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The effect of speech timing on velopharyngeal function

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Abstract

It is likely that the timing of the speech can affect velopharyngeal function and the opening and closing of the velopharyngeal port, but we do not have a good understanding of how speech timing affects the control of the velopharyngeal opening and closing. The purpose of this project is to study the effect of two speech-timing conditions on velopharyngeal function in individuals with normal speech through the measurement of nasal airflow and oral air pressure during speech.

Introduction

Speech is a complex motor task that includes the coordination and timing of different articulatory structures. One approach that is used to understand the control of speech articulation is the manipulation of speaking rate. Previous research (Lindblom, 1963; Gay, 1978; Kent et al, 1974) has shown that an increase in speaking rate is accompanied by a decrease in duration of articulatory movements. In essence, the articulators increase velocity of movement as speech rate increases. Lindblom (1963) also showed that as speech rate increases, spme speakers move the articulators a reduced distance, which was referred to as "undershoot". Simply put, the articulators travel shorter distances to-and-from articulatory targets during faster speaking rates.

One component of the articulatory system that is critical for normal speech is the velopharyngeal mechanism. The velopharyngeal mechanism includes the velum and walls of the pharynx. In normal speakers, the velum (e.g., soft palate) is elevated during the production of most speech sounds, separating the oral and nasal cavities by closing the velopharyngeal port. This allows a speaker to direct air out of the mouth because the nasal cavity is blocked. This process is referred to as velopharyngeal closure. If the velopharyngeal mechanism is not working properly, the velum will not be adequately elevated to close off the oral and nasal cavities. When this happens, air and sound escape out of the nasal cavity instead of the mouth, creating an overall nasal quality of speech.

In normal speakers, the velopharyngeal mechanism has full range of motion that creates adequate closure. However, this normality of function may not be typical for individuals with a repaired cleft palate. The structural limitations of the repaired cleft make it harder for the speaker to maintain the control of the mechanism. The cleft palate population shows a variability in velopharyngeal function, which result in variability of perceived nasalization (Jones, 1990). Although many have normal velopharyngeal function, others exhibit velopharyngeal inadequacy which is characterized by hypernasal speech. In addition, some individuals with repaired cleft palates have what is referred to as “borderline” velopharyngeal function. These individuals are perceived to have mild, inconsistent nasality during speech because the repaired mechanism does not fully close off the velopharyngeal port.

Effect of Speech Rate on Velopharyngeal Function:

Kuehn (1976) studied how the velum moves as a function of speaking rate in two normal speakers. He found that the velum of a normal speaker changes quite efficiently to achieve closure at the appropriate times, even when speaking rate is increased. One speaker showed increased velocity of movement and decreased velum displacement while the other speaker showed only decreased displacement. Kuehn theorized that, when speaking rate is increased, speakers might adopt different strategies for changing velar activity to create adequate closure.

It is important to note that, in studying only velar movement, Kuehn did not necessarily study the opening and closing of the velopharyngeal port. Thus, there are no studies that have provided an understanding of how speech timing affects the control of velopharyngeal opening and closing during speech. Although there is no valid approach to measuring the kinematics of the velum and pharyngeal walls simultaneously during speech, aerodynamic assessment of velopharyngeal function provides information about the opening and closing of the velopharyngeal port (Warren & Dubois, 1964). Aerodynamic assessment will be used during this project to gather more information about speech timing on velopharyngeal function in individuals with normal speech.

The purpose of this project is to study the effect of speech timing on the opening and closing of the velopharyngeal port in individuals with normal speech. It is hypothesized that as speech rate is increased, speakers will either close the velopharyngeal port faster, or maintain smaller port areas.

Methods

Participants:

Participants included five females and five males who volunteered for this study at the University of Wyoming. Eleven students were enrolled for data collection, but data for one Participant were omitted due to equipment malfunction. The mean age of the participants was 22 years. Participants were asked questions regarding medical history that would affect oral, nasal, or pharyngeal structures (e.g., history of a speech disorder, laryngectomy, nasal congestion, etc.). None of the participants reported a prior or current speech disorder. Participants 1 and 5 reported having adenoidectomy and tonsillectomy during childhood, participant 9 reported having undergone tonsillectomy during childhood, and participant 8 reported having chronic nasal congestion/allergies during youth. All participants exhibited normal speech as determined via perceptual assessment by the investigator and faculty supervisor. All participants were native American English speakers who were free of moderate-severe nasal congestion on the day of scheduled data collection.

Instrumentation:

Nasal airflow was measured with polyethylene (PE) tubing that was secured to a pneumotach (Hans Rudolph 3719); the pneumotach was coupled to a differential pressure transducer (Microswitch 163PC01D36). Intraoral air pressure (IOP) was measured with a rigid PE tube that was placed between the participants' lips from the corner of the mouth and positioned in the anteromedial aspect of the oral cavity. The PE tube was coupled to a pressure transducer (Microswitch 164PC01D37). Intranasal air pressure was measured with a rigid PE tube that was inserted through a foam earplug, secured within the less patent nostril, and coupled to a pressure transducer (Microswitch 164PC01D37). The IOP, intranasal pressure, and nasal airflow signals were amplified and low-pass filtered at 50 Hz using a Biocommunication Electronics 215 bridge amplifier, then digitized at a sampling rate of 1000 Hz per channel using a DATAQ DI-720 A/D board. The pneumotach was calibrated for milliliters per second (ml/s) using a constant flow source and a Gilmont GF-1460 flow meter. The pressure transducer was calibrated for centimeters of water (cmH_2O) pressure using a 10 cubic centimeter syringe and u-tube water manometer. The speech acoustic signal was recorded simultaneously using an Audio-Technica AT831b miniature cardoid condenser microphone and AudioBuddy preamplifier, and digitized at 1000 Hz. The acoustic signal was recorded for the purpose of token identification. The microphone was positioned approximately 4” from the participants’ lips to record the speech tasks.

Speech Sample:

The speech sample included repetitions of the single word “pamper”, and repetitions of the phrase “We were a pamper away”. The phrase was produced in both a conversational and fast speaking rate. The order of the speech tasks was randomized. Data for the single word productions were acquired for later analysis, and will not be presented here.

Procedure:

The nasal airflow tube was positioned within the more patent nares which was determined by participant report. The nasal pressure tube within a foam earplug was placed in the opposite nares. The investigator held the oral pressure tube within the side of each participant’s mouth. Both the nasal tubes and microphone were held to the tabletop by clamps that were individually positioned for each of the participants.

Prior to data acquisition, each speech task was modeled by the investigator and practiced by the participant. During data acquisition, each participant produced approximately 15 repetitions of the phrase “We were a pamper away” spoken at a conversational speaking rate, and approximately 15 repetitions of the same phrase speaking at a fast speaking rate. A fast speaking rate was described as a production that was not any more forceful or unintelligible as the conversational rate, just simply spoken faster.

During participation in the study, if the participants were not producing the utterances according to protocol, the participants were prompted by the investigator to perform the tokens as instructed. For example, if the participants were not producing the phrase fast enough for the fast rate condition, the investigator would prompt the participant by saying, “faster”, or would re-model the desired production.

Measurements:

WinDaq software was used to measure the nasal airflow, intranasal pressure, and intraoral pressure signals. FIGURE 1 shows the aerodynamic measures associated with the /m-p/ segment of the word ‘pamper’. Intraoral pressure (IOP), nasal pressure (NP), and nasal airflow (NF) were acquired for each token.

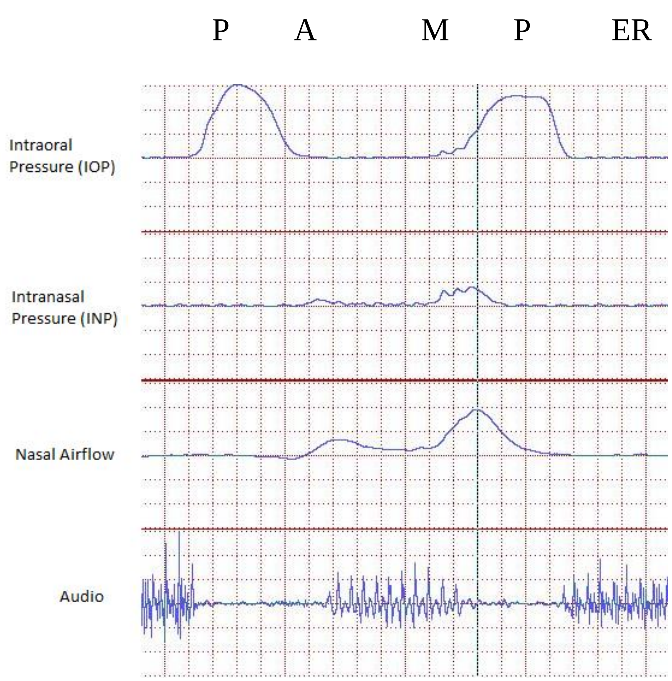

FIGURE 1: Sample of the intraoral pressure and nasal airflow signals acquired during the production of “peempuh” and the point of measurement. Measurement descriptions are provided in the text. (IOP=Intraoral Pressure; NF=Nasal Airflow)

Please refer to FIGURE 2 to view the measurements taken from the aerodynamic tokens.

Peak IOP: The point at which the maximum deviation from the baseline occurs. This is achieved by the lips approximating during the production of the second /p/ in ‘pamper’ (Figure 2, point A).

Nasal Peak: The point at which maximum deviation from the baseline occurs. This is achieved by the lips approximating together during the production of the /m/ in ‘pamper’ (Figure 2, point B).

Nasal Airflow Duration: The time from nasal airflow onset to nasal airflow offset (Figure 2, points E – D). That is associated with velopharyngeal port opening during the production of the /m/ in ‘pamper’.

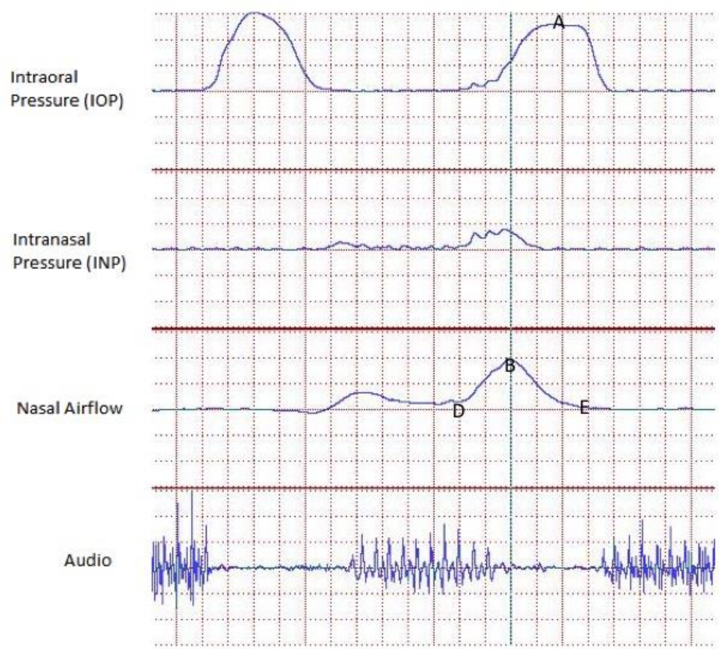

FIGURE 2: Sample of the intraoral pressure and nasal airflow signals acquired during the production of “peempuh” and the point of measurement. Measurement descriptions are provided in the text. (IOP=Intraoral Pressure; NF=Nasal Airflow)

Maximum Flow Declination Rate (See FIGURE 3)*:* Is found by dividing the NF declination (**) velocity by the NF peak (*) [MFDR = (dV/dt)peak/Vpeak] as described by Dotevall (2000). This represents the maximal closing velocity of the velopharyngeal port at the transition from nasal (e.g., /m/) to voiceless stop consonants (e.g., /p/).

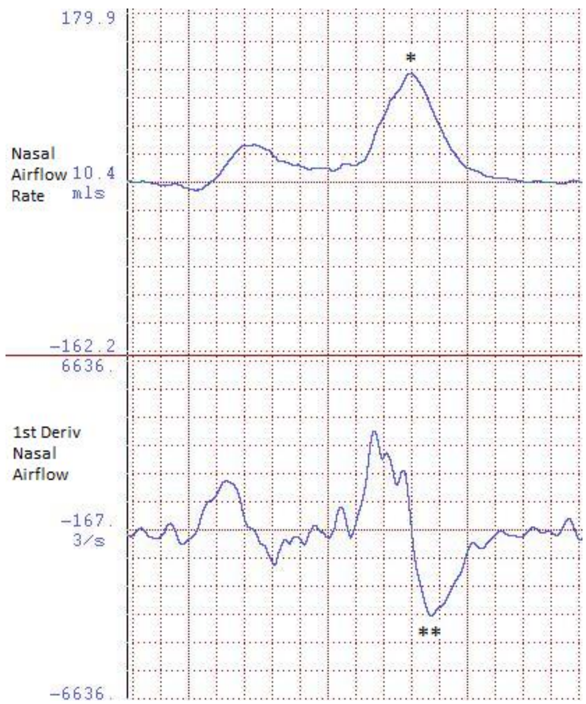

FIGURE 3: Sample of the intraoral pressure and nasal airflow signals acquired during the production of "peempuh" and the point of measurement. Measurement descriptions are provided in the text. (IOP=Intraoral Pressure; NF=Nasal Airflow)

Velopharyngeal Port Area (See FIGURE 4)*:* As defined by Warren and Dubois (1964), the velopharyngeal port area is calculated by measuring the peak nasal airflow rate, and then measuring the intraoral pressure and intranasal pressure at that point. This information is then inputted into the equation:

$$\text{Orifice Area} = \frac{\text{Rate of Airflow through Orifice}}{\sqrt{2\left(\dfrac{\text{Orifice Differential Pressure}}{\text{Density of Air}}\right)}}$$

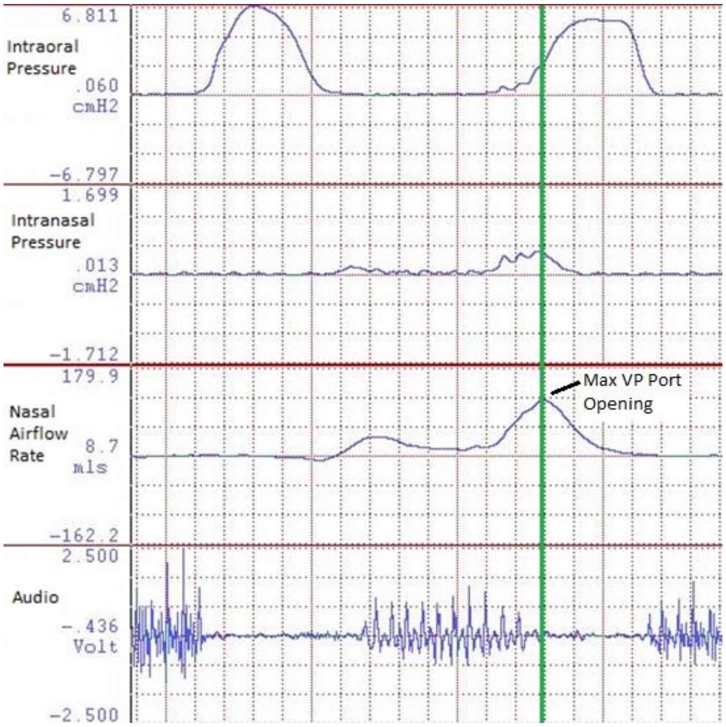

FIGURE 4: Sample of the intraoral pressure and nasal airflow signals acquired during the production of "peempuh" and the point of measurement. Measurement descriptions are provided in the text. (IOP=Intraoral Pressure; NF=Nasal Airflow)

A general linear model was used to conduct an analysis of variance with velopharyngeal port area and maximum flow declination rate (MFDR) as the response variables. Rate condition and Participant were included as independent variables in the model.

Results

Confirming increased rate:

Two temporal measures were taken (initial peak IOP time-point to medial peak IOP time-point) to confirm that an increase in speaking rate between the conversational and fast speaking rates for had occurred.

Peak IPO1 – Peak IOP2: The time between IOP peaks associated with the initial and medial /p/ was measured and then averaged for each of the participants for both the conversational and fast speaking rates. It was found that as the rate of speech increased, the time between the initial and medial /p/'s decreased, indicating that each participant increased their speaking rate during the target word to create a faster rate of speech. For participant 2, the IOP1 – IOP2 time did not decrease.

Nasal Airflow Peak – Peak IOP2: The time between the nasal airflow peak associated with /m/ and IOP peak associated with medial /p/ was measured and averaged for each of the participants for both the conversation and fast speaking rates. It was found that as the rate of speech increased, the average time between the /m/ and medial /p/ decreased for most of the participants. However, Participant 2's "m – p" time at the conversational rate of speech was faster than the fast rate of speech. Additionally, Participants 7 and 9 did not have a significant difference in time between the conversational and fast rate of speech.

Statistical Analysis

Results of the analysis of variance for velopharyngeal port area and MFDR as a function of rate and participant showed no main effect for rate condition, but a statistically significant interaction for Rate condition by Participant. *t* tests were carried out to compare mean variable values by Participant.

Velopharyngeal port area as a function of rate:

Port decrease: The area of the velopharyngeal port was calculated as a function of rate to determine how open the velopharyngeal port was with an increase of speech rate. FIGURE 5 shows the velopharyngeal port areas as a function of speech rate. It was found that speakers 3, 4, 5, and 9 decreased the velopharyngeal displacement with an increase of speaking rate. Participants 1, 6, 7, and 10 increased port size as rate increased; Participants 2 and 8 did not change port size with an increase of speech rate.

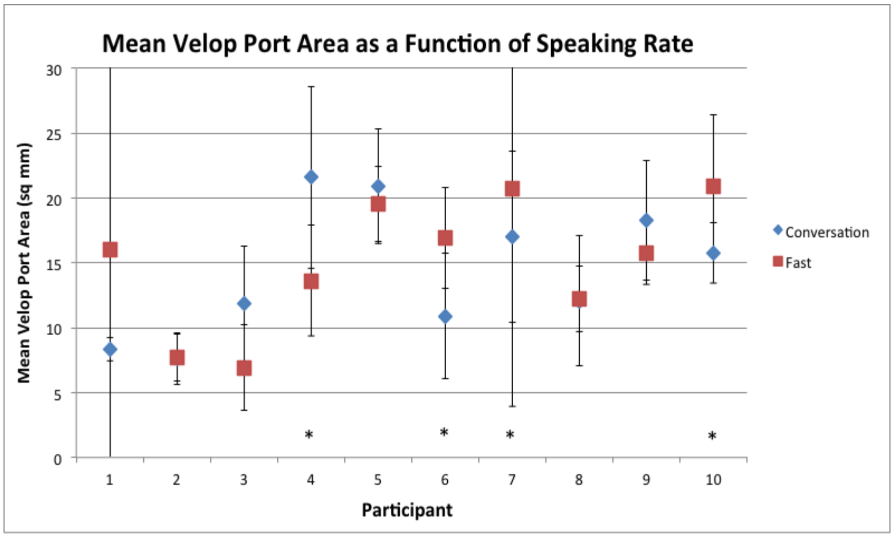

FIGURE 5: The mean velopharyngeal port area as a function of speaking rate for each of the participants. * = statistically significant t test ($p \leq .05$)

MFDR as a function of rate:

Maximum Flow Declination Rate: FIGURE 6 shoes MFDR as a function of speech rate. Speakers 1, 3, 4, 5, 6, 9, and 10 increased the velopharyngeal port closing velocity with an increase of speaking rate. However, this was not seen for Participant 2, 7, and 8 did not show increased velocity of closure with increased rate.

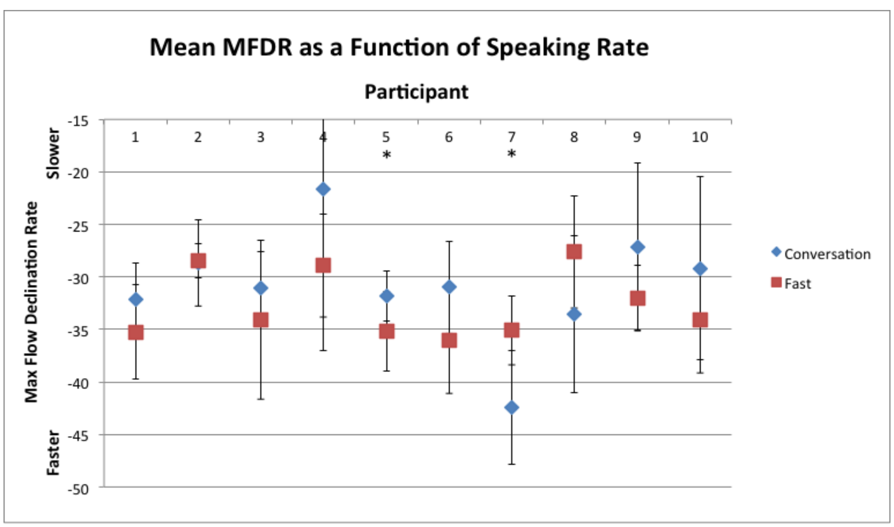

FIGURE 6: The mean velopharyngeal port area as a function of speaking rate for each of the participants. * = statistically significant t test ($p \leq .05$)

Discussion

The purpose of this project was to study the effect of speech timing conditions on the opening and closing of the velopharyngeal port. Earlier research studied the velum and how it (and not the velopharyngeal mechanism) functions during changes in speech rate. Kuehn (1976) found that the velum of a normal speaker changes quite efficiently to achieve closure at the appropriate times even when speaking rate is increased. Additionally, Lindblom (1963) studied that a faster speaking rate can be associated with faster movement of articulators or decreased displacement of the articulators. It was hypothesized that participants would either simply move their articulators faster with a faster speaking rate, or move a reduced distance to create the faster rate of speech.

The data obtained suggest that both of these methods were used to accommodate the faster speech rate (i.e., decrease velopharyngeal displacement). As a response to speech rate, some participants decreased their port size while others increased the velocity of the closure of the velopharyngeal mechanism. The data suggest that Participants 3, 4, 5, and 9 decreased their velopharyngeal port size as rate increased indicating decreased. Participants 1, 6, and 10 increased their port size and moved to a point of closure with greater speed in response to the faster speaking rate.

Regarding the MFDR measure, Participant’s 1, 3, 4, 5, 6, 9, and 10’s velopharyngeal port closing velocity increased as the rate of speech increased. Participants 2, 7, and 8 did not increase closing velocity as the rate of speech increased. This could be due to the fact that Participant 2’s conversational speech was faster in duration than the fast rate of speech. Additionally, Participants 7 and 8 did not have a significant difference in time between the conversational and fast rate of speech. Because of these two factors, the closing velocity of the velopharyngeal port may not have increased because the rate of the target word had not increased significantly enough for these participants.

One additional measure seemed to show a consistent change with an increase of speech rate. The mean of the nasal airflow duration as a function of speaking rate was taken for each of the speakers. Speakers 1, 2, 3, 5, 6, 8, 9, and 10 opened their velopharyngeal port for a shorter duration with an increase of speaking rate. Instead of only using one or two of the different strategies to create a faster speaking rate, there may be a third strategy. The shorter duration of the velopharyngeal port opening may be another strategy that may be used to create faster speech. Eight out of the ten speakers decreased the duration of the port opening. It may be that these speakers decreased the time that the port was opening from the vowel into the nasal to accommodate the speech timing, but this was not something that was measured during this study.

Limitations

In some instances, results may have been more consistent if the rate of speech was controlled differently. Even though there was a decrease in duration between all of the initial /p/ to medial /p/ calculations for each of the participants, there was not a decrease in duration between all of the /m/ and medial /p/ calculations. The investigator may not have been taxing the participants enough in their fast rate of speech. To ensure a decrease in duration of the /m/ and medial /p/ segment for all participants, it may be beneficial to either make the sentence “we were a pamper away” shorter, or to take out all of the words except for the target word. This way the participant does not have the option of decreasing the timing of all of the words except for the target word. However, if all of the words except for the target word were eliminated from the spoken tokens, the results would not generalize to conversational speech. Another way to ensure the decrease in duration for the /m/ and medial /p/ segment would be if the investigator had chosen to calculate ten of the shortest tokens that were spoken by Participant's 2, 7, 8, 9, and 10.

Conclusion

It was hypothesized that as speech rate is increased, speakers will either close their velopharyngeal port faster, or reduce the range of the velopharyngeal port opening. It was found that the majority of the speakers (7/10) closed the velopharyngeal port with an increase in velocity as speech rate increased and almost half of the speakers (4/10) opened their velopharyngeal ports to a lesser extent. However, none of the speakers that decreased their velopharyngeal port area did so exclusively.

Instead of using one strategy or the other to accommodate faster speaking rate, it may be concluded that (1) some speakers may use both strategies to accommodate faster speaking rate while (2) other speakers may simply move their mechanism faster. Future research is required to determine if speakers reduce the displacement of the velophayngeal ports exclusively without the increase of velocity of closure.

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