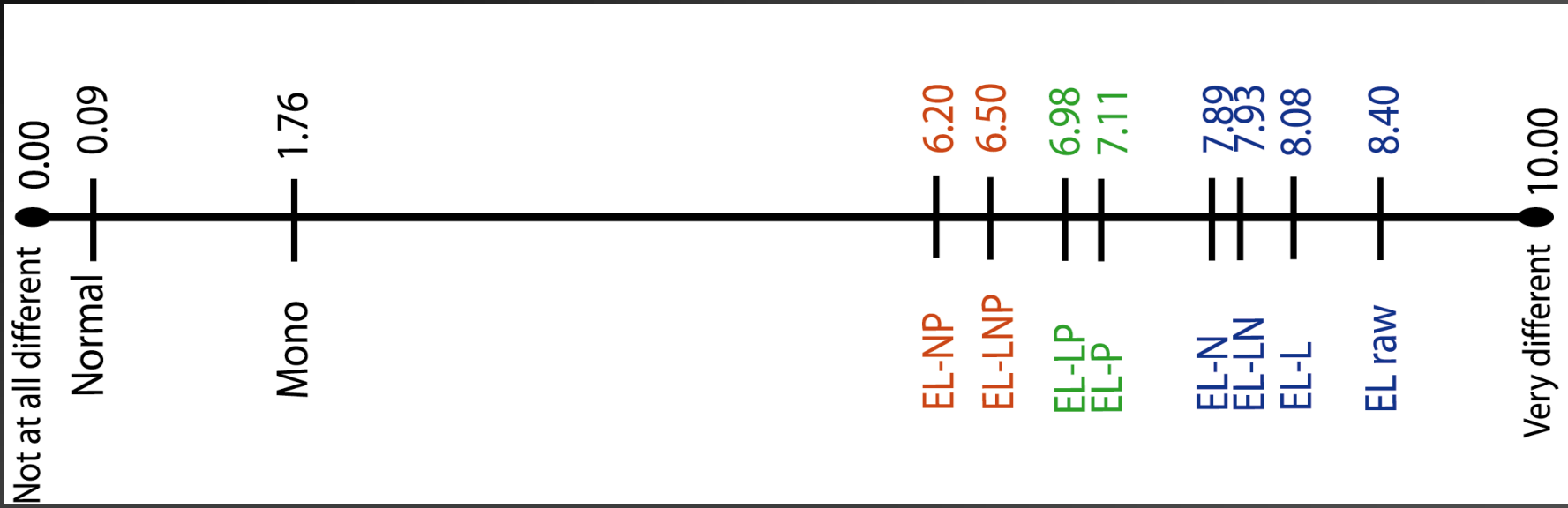


- Monotonous normal speech is the most normal (other than normal speech).
- EL-NP and EL-LNP are the most natural sounding versions of EL speech.
- Much can be done to improve EL-LN speech to make it equal to monotonous normal speech.

Perceptual Experiments: Ranking Results

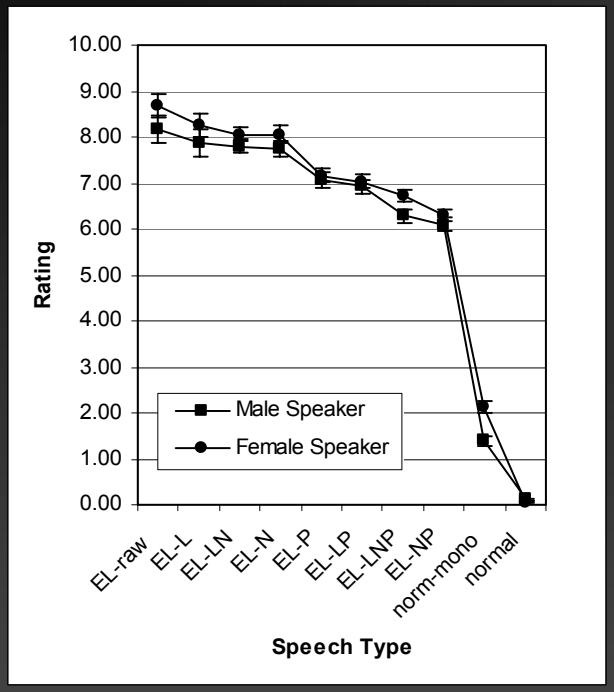
- Listener reliability was found to be 88.3 ± 8.9%
- Rankings of male and female sentences were similar
  - Ranking of EL-LN and EL-P were reversed
- Rankings of EL versions of voiced/voiceless sentence (Sen. 2) were consistently lower than those of their all-voiced counterparts

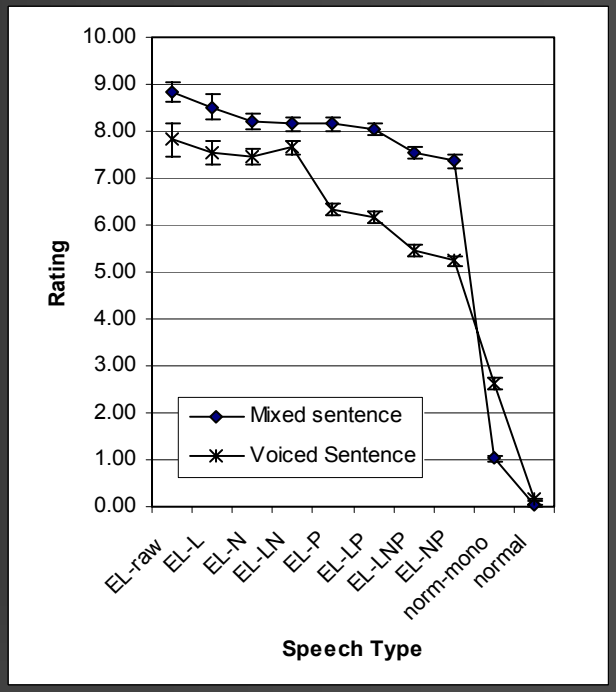
Perceptual Experiments: VAS Results



- Rank order similar to paired-comparison data
  - EL-N and EL-LN are reversed
- EL-NP and EL-LNP are again the best versions of EL speech
- Large gap between normal-mono speech and all EL speech versions
- Ratings of 4 highest rated speech types not significantly different from each other

Perceptual Experiments: VAS Results





- Little difference between ratings of male and femal speakers
- Ratings of voiced/voiceless sentences significantly higher than those of all-voiced sentences

Perceptual Experiments: Summary

- EL-NP and EL-LNP are the most natural sounding versions of EL speech
- Normal-monotonous speech was found to be more natural than any version of EL speech.
  - VAS results indicate a large gap between normal-monotonous and best rated EL speech
- Enhancements not as effective for voiced/voiceless sentences

Perceptual Experiments: Interpretation

- While pitch is important, large improvements can be accomplished without it.
- There are problems with EL speech other than pitch, low frequency deficit and direct noise corruption.
  - Source is still incorrect.
  - Vocal tract transfer function is distorted.

Future Work:

- Look for other potential abnormal properties of EL speech
  - Distortions of vocal tract acoustics
  - EL source has no noise component to it
- Improve EL speech based on findings
  - Develop EL speech enhancement scheme