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Comparison of labial and mechanical interruption for measurement of aerodynamic parameters

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Abstract

Objectives/Hypothesis—To directly compare the mechanical and labial interruption techniques of measuring subglottal pressure (P_s), mean flow rate (MFR) and laryngeal resistance (R_L).

Methods—Thirty-four subjects performed 10 trials with both mechanical and labial interruption. P_s and MFR were recorded while R_L was calculated by dividing P_s by MFR. Coefficients of variation were calculated in order to compare intra-subject precision. A subset of 10 subjects performed the tasks twice with thirty minutes between sessions. Bland-Altman plots were used to determine intra-subject repeatability for each of the methods.

Results—Mechanical interruption produced coefficients of variation for P_s , MFR, and R_L of 0.0995, 0.127 and 0.129 respectively. Labial interruption produced coefficients of variation of 0.102, 0.147 and 0.169 respectively. P-values were 0.824 for P_s , 0.159 for MFR and 0.043 for R_L . The Bland-Altman plots revealed comparable repeatability between the two methods. The 95% confidence intervals of the Bland-Altman plots for mechanical interruption were (-0.050 to 0.072), (-0.543 to 1.832), and (-2.498 to 10.528) for MFR, P_s , and R_L . Confidence intervals for labial interruption were (-0.018 to 0.031), (0.057 to 2.442), and (-3.267 to 10.595) for MFR, P_s , and R_L .

Conclusions—Mechanical interruption produced higher precision when measuring R_L due to more reliable airflow measurements. Mechanical and labial interruption showed comparable repeatability. Further research into using mechanical interruption clinically is warranted.

Introduction

Vocal pathologies are often diagnosed using visual assessment such as videostroboscopy. Though useful, visual assessment can also be subjective. Dejonckere et al. indicate that even objective data such as audio recordings or videostroboscopic pictures can be interpreted subjectively (1). Aerodynamic assessment, however, aims to determine anomalies in subglottal pressure (P_s), mean flow rate (MFR), laryngeal resistance (R_L), and vocal efficiency (V_E) in order to assess laryngeal function quantitatively and objectively. V_E is the ratio of acoustic power to aerodynamic power (2) and is a reliable figure in assessing laryngeal health (2,3). To calculate V_E , one needs the value of aerodynamic or subglottal

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power which is defined as the product of MFR and P_s (2). Developing an accurate and clinically feasible means to determine P_s can potentially reinforce diagnoses and be used to evaluate treatment efficacy.

The most accurate measurements of P_s involve tracheal puncture (4) or inserting a pressure transducer through the nose or mouth into the trachea (5,6). While these methods are accurate, they are invasive and not practical for routine clinical application. Several noninvasive techniques have been introduced to improve P_s measurement efficiency. One such method was introduced by Smitheran and Hixon in which the patient uses labial plosives that allow for the measurement of P_s and MFR which can then be used to calculate R_L (7). While accurate (8), it may be difficult for subjects to master the labial interruption technique required to achieve consistent results (9).

In addition to labial interruption techniques, Bard et al. introduced mechanical interruption using rapidly inflating balloons to interrupt airflow in order to estimate P_s (10). The estimates of P_s obtained have been shown to correlate well with P_s values obtained via tracheal puncture in the same subject (10). A similar device that uses mechanical interruption is the airflow interrupter. The device uses the rapid inflation of a balloon valve to interrupt subject airflow so that supraglottal pressure equilibrates with the subglottal pressure and intraoral pressure can be recorded as subject P_s (11). Though the accuracy of this method was demonstrated with a simultaneous direct measurement in a tracheotomy patient, intrasubject consistency remains an issue due to reflexes which can be elicited by the interruption (12). Kearney et al. found that the laryngeal adductor response (LAR) is triggered approximately 150 to 175 ms after an air puff stimulus (13). The response time for the LAR has not been calculated for airflow interruption. As airflow interruption does not produce as strong a force as an air puff stimulus, the reflex latency may be greater. Using the response time for the air puff allows for a conservative approach that ensures any potentially confounding effects of the LAR are mitigated (12). Using mathematical and physical modeling, we demonstrated that 150 ms is more than sufficient to allow supraglottal pressure to equilibrate with subglottal pressure during a mechanical interruption (12). Measuring P_s consistently at 150 ms retains measurement accuracy while improving precision.

Both the labial interruption method and airflow interruption method have been extensively studied, but they have not yet been directly compared. This study aims to compare the intra-subject precision of mechanical interruption to that of labial interruption as well as the repeatability of each method across time. The outcome measures of each method were P_s , MFR, and derived R_L .

Materials and Methods

Experimental Design

The KayPentax Phonatory Aerodynamic System Model 6600 (PAS) (PAS Model 6600, KayPentax, Lincoln Park, NJ) was modified to accommodate mechanical as well as labial interruption. A cardboard tube (PAS Model 6600 Mouthpiece Tubes, KayPentax) was used to connect the flow meter of the PAS to a rapidly inflating balloon valve (Series 9340, Hans Rudolph, Inc., Kansas City, MO). A small hole of the same diameter of the microphone in the PAS was cut in the cardboard tube to house the microphone in the same position that it would be housed in the unmodified PAS. Subjects formed a tight seal with their lips around a cardboard mouthpiece tube (PAS Model 6600 Mouthpiece Tubes, KayPentax) that was attached to the PAS to prevent air leakage from the mouth during the trials and the subjects wore a nose clip (Series 9014, Hans Rudolph, Inc.) to prevent velopharyngeal leaking. The inflatable balloon valve rapidly inflated in 84 ms and remained inflated for 500 ms during

each trial. Inflation of the balloon valve was controlled manually and performed randomly by the investigator to ensure that the subject could not anticipate the interruption and change their glottal configuration. Visual feedback was displayed with the KayPentax PAS software (PAS Model 6600, KayPentax). A schematic diagram of the mechanical interruption setup is included in Figure 1.

Labial interruption trials were performed using the KayPentax Phonatory Aerodynamic System (PAS Model 6600, KayPentax). Subjects were asked to repeat the syllable /pa/ while airflow, sound pressure level (SPL), and air pressure were recorded by the software.

Human Subject Testing

Human subject testing was done under the approval of the Institutional Review Board of the University of Wisconsin-Madison. A total of 35 subjects were recruited from the UW-Madison campus and any individual over the age of 18 without a history of respiratory or laryngeal disease was eligible to participate. To measure the intra-subject precision of each method, a set 34 subjects performed trials using both methods. In order to control for a learning effect, half of these subjects performed labial interruption first, while the other half performed trials in the opposite order. Repeatability of each device was measured by having nine subjects from the first set and one additional subject perform the methods again in an additional session thirty minutes after the first. Since another learning effect was possible in this subset, each subject began the second session with the opposite test as in the first. Five subjects performed mechanical interruption trials first, while the other five performed labial interruption trials first.

Before both labial and mechanical interruption trials, a sound pressure meter (RadioShack, Fort Worth, TX) that was not part of the system was held level with the PAS and pointed at the subject's mouth. The subject was asked to say /a/ into the tube or airflow mask (depending on which method was being used first) and was verbally directed to phonate at the predetermined SPL of 72 ± 2 dB. Once subjects achieved this SPL, the SPL trace on the PAS was observed and subjects were given a target SPL at which to phonate during trials. This was necessary because the acoustics of the modified PAS system greatly amplified the SPL signal as recorded by the PAS.

For the labial interruption trials with the PAS 6100, all subjects were verbally instructed of their task via the instructions provided by the PAS software. This instruction included holding the PAS tightly to the face, inhaling, and repeating /pa/ 5-7 times on a single breath at a rate between 1.5 and 2 syllables per second. We also verbally specified that equal emphasis should be put on each syllable. Subjects were given visual feedback and instruction to maintain a SPL of 72 ± 2 dB. Subjects were given a practice trial to maintain the correct SPL and become comfortable with the device. Each of the subjects performed 10 trials with a trial consisting of a set of 5-7 labial plosives.

For mechanical interruption trials, subjects were told to phonate a constant /a/ into the cardboard tube attached to the PAS for 3 – 5 seconds. Subjects were given visual feedback to maintain a SPL of 72 ± 2 dB and comfortable fundamental frequency before and after each interruption. Subjects also performed a practice trial to achieve the correct SPL and become comfortable with the device. During each trial, subject airflow was interrupted 5 times by the investigator who manually triggered the inflation of the balloon valve.

Statistical analysis

Coefficients of variation of the aerodynamic parameters as measured by the two methods were compared using paired t-tests with a significance level of $\alpha = 0.05$. If data were not normal or did not display equal variance, a Mann Whitney rank sum test was performed. To

evaluate the repeatability of each method, 95% confidence intervals were calculated for the mean difference between data collection sessions.

Results

The coefficient of variation for P_s measurement was 0.0995 for mechanical interruption and 0.102 for labial interruption ($p=0.824$). Coefficient of variation for MFR was 0.127 for mechanical and 0.147 for labial interruption ($p=0.159$). Coefficient of variation for R_L was 0.129 for mechanical and 0.169 for labial interruption ($p=0.043$). The 95% confidence intervals of measurement repeatability for mechanical interruption were (-0.050 to 0.072), (-0.543 to 1.832), and (-2.498 to 10.528) for MFR, P_s , and R_L respectively. Confidence intervals for labial interruption were (-0.018 to 0.031), (0.057 to 2.442), and (-3.267 to 10.595) for MFR, P_s , and R_L .

Discussion

This study directly compared mechanical and labial interruption and examined which, if either, produced greater measurement precision and repeatability. Ten trials were performed as that is a commonly used number for test-retest experiments (12,14,15,16,17); however, in future studies it would be valuable to investigate how many trials are necessary to achieve measurement stability. Both labial and mechanical interruption can be accurate (8,11), but issues with intra-subject variability remain.

Efforts were made to standardize the procedures to obtain a more direct comparison. Slight changes needed to be made to effectively isolate a single variable: the type of interruption used to estimate P_s . Changes included modifying the PAS to accommodate mechanical as well as labial interruption. This ensured that variations were not due to data acquisition hardware or the data analysis software. While flow was analyzed for both mechanical and labial interruption with the PAS software, customized LabVIEW software had to be used to analyze pressure for mechanical interruption because of the need to analyze the pressure peaks with the 150 ms time constant as proposed by Hoffman et al. (12). The standard PAS was modified by attaching a rapidly inflating balloon valve by means of a cardboard tube attached to the back end of the flow meter. Microphone placement on the PAS remained constant; however, this meant that it would be inside of the tube used to attach the balloon valve to the PAS. This greatly altered the acoustic properties of the entire system. Using an airflow mask for labial interruption trials and a cardboard tube for mechanical interruption trials further altered system acoustic properties. This was controlled for by calibrating subject SPL before each set of trials with the external decibel meter. Because P_s varies directly with SPL (18), precautions were taken to ensure that SPL was constant across all trials and not confounded by the acoustics of the altered apparatus. These altered acoustics were accounted for by giving the subject a target SPL on the PAS software based on a SPL of 72 ± 2 dB measured using an external sound pressure meter. This calibration was done for whichever method was tested first and the target SPL was the same for both methods.

In addition to the above modifications, the usual process for data acquisition and analysis for mechanical interruption was altered. Rather than interrupting the airflow of the subject once per trial, five consecutive interruptions were performed in order to analyze the data in the same manner in which the labial interruption trials are analyzed. This method involves averaging five pressure and flow values to constitute one trial. This eliminated the potentially confounding effect that could occur if comparing a labial interruption trial consisting of 5-7 labial plosives with a mechanical interruption trial consisting of only one 500 ms interruption. Typically, only one complete interruption is required for subglottal pressure measurement. A single mechanical interruption of a sustained vowel has been

successfully applied to dysphonic populations, including patients with polyps (2), nodules (2), Parkinson's disease (19), and spasmodic dysphonia (15). A strength of the mechanical interruption method is that subjects cannot anticipate the interruption and alter their glottal configuration; however, interrupting phonation five times per trial may have led to some subjects anticipating interruptions. To prevent this, interruptions were not actuated at regular intervals. Even with this potential disadvantage, mechanical interruption achieved lower coefficients of variation for P_s and MFR and produced significantly lower coefficients of variation for R_L . These results reflect that the mechanical interruption method may be better suited than labial interruption to produce a high level of intra-subject precision. Further research into refining the mechanical interruption method for estimating P_s is warranted.

One potential reason for the more precise values of R_L for mechanical interruption trials is that some patients and untrained subjects have trouble meeting the requirements of labial interruption that are needed for accurate measurement (9). Specifically, the lower coefficient of variation for MFR for mechanical interruption may indicate that the mechanical interruption method is better suited to produce consistent values of flow than is labial interruption. For example, Figure 2a includes data from Subject 22 who produced extremely consistent intra-trial flow; however, inter-trial flow had a very high coefficient of variation accompanied by very consistent P_s and SPL. This may indicate that the subject experienced a change in glottal configuration between trials making it difficult to produce a consistent MFR using labial interruption. In Figure 3a, several trials are included from Subject 30 who had a large coefficient of variation for MFR and R_L . In these trials, there is a large spike in flow immediately following the plosive due to a larger than normal exhalation by the subject. This large exhalation makes it difficult for flow to equilibrate before the next labial occlusion, potentially confounding MFR measurement. While performing labial interruption method may be difficult for some subjects, many subjects performed the trial properly. Subject 23 had a low coefficient of variation for P_s , MFR, and R_L when performing labial interruption trials. The pressure peaks are consistent and characterized by a rapid increase in pressure immediately after oral airway closure and rapid decrease in pressure immediately following oral airway opening as described by Smitheran and Hixon (7) indicating that the labial interruption method was performed properly.

Samples of flow traces for mechanical interruption trials are also included in Figure 2b and Figure 3b for Subjects 22 and 30 respectively. While some subjects are capable of effectively performing both methods, it may be easier for subjects who struggle with labial interruption to perform mechanical interruption due to differences in voicing task. Mechanical interruption requires only a sustained vowel; labial interruption requires repeated labial plosives. There may be greater potential for variation in the way plosives rather than sustained vowels are produced. Potential sources of variation include differences in emphasis, variations in SPL between plosives, as well as varying glottal configurations between plosives. Due to these reasons, some subjects may have difficulty mastering the techniques necessary to perform the labial plosives in a way that allows for accurate measurement of P_s , MFR, and R_L (9).

With mechanical and labial interruption producing similar coefficients of variation for pressure, it is logical that differences in the coefficients of variation of R_L between labial and mechanical interruption would be due to differences in MFR (because $R_L = P_s / \text{MFR}$). Using the same flow meter and analysis software ensured any potential differences in flow measurement were due to interruption method alone. This might indicate that while pressure measurements between the two methods are comparable, mechanical interruption may produce more consistent flow measurements and ultimately, more consistent measurements of R_L .

The repeatability portion of the study showed a difference in repeatability for mechanical interruption over labial interruption in both P_s and R_L based on narrower 95% confidence intervals with mechanical interruption data. The Bland-Altman plots for R_L for labial and mechanical interruption are included in Figure 4a and Figure 4b, respectively.

Subglottal pressure and fundamental frequency have a direct relationship (20). In this study, we directed subjects to phonate at a comfortable frequency, as we are most interested in the aerodynamic characteristics of subjects' normal voice production. As speech pathologists may be interested in measuring subglottal pressure at varying phonatory frequencies, evaluating each device at varying frequencies of phonation may be beneficial.

Due to the higher precision of R_L measurement with mechanical interruption, it may improve clinical objective voice assessment. One benefit of labial interruption is the minimal equipment needed for clinical measurement. The equipment used for mechanical interruption in this study is still at a prototypical stage and could be modified to enhance clinical applicability. For example, a mechanical shutter could replace the balloon valve, eliminating the need for the balloon box and air tank. While our modification of the PAS in this study was done only to control for potential variability in data collection devices, it does represent one means of applying mechanical interruption to the clinical setting. Refinements to the mechanical interruption apparatus to make the system more clinically useful are warranted.

Conclusions

Mechanical and labial interruption methods for estimating subglottal pressure were directly compared in the same subjects. Changes were made to the procedure in order to effectively isolate only one variable; the method of the interruption. Coefficients of variation were used as a reliable indicator of the precision of each of these methods for subglottal pressure, flow, and laryngeal resistance. Mechanical interruption achieved significantly lower coefficients of variation for laryngeal resistance, while both methods showed comparable repeatability. The results indicate that while both mechanical and labial interruption methods are accurate, mechanical interruption shows the potential to improve precision over labial interruption. Further research using mechanical interruption clinically should be conducted.

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Figure 1. Schematic diagram showing the experimental setup for mechanical interruption trials using the modified PAS. Dotted lines represent pneumatic tubes while solid lines represent electrical wires.

Figure 2.

Airflow trace for two labial interruption trials performed by Subject 22 (a). Note the inter-trial variability in flow. The flow trace for two trials of the same subject using mechanical interruption is also provided (b). Mechanical interruption shows more consistent inter-trial flow.

Figure 3.

Airflow trace for two labial interruption trials performed by Subject 30 (a). Note the larger-than-normal spike in airflow before each vowel. The flow trace for two trials of the same subject using mechanical interruption is provided (b) with trials exhibiting less of a spike in airflow immediately preceding the vowel.

Figure 4. Bland-Altman plot for R_L using mechanical interruption (a) and labial interruption (b). Mean difference between the two data collection sessions is plotted against mean R_L . Mean difference (solid line) and 95% confidence intervals (dotted lines) are also displayed.