Use of a Telehealth Platform to Automatically Assess Prosodic Contours in Parkinson Disease

Andrew H. Exner[1], Vikram Ramanarayanan[2], David Pautler[2], Sandy Snyder[1], Hardik Kothare[2], Jackson Liscombe[2], Oliver Roesler[2], William Burke[2], Michael Neumann[2], David Suendermann-Oeft[2], & Jessica E. Huber[1]

PURDUE UNIVERSITY
MOTOR SPEECH LAB

[1]Purdue University, [2]Modality.AI

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Relevant Disclosures

- Financial Disclosures
  - Modality.AI, Inc., Salary & Shares
    - Vikram Ramanarayanan – Chief Scientific Officer
    - David Pautler – Founder, Chief Technology Officer
    - Hardik Kothare – Research Scientist
    - Jackson Liscombe – Research Scientist
    - Oliver Roesler – Research Scientist
    - William Burke – Director
    - Michael Neumann – Research Scientist
    - David Suendermann-Oeft – Founder, Chief Executive Officer
  - Purdue University, Salary
    - Andrew Exner – doctoral student, trainee on NIH T32 grant
    - Sandy Snyder – Research Associate
    - Jessica Huber – Professor
- Non-Financial Disclosures
  - Jessica Huber – Medical advisory board for Rock Steady Boxing

Parkinson Disease

- Neurodegenerative disorder primarily affecting motor system
  - Motor, cognitive, and sensory
- Speech: Hypokinetic Dysarthria
  - Hypophonia
  - Variable rate
  - Breathiness
  - Monopitch
  - Monoloudness
  - Imprecise consonants
  - Decreased intelligibility

Hypokinetic Dysarthria: Prosody

- Hypokinetic prosody abnormalities include
  - Reduced f_0 range and variability (monopitch)
  - Reduced ability to use prosody for emotional expression
  - Not everything is impaired
    - Lexical stress is spared
    - Need: what is impaired vs what is not and why?
    - i.e., is sentence mode differentiation impaired?

Rationale

- Needs
  - Accessibility of care by people with PD
  - Need for monitoring of dynamic symptoms
  - Burden of technical assessment and measurement
- Solution
  - Conversational artificial intelligence agent
  - Automatic computation and delivery of relevant patient data
- Features
  - Automated, customizable assessment
  - Convenient time
  - Home environment
  - Minimal technological requirements
  - Automatic computation of speech acoustic metrics, facial kinematic metrics, and limb motor function
  - User-friendly dashboard for healthcare providers
  - Symptom tracking over time

Aims and Hypotheses

- Compare automatic measures produced by the Modality system with default Praat settings and data extraction algorithms to human-generated measurements calculated by members of the Purdue Motor Speech Lab in order ascertain the feasibility and reliability of automated analytics for assessing the prosody of people with PD.

- **Hypothesis**: There will be no significant differences between the automated f_0 measures generated through default Praat settings and those made by human researchers.

Methods: Participants

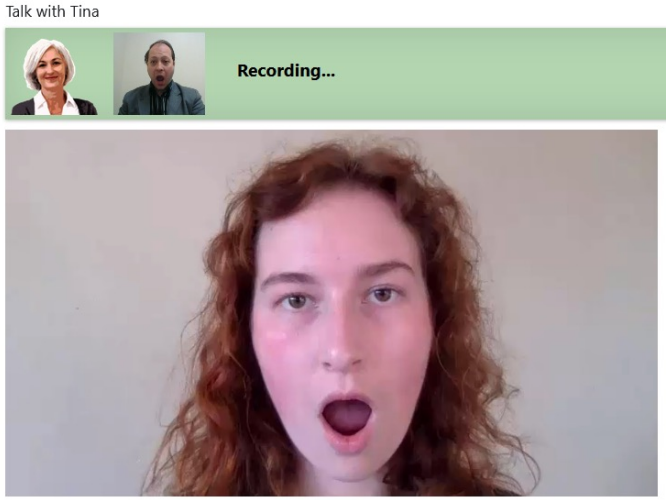
- *n* = 40 people with PD; 23 age- and sex-matched controls
- Inclusion criteria:
  - Age 30-85
  - Dx idiopathic PD
  - Internet access
  - Device w/ microphone & camera
  - Self-reported adequate hearing and vision
  - Fluency in English
- Exclusion criteria:
  - Dx neurological disease other than PD
  - Hx HNC cancer or surgery (except for implantation of DBS)
  - Hx voice disorder or pulmonary disease
  - Recent Hx smoking (<5 years)
  - More than moderate cognitive impairment <10 on MoCA)

Methods: Initial Visit

- WebEx meeting with lab staff member
  - Discuss Study
  - Obtain Consent
  - Obtain Medical History
  - Complete Montreal Cognitive Assessment
  - Orientation to System Access
  - Receive individualized link to complete online assessments

Methods: Conversations with Tina

- Number of Assessments: 4
- Frequency of Assessments: 1/week
  - Median 8 days, Mean 10 days
- Timing: When convenient for participants, on-state of PD medication
- All tasks completed each session
- Total Duration: 15-20 minutes



- Speech Tasks
  - Sustained vowels
  - Sentence Intelligibility Test (SIT)
  - Reading 1 paragraph of Rainbow Passage
  - Short narrative
  - **Intonational prosody**
  - Monologue
- Non-Speech Tasks
  - Abbreviated oral mechanism exam
  - Finger tapping
- Surveys
  - Parkinson Disease Questionnaire (PDQ-39)
  - Communication Participation Bank, Short (CPIB-S)
  - Task Load Index (TLX)

Methods: Intonational Prosody Task

- Participants presented with a short scenario and asked to say the sentence provided.
  - Five pairs of sentences (three words each)
  - Same except for the prosodic falling or rising contour cued by different scenarios
- Examples

- Tina: “You just got back from holidays in Florida. Jane asks if the weather was nice. Now you say…”
- Target: “It was hot.” *(Statement)*

- Tina: “Jane says her vacation to Alaska was too hot. Now you say…”
- Target: “It was hot?” *(Question)*

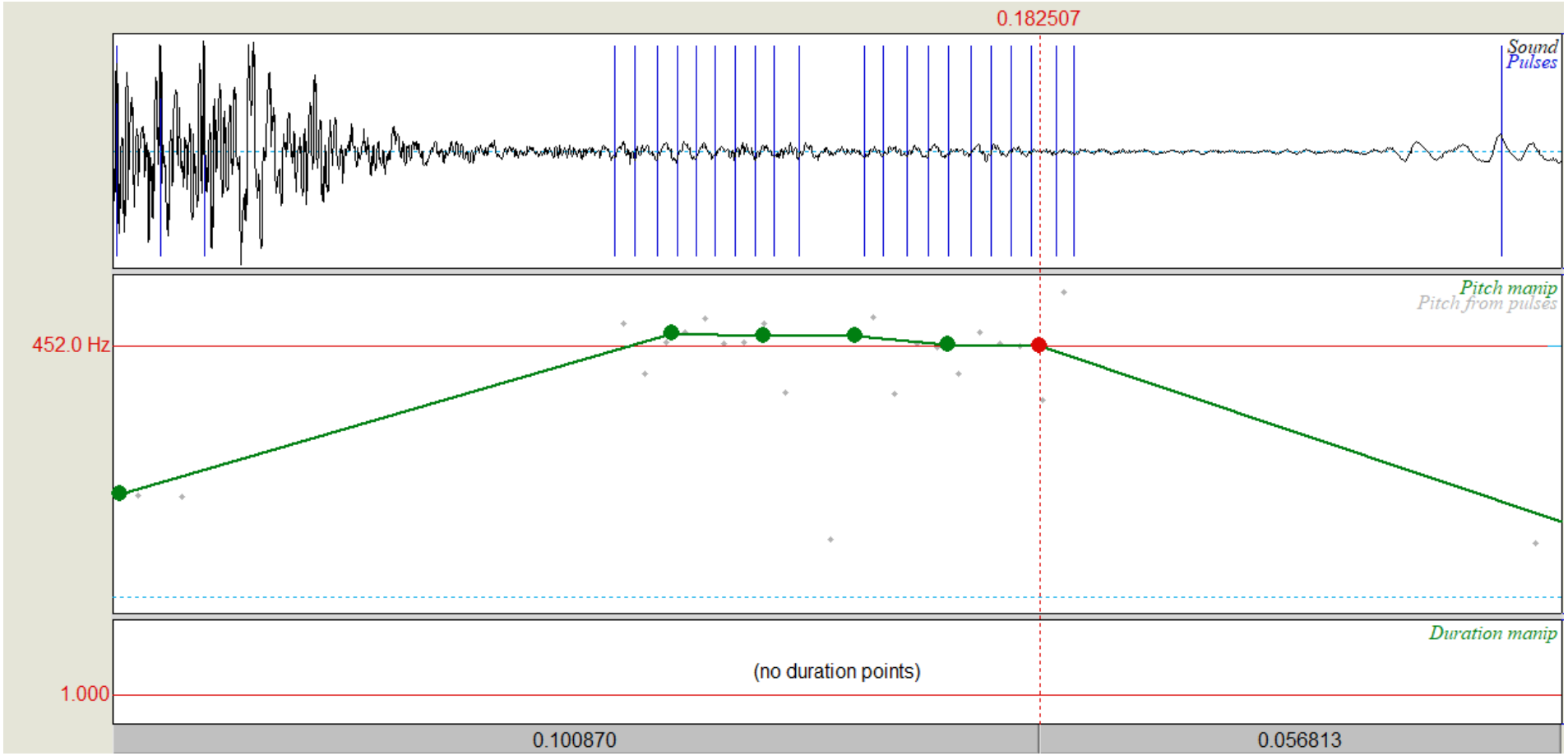
Methods: Measurements

- **Key measurements of intonational contour direction and variability**
  - Minimum f_0 (Hz)
  - Maximum f_0 (Hz)
  - Standard deviation of f_0 (Hz)
  - Range of f_0 (maximum - minimum f_0) (Hz)
- Human-Corrected Measurements: standard Praat settings to assess pitch points within the Manipulation file
  - Deleting pitch points during voiceless segments
  - Adding pitch points not identified by Praat (e.g., rapid pitch changes, occurring above/below Praat's default)
  - Correcting pitch points during diplophonia
- Modality.AI system (1): automatic extraction of the same f_0 values using Praat's default settings
  - No alteration of the default pitch contour extracted
- Modality.AI system (2): optimized f_0 extraction with optimized parameters based on subset of data

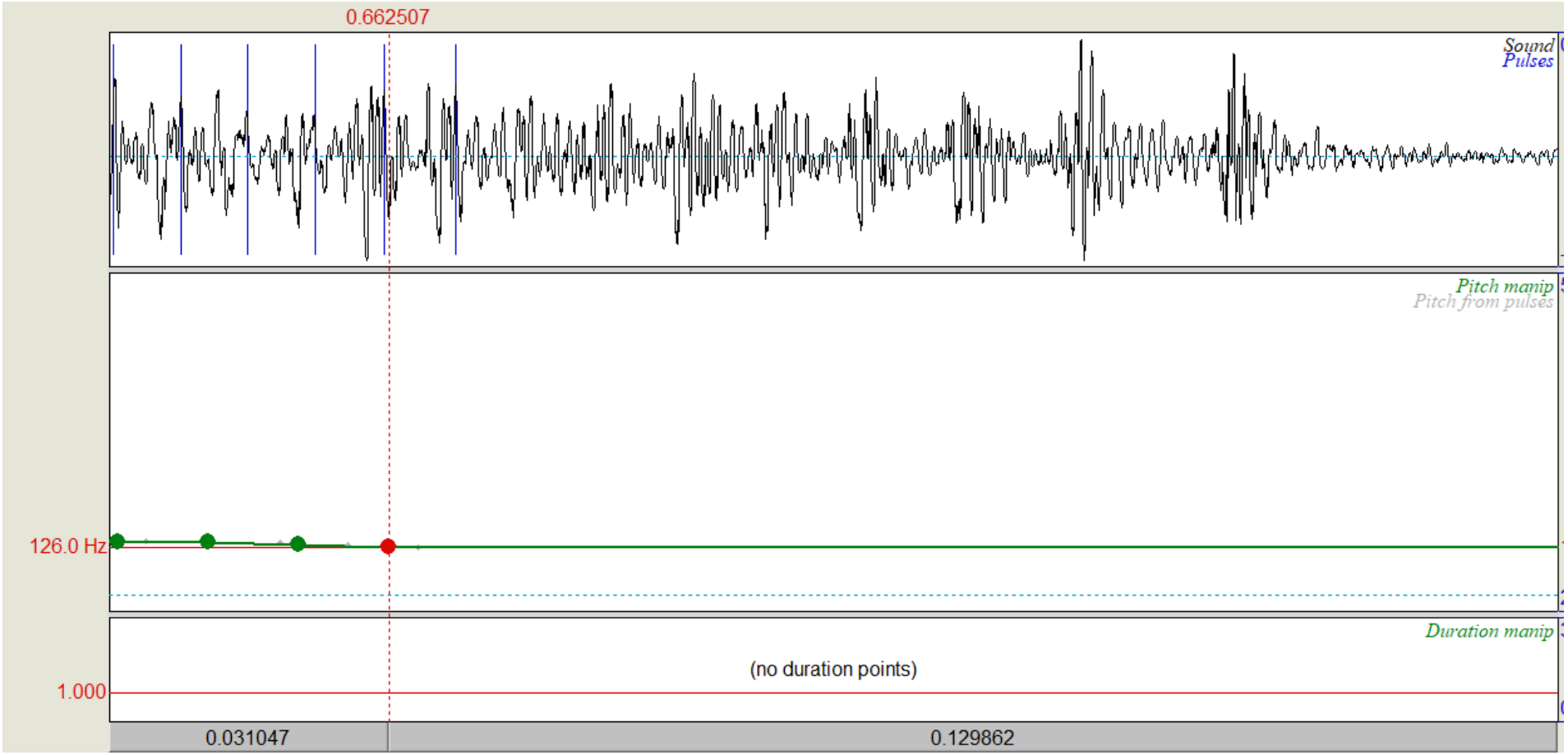
Methods: Pitch Correction

- High prevalence of aperiodic voicing, periodic vocal fry, and diplophonia
  - Of 788 utterances, 486 (61.7%) contained aperiodic voicing
  - Of these, the mean percentage of aperiodic voicing per utterance was 13.3% (± 9.2 % SD)

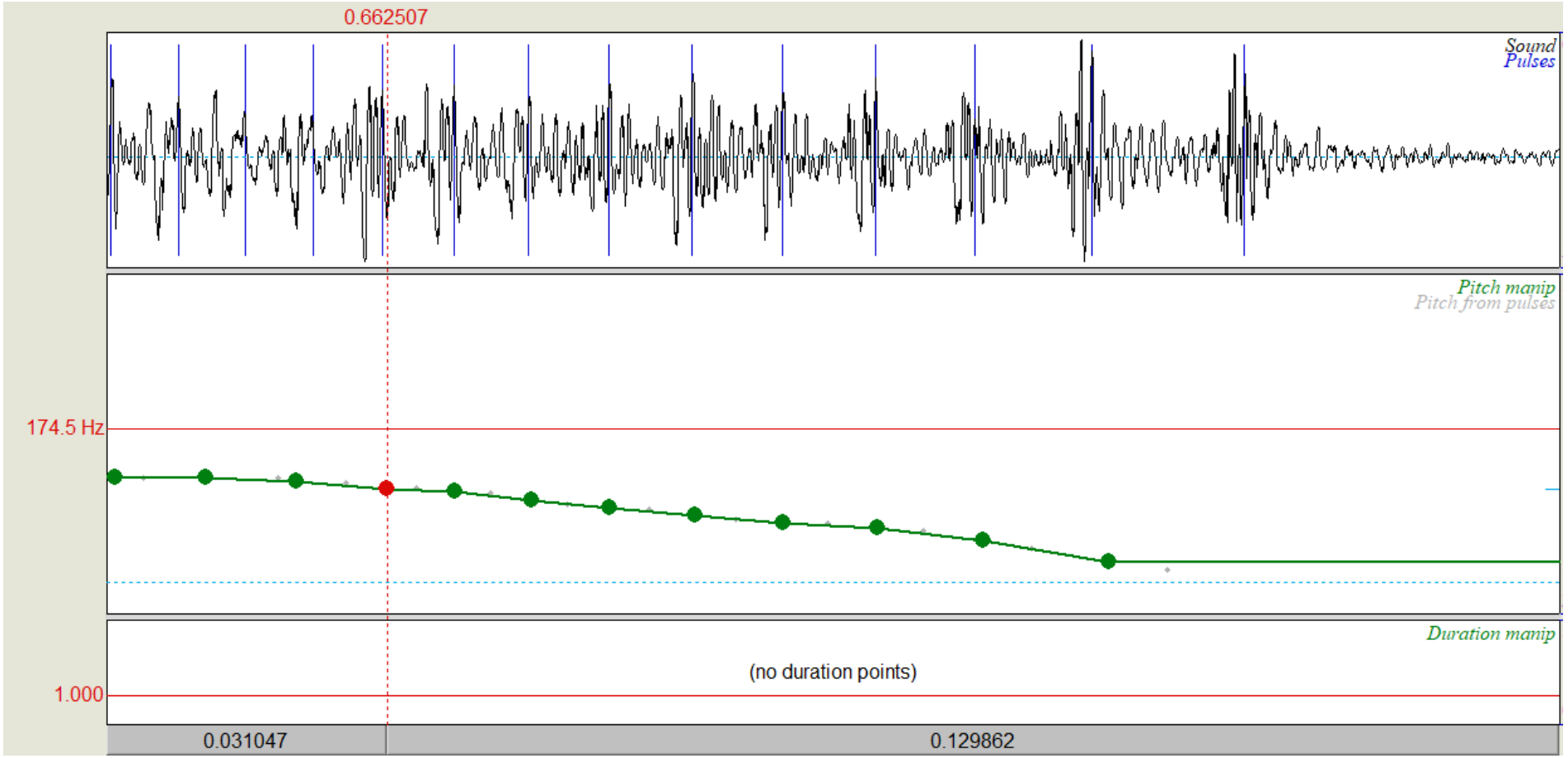
Example: Noise marked with pitch periods during a /t/



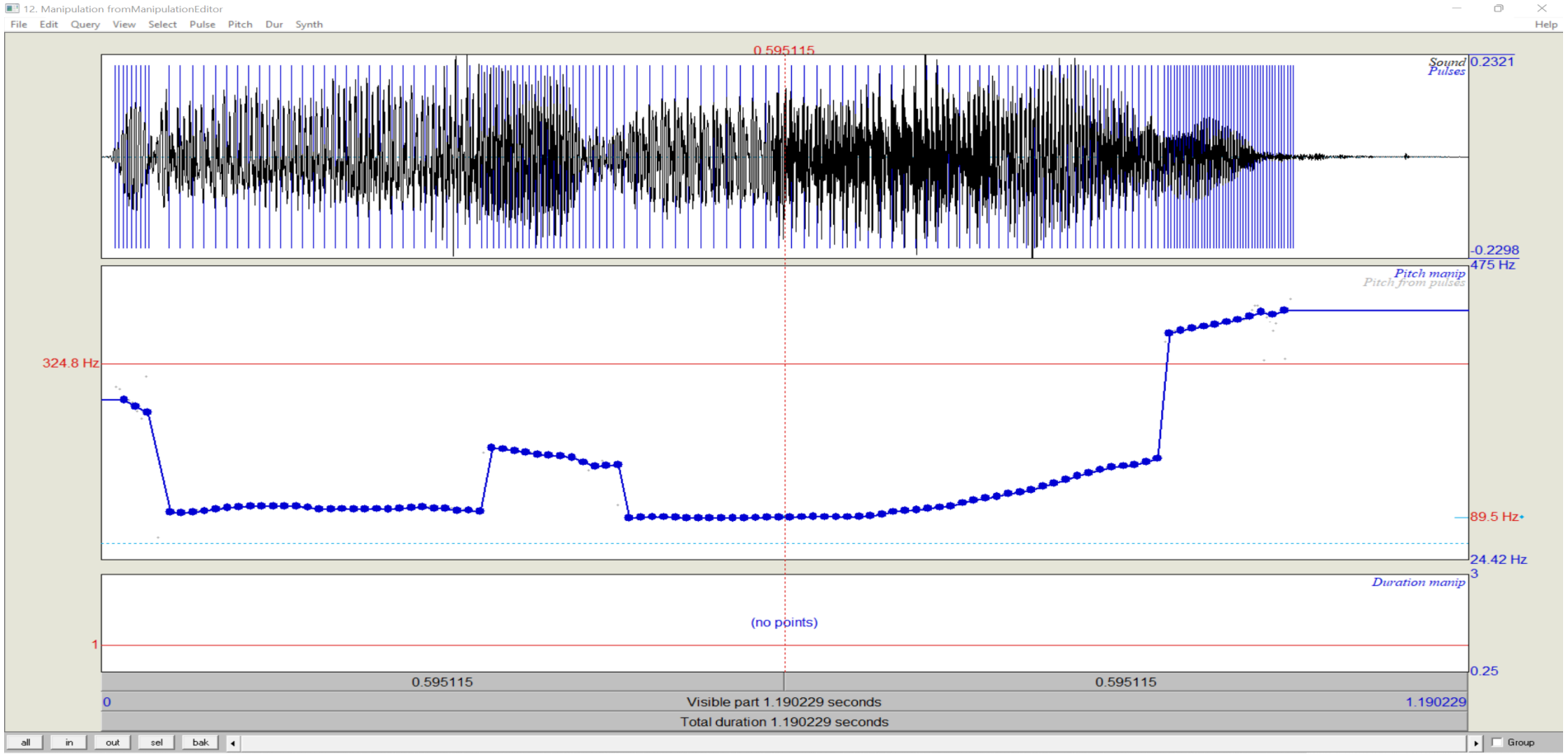
Example: No f_0 marked during falling vocalization



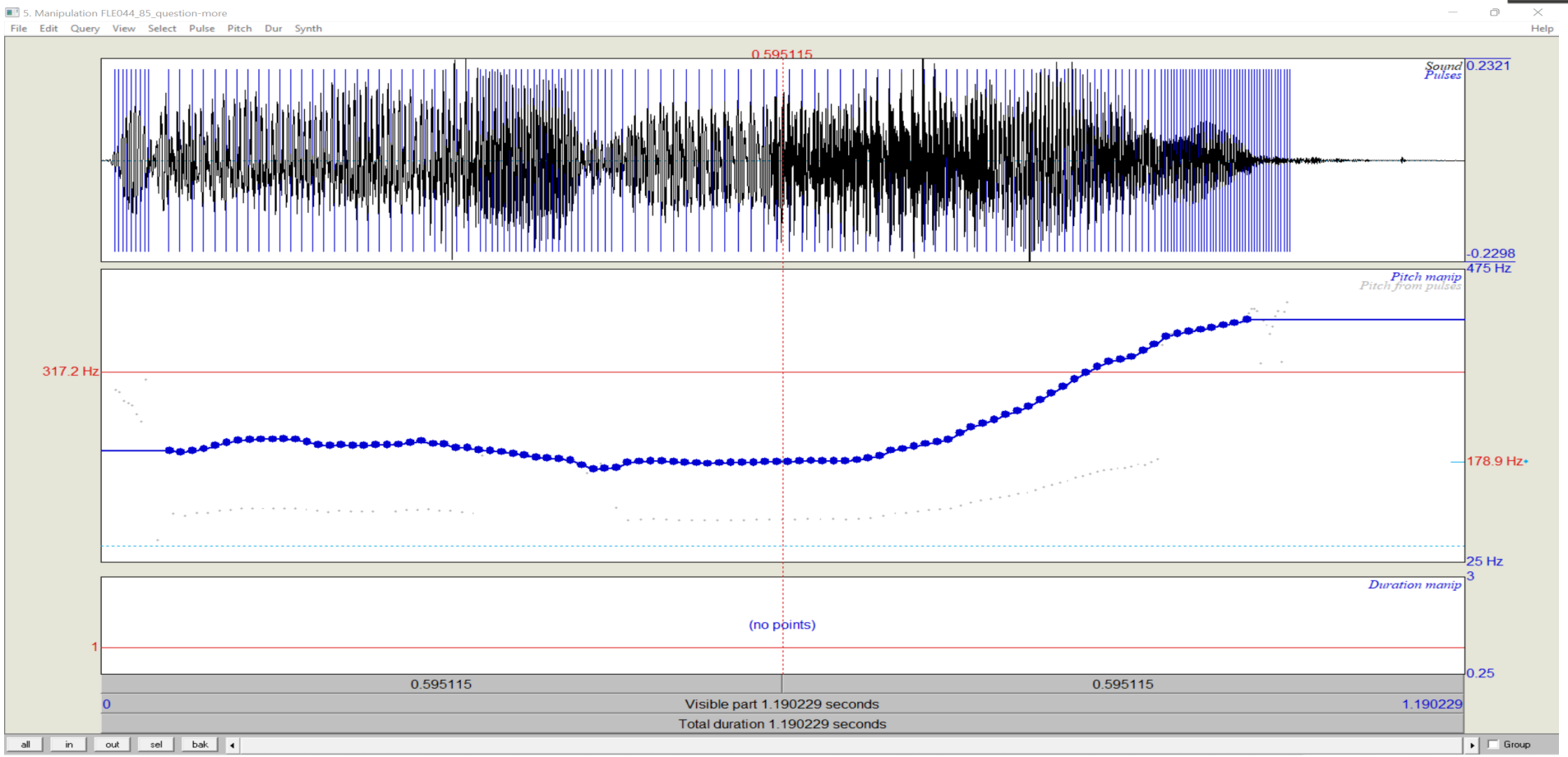
Example: Correction of falling contour



Example: Roughness/Fry (Female) (Original)



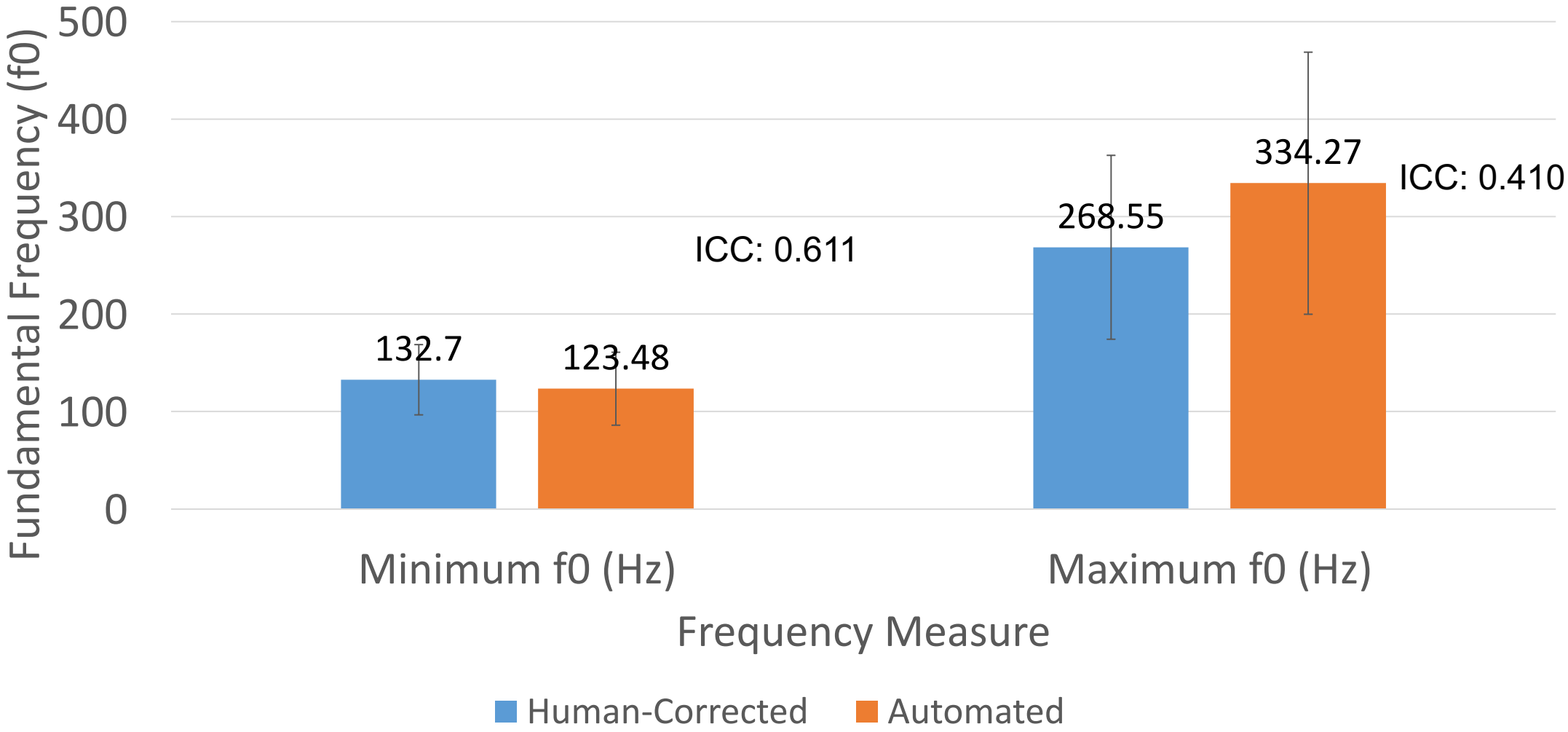
Example: Roughness/Fry (Female) (Corrected)



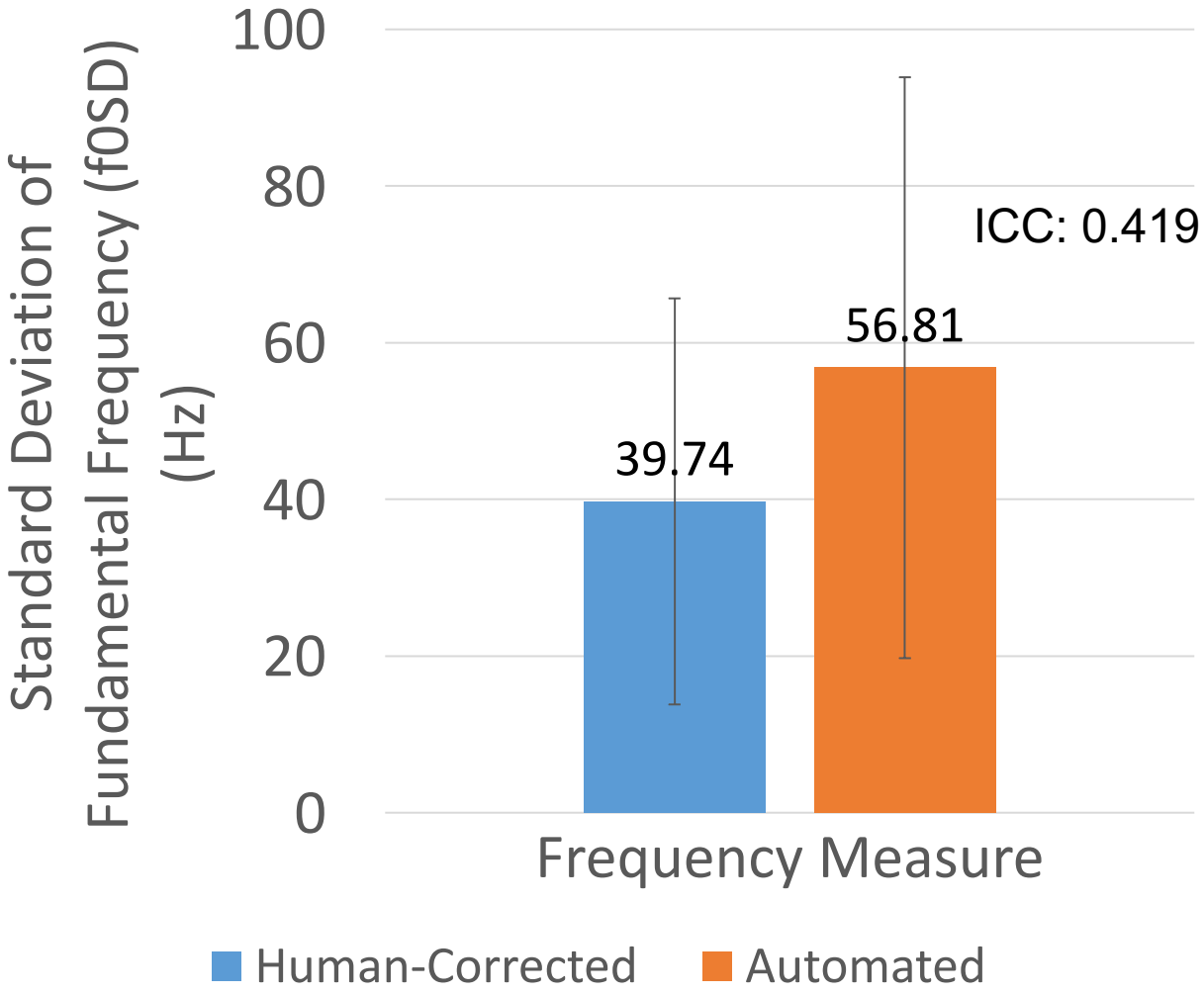
Methods: Statistical Analysis

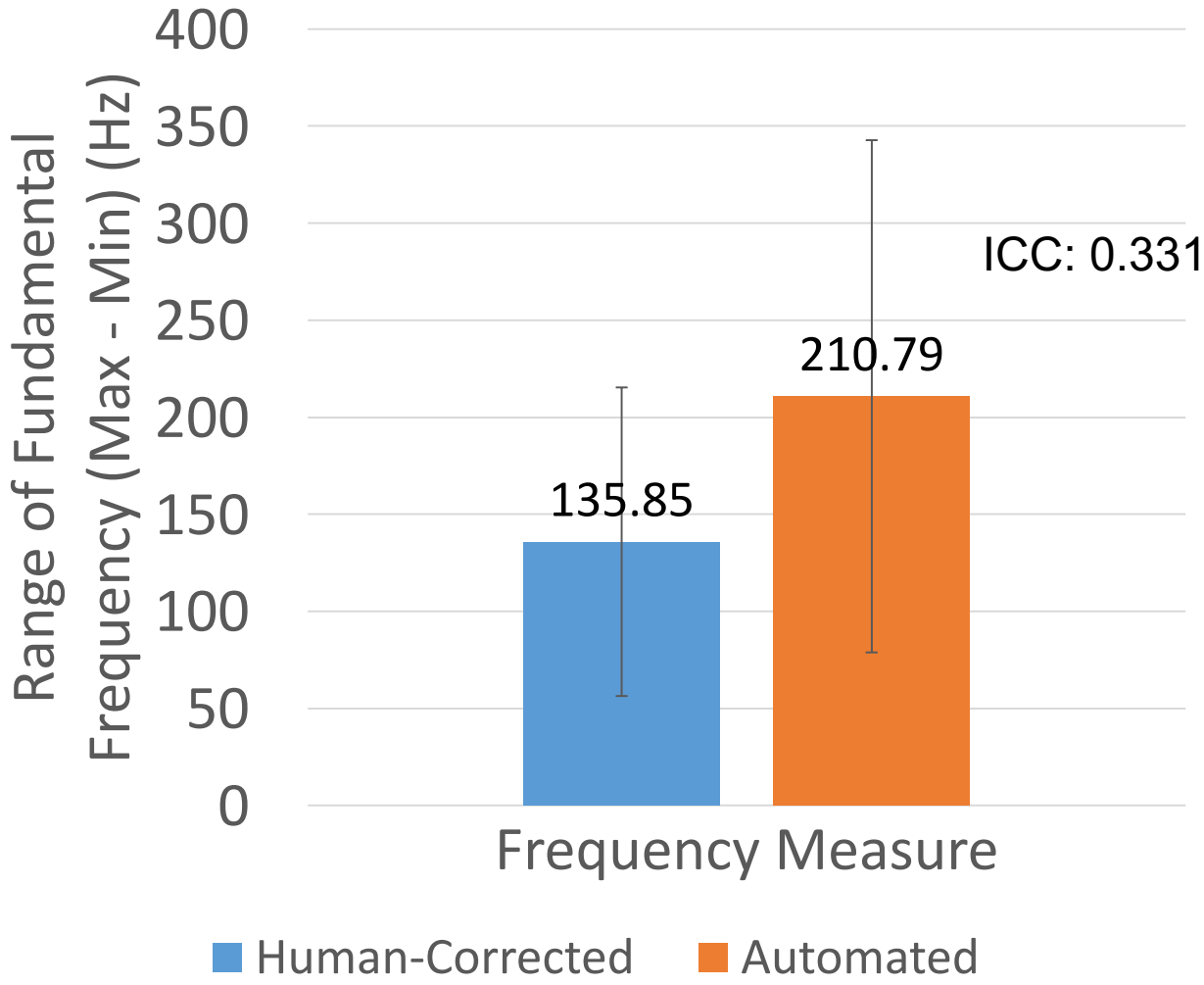
- To determine whether the automated measurements differed significantly from the clinician-researcher measurements
  - ICC estimates and their 95% confidence intervals were calculated
  - Excel
  - Single-rating, absolute-agreement, two-way random-effects model with one rater across all subjects

Results: Means and Standard Deviations of Fundamental Frequency Measures in a Prosody-Specific Speech Task, Human-Corrected vs Unoptimized Automated (*n* = 40 PD, 23 controls)

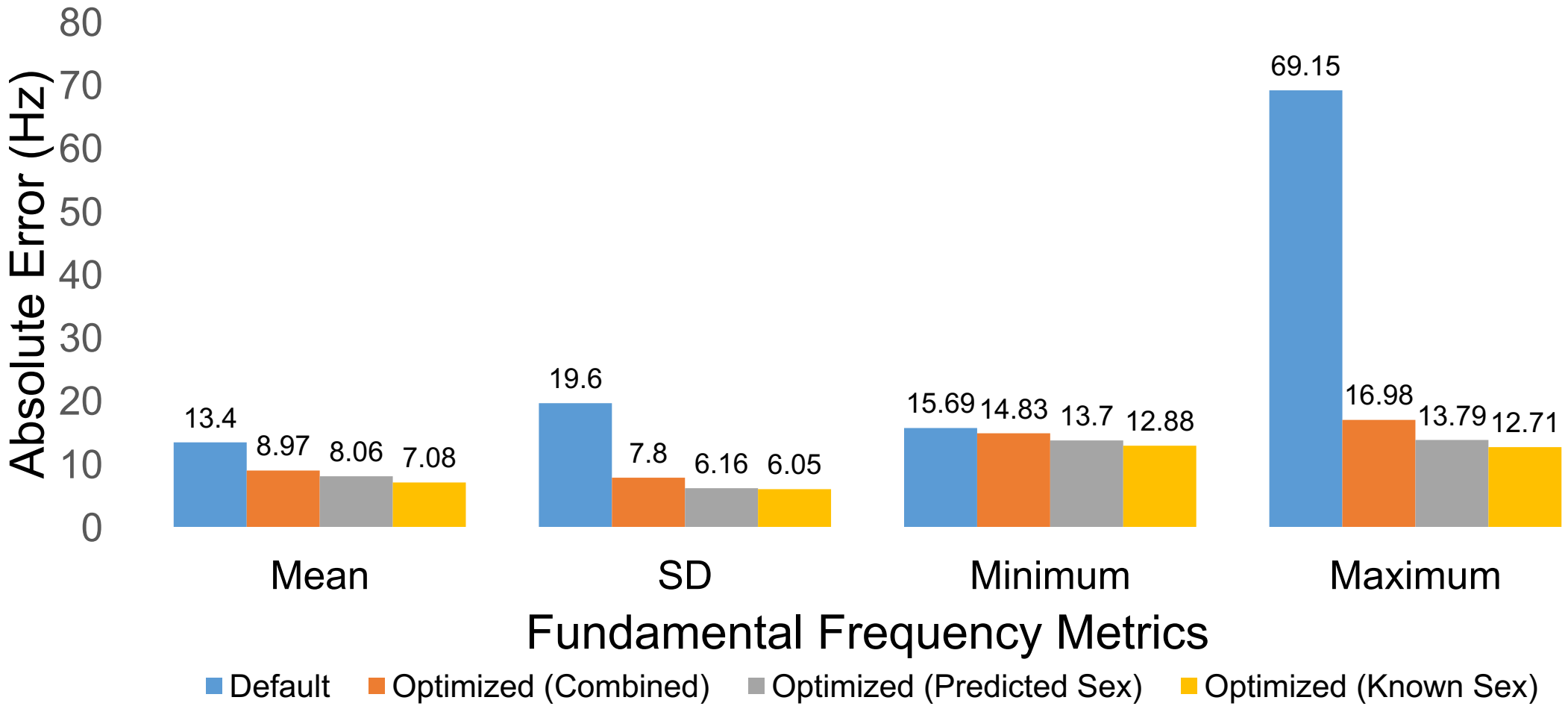


Results: Means and Standard Deviations of Fundamental Frequency Variation in a Prosody-Specific Speech Task, Human-Corrected vs Unoptimized Automated (*n* = 40 PD, 23 controls)





Results: Mean Absolute Errors of Fundamental Frequency Metrics



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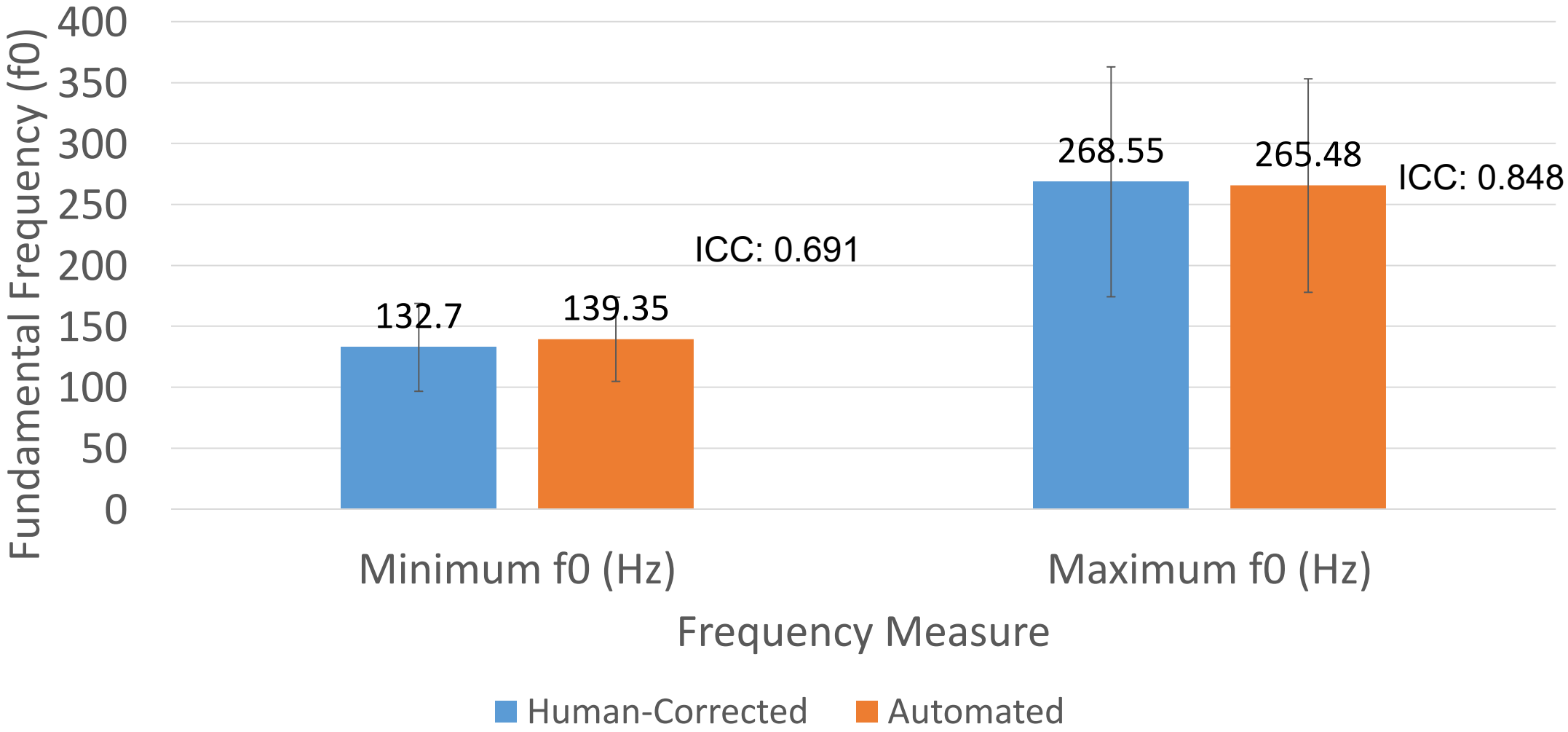

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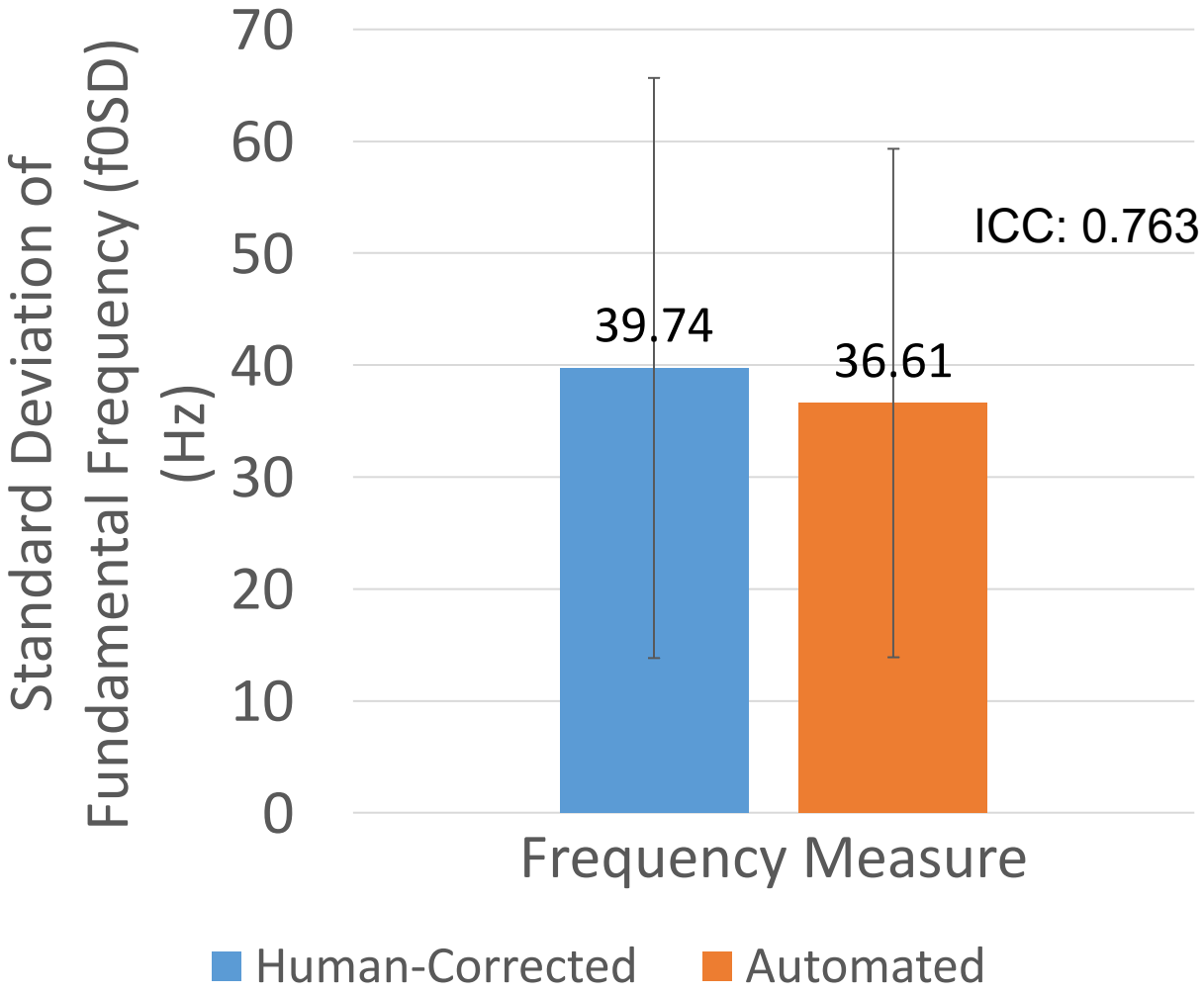

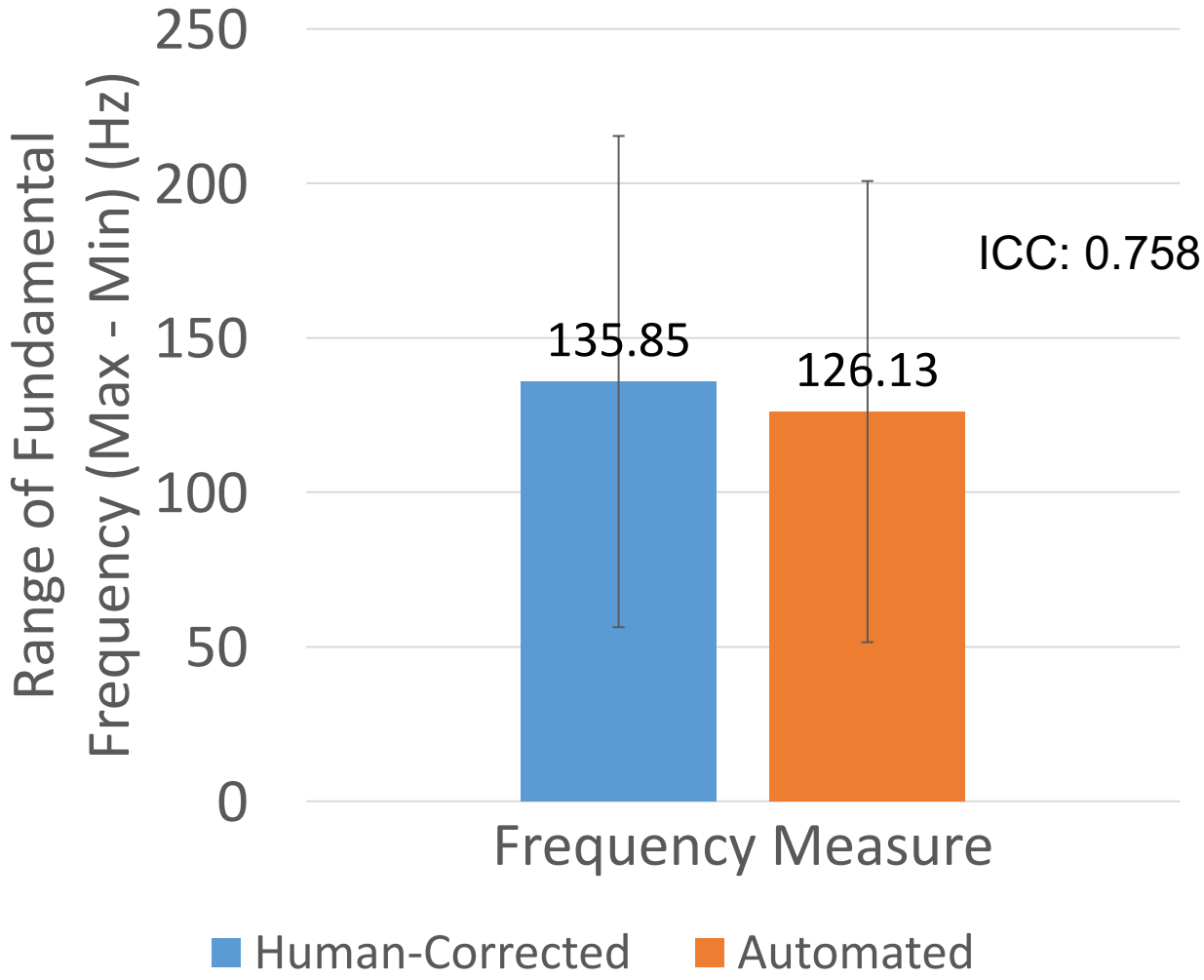

Discussion: Reliability of Prosodic Measures

- Initial substantial differences in human-corrected and automated measures of all 4 f_0 measures
  - Minimum f_0 differences were small, likely of little to no clinical significance
  - Other differences were larger and likely of clinical significance
- Following optimization, differences are significantly reduced
- Remaining Issues to be Addressed
  - How to detect and correct prevalent aperiodic voicing
  - How to prevent autocorrelation method from assigning pitch periods to unvoiced segments without changing pitch floor/ceiling

Discussion: Clinical Feasibility

- Patients can perform this task independently over the internet
- System can identify pitch periods with moderate-to-good accuracy
- System reported intonation measures have moderate-to-good reliability with human-corrected measures

Future Directions

- Determine whether optimized parameters can generalize to a larger sample of people w/ PD (in process)
- Nuclear tone analysis (in process)
  - Compare whole-utterance intonation contour
  - To nuclear tone (final word in utterance) contour
  - To determine which is a better representation of speaker's intonation (for PD)
- Compare objective measurements to subjective ratings of rate and naturalness (in process)
  - E.g., PDQ-39, CPIB-S, clinician ratings of speech severity

Acknowledgments

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- NIH T32 Training Grant (SLHS @ Purdue, 2021-2022)
- Modality.AI Team

Questions?

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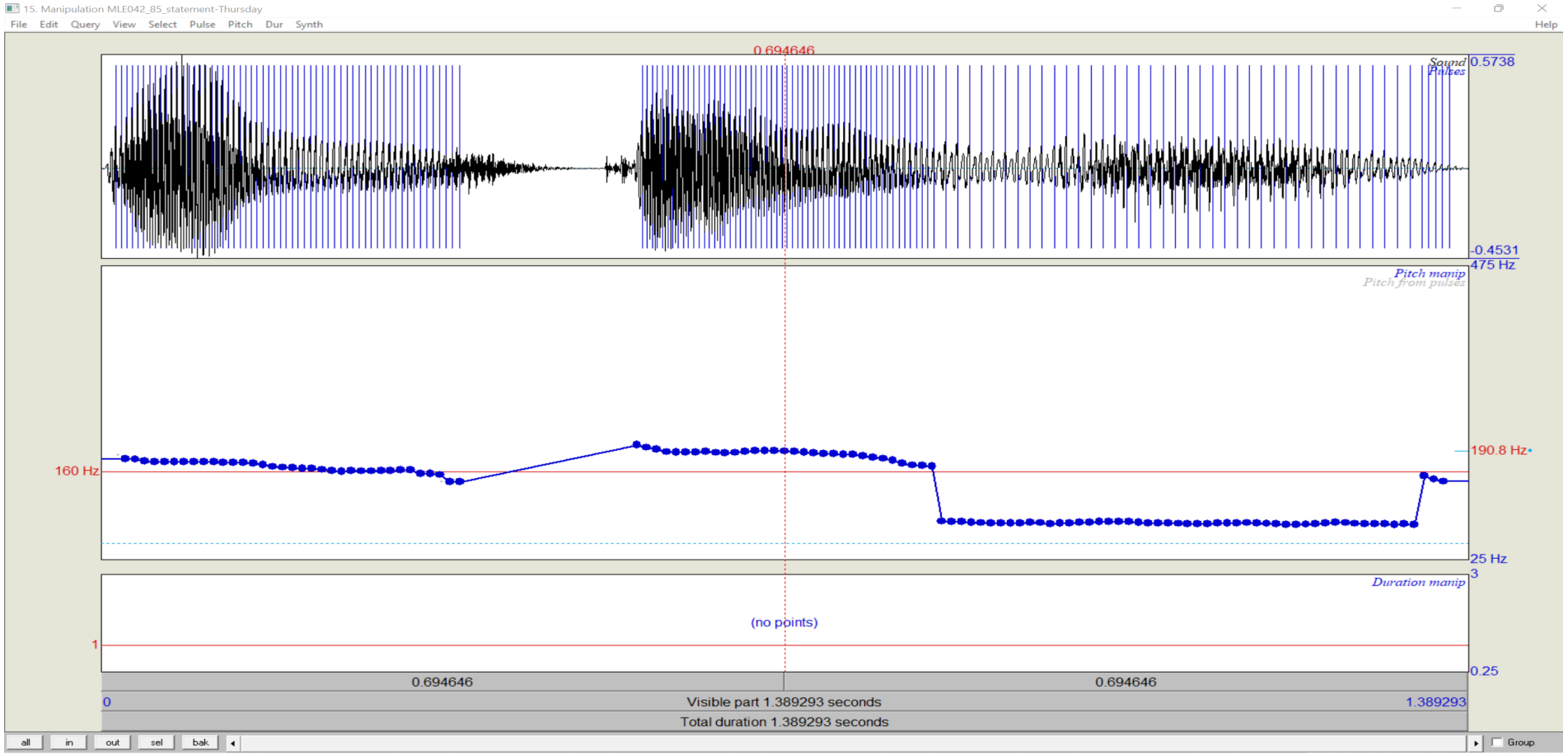
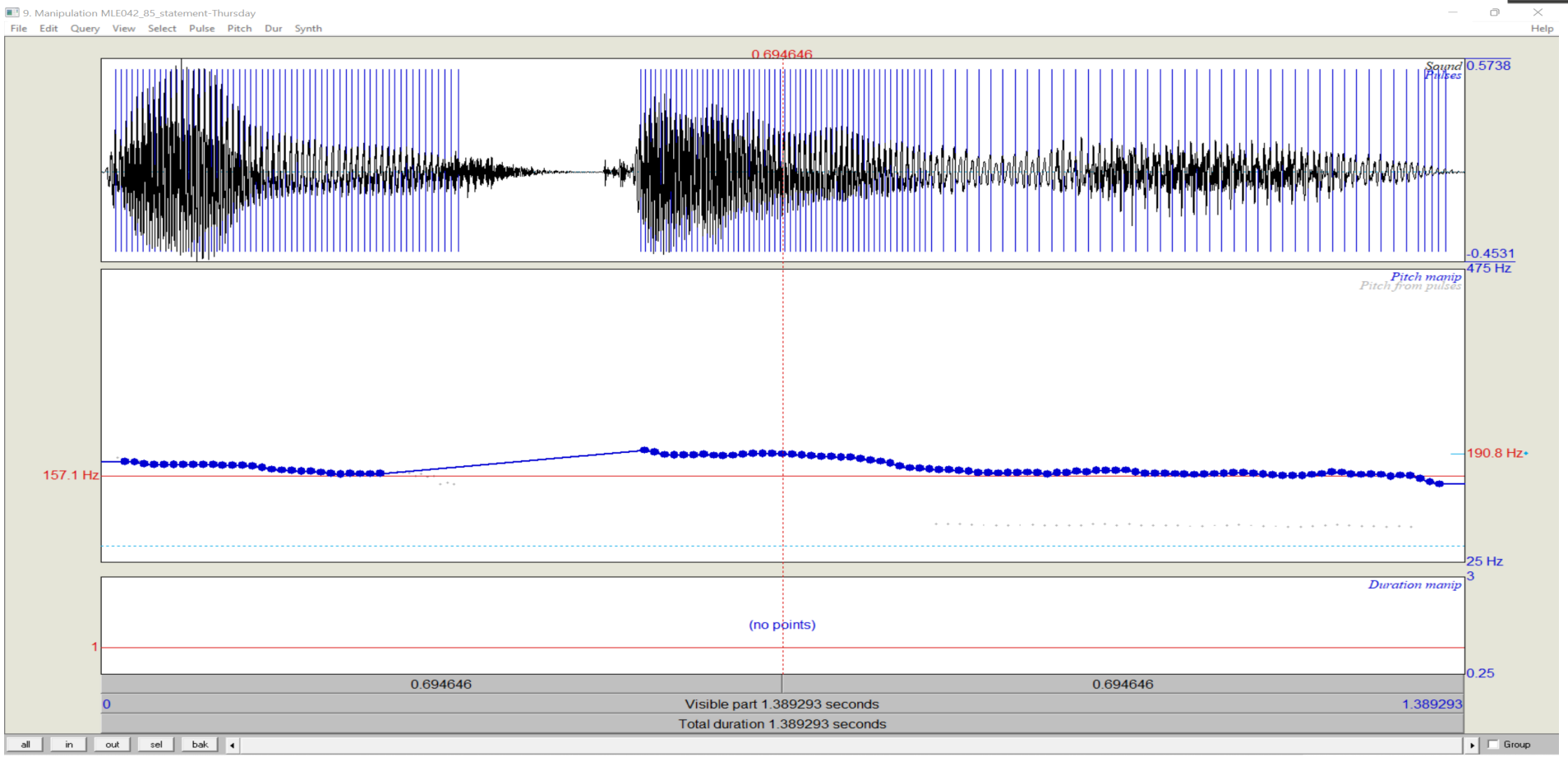
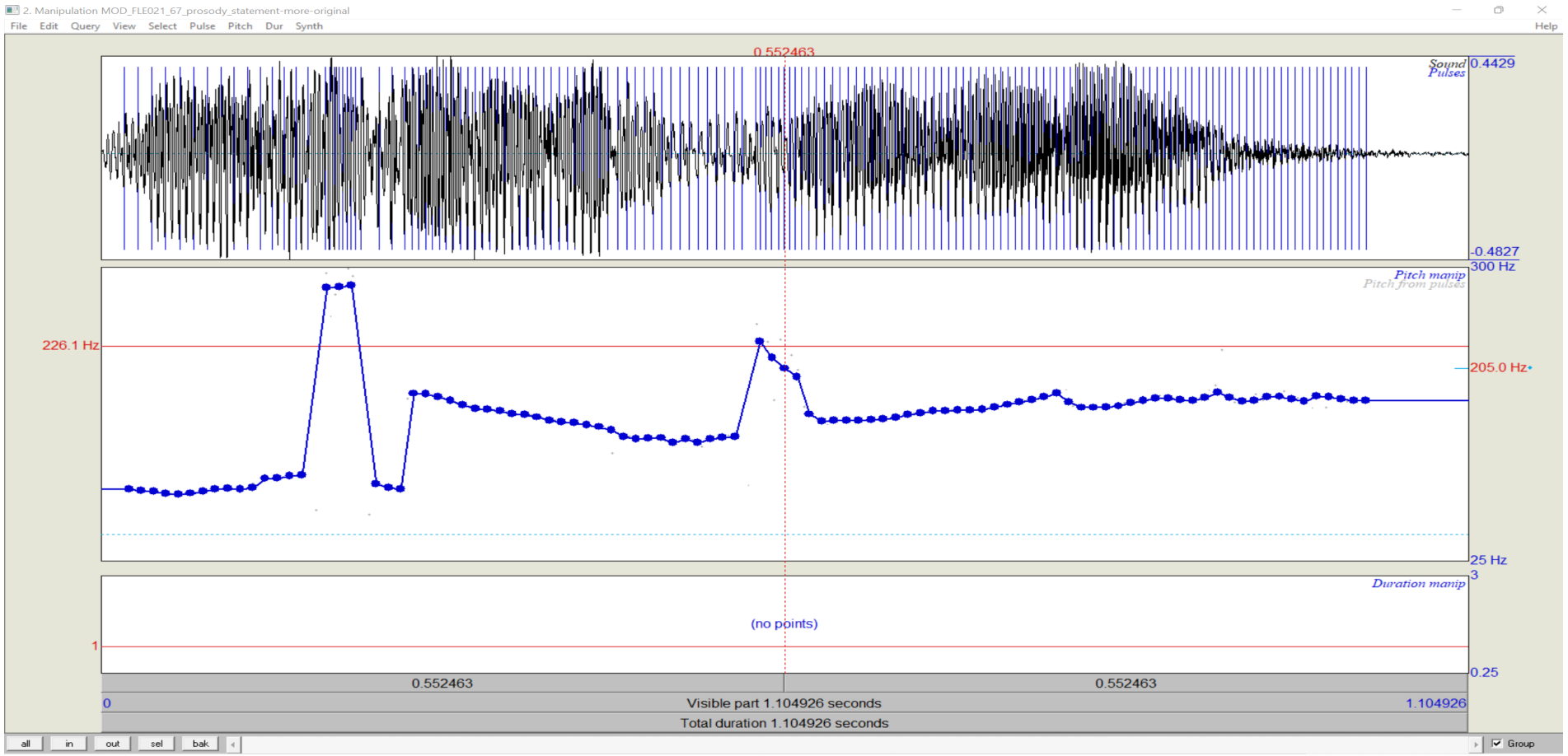
Example: Roughness (Male) (Original)



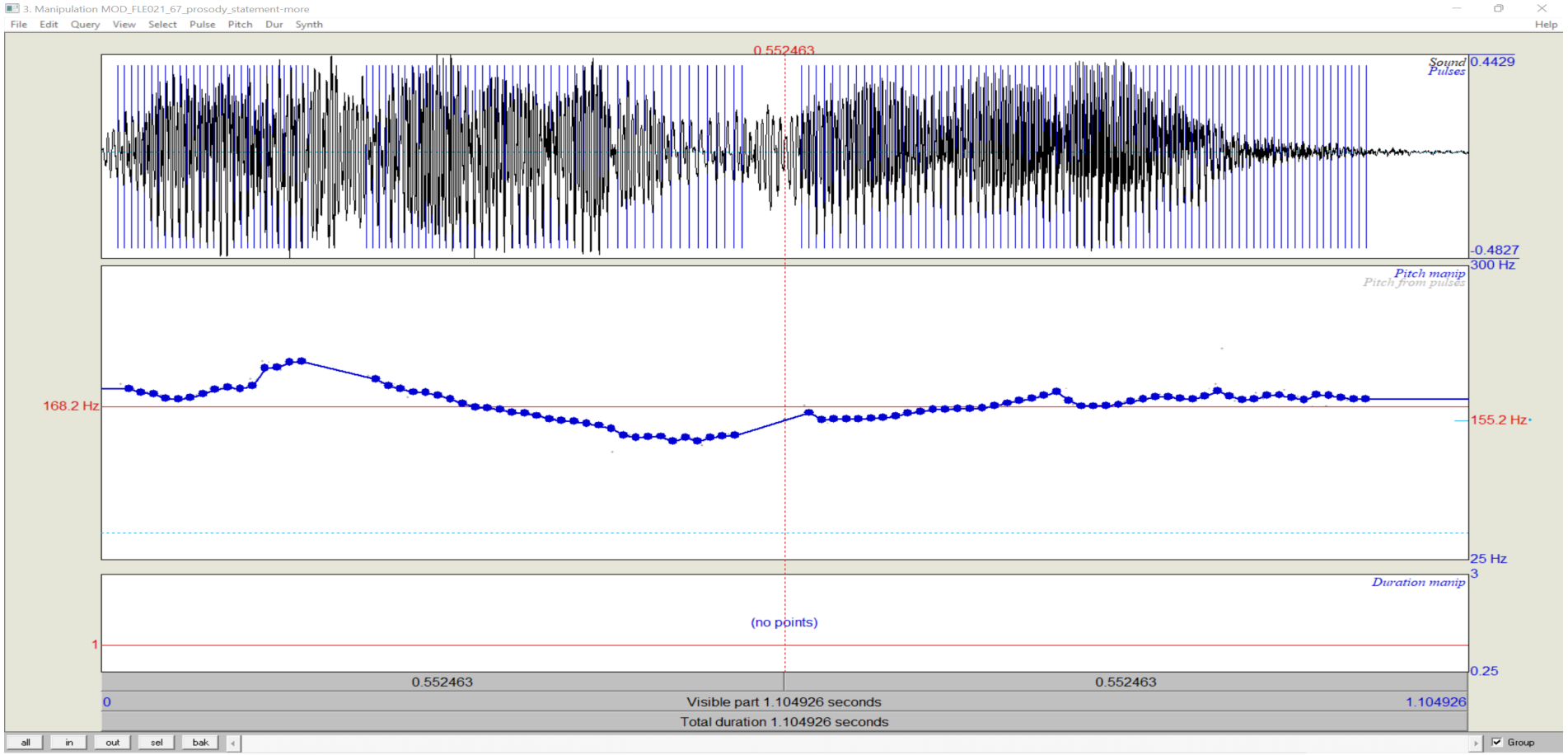
Example: Roughness (Male) (Corrected)



Example: Roughness/Fry (Female) (Original)



Example: Roughness/Fry (Female) (Corrected)



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	Human-Corrected Mean (SD)	Automated Mean (SD)	ICC (95% CI) (agreement)
Minimum f_0 (Hz)	132.70 (36.03)	123.48 (37.42)	0.611 (0.538, 0.672) (moderate)
Maximum f_0 (Hz)	268.55 (94.32)	334.27 (134.41)	0.410 (0.218, 0.551) (poor)
f_0SD (Hz)	39.74 (25.92)	56.81 (37.08)	0.419 (0.243, 0.550) (poor)
f_0 Range (Hz)	135.85 (79.51)	210.79 (131.98)	0.331 (0.122, 0.488) (poor)

Results: Means and Standard Deviations of Fundamental Frequency Measures in a Prosody-Specific Speech Task, Human-Corrected vs Optimized Automated (*n* = 40 PD, 23 controls)

	Human-Corrected Mean (SD)	Automated Mean (SD)	ICC (95% CI) (agreement)
Minimum f_0 (Hz)	132.70 (36.03)	139.35 (34.56)	0.691 (0.637, 0.735) (moderate)
Maximum f_0 (Hz)	268.55 (94.32)	265.48 (87.60)	0.848 (0.827, 0.866) (good)
f_0SD (Hz)	39.74 (25.92)	36.61 (22.72)	0.763 (0.727, 0.794) (moderate)
f_0 Range (Hz)	135.85 (79.51)	126.13 (74.64)	0.758 (0.722, 0.790) (moderate)

F0 Tuning Process

- Single measurer identified 575 turns of interest
- Ran Praat's default pitch calculation algorithm
- "Sound: To Pitch", autocorrelation method, time step = 0.0, pitch floor = 75Hz, ceiling = 600Hz
- Human-corrected contours
- Compared f0 metrics (e.g., mean) from the reference contours and our baseline predicted ones using mean absolute error (MAE). **Green bars.**
- Ran 7,186 pitch calculations using different Praat algorithms and settings.
- Extracted f0 metrics and found Praat settings that minimize MAE. **Blue bars.**
- Identified the optimal settings for known sex-based cohorts. **Red bars.**
- Ran a machine learning experiment to predict patient sex. **Yellow bars.**
- Implemented code for doing the last experiment.

Tuning Observations

- It is well known that automated pitch extraction is best when one uses sex-specific settings.
- This was shown in our results as well, though the increase in metric accuracy was not that big (compare red to green bars).
- Nevertheless, using a machine classifier to predict sex (since we may not always know it at the time of metric extraction) was almost as good as knowing the sex a priori (yellow vs green bars) and still better than a sex-agnostic pitch extract algorithm (red vs yellow bars).

- All three algorithms, however, show drastic improvement over the default Praat settings, with most reduction in error being for max F0.

Tuning Parameter Space

- f0_type = "ac" (autocorrelation) or "cc" (cross-correlation)
- pitch_floor = 10-600 Hz
- pitch_ceiling = 100-700 Hz
- max_candidates = 1-100
- very_accurate = "on" or "off"
- silence_thresh = 0.01-1.0
- voicing_thresh = 0.1-1.0
- octave_cost = 0.0-1.0
- octave_jump_cost = 0.1-1.0
- voiced_unvoiced_cost = 0.1-1.0
- kill_octave_jump = "yes" or "no"

Old Praat F0 Code

- To Pitch: 0, 75, 600

New Praat F0 Code: Step 1 Predict Sex

- f0_type$ = "cc"
- pitch_floor = 55.0
- max_candidates = 9
- very_accurate$ = "off"
- silence_thresh = 0.07
- voicing_thresh = 0.49
- octave_cost = 0.03
- octave_jump_cost = 0.5
- voiced_unvoiced_cost = 0.16
- pitch_ceiling = 350.0
- kill_octave_jump$ = "no"
- smoothing = 25
- To Pitch (cc): 0.01, pitch_floor, max_candidates, very_accurate$, silence_thresh, voicing_thresh, octave_cost, octave_jump_cost, voiced_unvoiced_cost, pitch_ceiling
- Smooth: smoothing
- sex$ = "F"
- if (mean_f0 <= 156.67555)
- sex$ = "M"
- elif (mean_f0 <= 189.532093) and (min_f0 >= 90.901626) and (min_f0 <= 127.179596)
- sex$ = "M"
- endif

New Praat F0 Code: Step 2 Create Sex-Optimized Contour

```
f0_type$ = "ac"
very_accurate$ = "off"
kill_octave_jump$ = "no"
if sex$ == "F"
  pitch_floor = 125.0
  max_candidates = 3
  silence_thresh = 0.09
  voicing_thresh = 0.57
  octave_cost = 0.02
  octave_jump_cost = 0.6
  voiced_unvoiced_cost = 0.2
  pitch_ceiling = 500.0
  smoothing = 24
else
  pitch_floor = 75.0
  max_candidates = 14
  silence_thresh = 0.04
  voicing_thresh = 0.56
  octave_cost = 0.01
  octave_jump_cost = 0.45
  voiced_unvoiced_cost = 0.19
  pitch_ceiling = 350.0
  smoothing = 22
endif

To Pitch (ac): 0.01, pitch_floor, max_candidates, very_accurate$, silence_thresh, voicing_thresh, octave_cost, octave_jump_cost, voiced_unvoiced_cost, pitch_ceiling
```