University of Nevada, Reno

Relationship among tongue pressures in healthy, English monolingual children aged four years in the United States

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by

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Abstract

Objective: The purpose of this study was to establish male and female anterior and posterior normative maximum isometric tongue pressures and anterior and posterior tongue pressure ratios in four-year-olds. Tongue pressures were examined for sex differences.

Methods: Researchers analyzed and compared anterior and posterior tongue pressures of 48 English monolingual, typically developing four-year-olds from preschools in Nevada and Washington State using the Iowa Oral Pressure Instrument.

Results: Statistical analysis suggests an average anterior tongue pressure of 28.35kPa (SD = 7.807) for females and 28.41kPa (SD = 7.908) for males and an average posterior pressure of 26.65kPa (SD = 8.23) for females and 27.75kPa (SD = 6.988) for males. The calculated anterior-posterior pressure ratio was 1.02 for males and 1.06 for females.

Conclusions: Results indicate that the pressure exerted by the tongue of a four-year-old is relatively the same from anterior to posterior, regardless of sex. Findings of anterior tongue pressure align with the limited existing data; however, posterior pressure in four-year-olds was not previously investigated. The ratios are the first established for anterior and posterior tongue pressure.

Key terms: *tongue pressure, ratio, MIP, pediatric tongue strength, muscle fiber types*

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This research would not have been possible without the collaboration of my advisor, Dr. Kristine Galek, and committee members Dr. Tami Brancamp and Dr. Julie Smith-Gagen from the University of Nevada, Reno, as well as Ed M. Bice, an outside faculty advisor from the University of Maryland. Thank you for your support and the opportunity to investigate a unique area of the speech pathology field.

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Introduction

An anatomical component of swallowing is the tongue, a muscular hydrostat comprised of intrinsic and extrinsic muscles (Dotiwala & Samra, 2022). Intrinsic muscles originate and insert within the tongue, whereas the extrinsic muscles attach to the hyoid bone, mandible, or styloid process (Sanders, I. & Mu, L., 2013; Dotiwala & Samra, 2022). With sufficient strength, intrinsic and extrinsic muscles form the position and shape of the tongue to allow versatile movements such as cupping, elongation, and retraction (Gilbert et al., 2007). In addition to movement, the tongue is responsible for generating pressure during the oral phase of swallowing. Tongue pressure contributes to the execution of essential everyday tasks such as articulation, oral hygiene, mastication, and swallowing (Blumen et al., 2004; Stierwalt & Youmans, 2007; VanRaventhorst-Bell et al., 2018).

The tongue changes shape and position in the oral cavity to facilitate the execution of swallowing, requiring the timely coordination of a sequence of neuromotor events, including elevation, depression, tension, and tongue relaxation (Seikel et al., 2019). The tongue can be subdivided into anterior and posterior portions, which serve different functions. Although the tongue operates as a single organ, during swallowing, the anterior tongue prevents premature spillage and creates a motion that assists in propelling the bolus into the pharynx. The posterior tongue prevents posterior spillage, facilitates oral processing of the bolus, and acts as a compressive force for bolus propulsion into the pharynx (McKay et al., 2020; Matsuo & Palmer, 2008). An understanding of the muscular composition of the tongue provides an explanation of the difference between anterior and posterior tongue pressures.

Tongue Muscle Fibers and Their Roles

The anterior two-thirds of the tongue is considered the "body" and the posterior one-third of the tongue is considered the "root" or "base" (Dotiwala & Samra, 2022; Sanders & Mu, 2013). Boundaries for the root and body of the tongue are indistinct as the tongue muscles and muscle fiber types run continuously through the hydrostat. Small, type II fast-twitch muscle fibers make up the body of the tongue and allow for controlled fine motor movements like bolus manipulation during swallowing (Van Ravenhorst-Bell et al., 2018). The larger muscles of the tongue root, comprised of type I slow-twitch muscle fibers, control gross motor movements for propulsion of the bolus into the pharynx (Cullins, 2017; Stal et al., 2003). Due to the nature of the muscle fiber types, the posterior muscles can exert maximum pressure for longer periods of time than the fast-twitch muscle fibers of the anterior tongue (Van Ravenhorst-Bell et al., 2018; Stal et al., 2003; Zaidi et al., 2013).

Measuring Tongue Strength

The maximum isometric pressure (MIP) exerted by the tongue is known as tongue strength (Stierwalt & Youmans, 2007; Van Ravenhorst-Bell et al., 2018; Clark & Solomon, 2012; Adams et al., 2013). Subjective measures of tongue strength are standard practice in speech-language pathology, relying on client/caregiver reports and clinical observation (McKay et al., 2020; Solomon, 2004). However, objective measures have higher accuracy, reliability, and validity and are better suited for monitoring progress and making evidence-based clinical decisions (McKay et al., 2020; Clark et al., 2003; Olswang et al., 1994). Several commercial devices are available for objective measurements of isometric tongue pressure. The Iowa Oral Performance Instrument

(IOPI) is the gold standard for measuring tongue pressure (McKay et al., 2020; Adams et al., 2014; Vitorino, J., 2010; Stoppani, J., 2014). The IOPI uses a small air-filled bulb to measure isometric tongue pressure in kilopascals (kPa), allowing comparison to normative pressures and ratios.

Ratio

Ratio is a quantitative metric allowing for value comparison. In medical research, ratio variables measure health outcomes essential for evaluating the effectiveness of treatments and monitoring progress (Hassan, 2022). In terms of muscle morphology, ratio is considered a comparison of proportions of muscle fiber types. Pairing knowledge of muscle fiber type ratios with pressure ratios can improve our understanding of the relationship between the anatomy and physiology of the human tongue, thus improving how we diagnose and treat swallowing disorders.

Stal et al. (2003) researched tongue muscle fiber composition in five samples collected from healthy humans who died suddenly and accidentally. They found the middle-anterior and anterior regions of the tongue to be comprised of 57-71% type II fibers and the posterior-medial and posterior regions to contain only 34-38% of the same fiber type, suggesting a greater concentration of type I slow-twitch muscle fibers in the posterior tongue. They concluded that regional fiber type differences may be the result of functional differences; high levels of type II fast-twitch fibers in the anterior tongue allow for rapid movements necessary for articulation and bolus manipulation, while the higher concentration of type I slow-twitch fibers of the posterior tongue are suited for prolonged, slow activities necessary for swallowing and airway protection.

Research by Sanders et al. (2013) supports Stal et al.'s (2003) findings. They investigated the tongues of six adult cadavers collected within 24 hours of death to analyze histological composition. Medially, Sanders et al. (2013) found the anterior tongue to contain 45% type I and 55% type II muscle fibers. The posterior tongue contained 69% type I and 31% type II muscle fibers. Given these results, the researchers hypothesized that differing compositions and physiological responsibilities of the anterior and posterior muscle fibers of the tongue suggest the likelihood that the pressure generated in each area will differ (Sanders et al., 2013). Research from Gingrich et al. (2012) supports this hypothesis as they found anteriomedian tongue pressure generation more powerful than posteromedian regions in young adults, suggesting a correlation between a higher concentration of type II muscle fibers and greater pressure generation. The fiber relationship in healthy adult tongues may suggest a similar relationship in those of children. However, there is a paucity of information concerning the pediatric tongue.

Establishing a normative tongue pressure ratio for healthy four-year-olds represents the first step in understanding tongue muscle fibers and pressure generation in the pediatric population. Determining normative values will provide a reliable comparison for lingual pressure exerted by children exhibiting tongue weakness, which may also suggest differences in the pediatric muscle fiber ratio when compared to the adult tongue (type I vs. type II). Research on normative anterior and posterior tongue pressure ratios is currently unpublished, but there is limited information available on MIP in children.

Normative Data

Clark & Solomon (2012) suggest that access to normative data for individuals across the lifespan is necessary to understand the relationship between reduced tongue strength and swallowing deficits. Few current studies report normative data on MIP in the healthy pediatric population. Most investigations focus on anterior tongue pressure in adult participants with little investigation of posterior tongue pressure.

Using the IOPI, Youmans et al. (2009) investigated maximum anterior isometric tongue pressure in 96 healthy adult participants (48 females, 48 males) aged 20-79 years to determine the differences in tongue pressure related to age and sex. They found no significant difference in sex ($p = 0.25$); however, they found the oldest participants to have the weakest tongues. Researchers found significant differences in tongue pressure between the younger and older groups ($p < 0.0001$) and the middle and older groups ($p = 0.008$), with no significant difference between the younger and middle groups ($p = 0.19$). The study assisted in establishing anterior MIP for three age ranges of healthy adults, improving our understanding of tongue strength. The investigation did not provide information concerning the investigation of MIP in children, nor did it provide a ratio of anterior-posterior tongue pressure ratios in any age group.

Vanderwegen et al. (2019) studied the influence of age and sex on maximum anterior and posterior tongue strength in healthy Belgian children aged three to 11. They did not collect posterior pressures in three- to five-year-old participants due to the size of the oral cavity in children that young. Using the IOPI, researchers found a statistically significant difference in anterior pressure measurements between age groups ($p < 0.001$). Children aged three to six years had a lower range of anterior MIP (18.82 - 38.45 kPa) than seven-to-11-year-olds (41.45 - 60.18 kPa). Male participants aged four years had an average MIP of 31.36 kPa and female participants averaged 37.73 kPa. They also found a statistically significant difference in posterior maximum tongue pressure measurements between age groups ($p < 0.001$). The six-year-old female (29.36 kPa) and male (33.91 kPa) participants exerted the lowest average posterior tongue pressures and the female (62.90 kPa) and male (64.18 kPa) 10-year-olds exhibited the highest. The authors concluded that MIP values increase slowly from three to six years, rapidly from six to seven years, and then peak around ten years of age. Researchers found a relationship between anterior ($p < 0.001$) and posterior ($p < 0.001$) maximum tongue pressures and age but no significant difference in maximum pressures anteriorly ($p = 0.34$) or posteriorly ($p = 0.93$) between sexes.

McKay et al. (2020) studied the relationship between anterior tongue strength and age and sex in a sample size of 119 (60 females, 59 males) healthy Australian children aged six to 11 years. Statistical analysis showed a significant main effect between age groups ($p < 0.001$). Eight-year-olds exhibited a mean tongue pressure of 54.77 kPa (SD = 11.23), a greater strength than the six-year-olds (44.58 kPa; SD = 12.75; $p = 0.001$). However, they found no significant difference between the mean anterior tongue pressure of eight-year-olds and 10-year-olds (56.88 kPa; SD = 10.64; $p = 0.69$) nor in tongue strength between sexes.

Potter & Short (2009) studied maximal anterior tongue pressure in healthy, typically developing children between three and 16 years of age. Using the IOPI device, researchers investigated a sample size of 150 participants and found tongue strength to increase with age. The mean tongue pressure in the three-year-old population (14 females, 14 males) was 20.55 kPa (*SD* = 7.75), and the mean tongue pressure in 16-year-olds (five females, five males) was 61.1 kPa (*SD* = 3.8); a threefold increase. The four-year-old participants (22 females, 18 males) scored a mean maximal tongue pressure of 33.4 kPa (*SD* = 9.7). Potter & Short (2009) found tongue pressure to increase rapidly between the ages of three and eight, slow down, and then peak in adolescence-adulthood. They found no significant difference in tongue strength between male and female participants aged three to 14 years ($p = 0.40$) and a slight difference between male and female 16-year-old participants ($p = 0.042$).

The body of literature suggests that maximum tongue pressures increase with age, exhibiting periods of plateau and rapid escalation with no significant difference in MIP between sexes. All the studies investigated MIP from reasonable sample sizes, and age ranges from adult and pediatric participants. Only one study reported posterior pressures. Pressure ratios were not established in any of the studies. Potter & Short (2009) and Vanderwegen et al. (2019) were the only reports reviewed that included participants of the current study's target population.

Establishing normative values offers a comparison for pressures exerted by individuals experiencing tongue weakness. The discrepancy between normal and impaired pressures assists professionals in creating therapy goals, as the data can be easily translated into the clinic. Further research is needed to establish norms and ratios of tongue pressures for all ages. The current study aims to establish normative data and ratios for children aged four years.

Purpose

Normative data establishes a baseline distribution for typical functioning to which individual performance can be compared (Campbell, D., 2013). Pediatric swallowing disorders are understudied in etiology, diagnosis, and treatment. A 2014 study found that swallowing disorders affect nine in 1,000 children (<1%) annually (Bhattacharyya, N., 2015). However, a general lack of education on signs and symptoms of swallowing disorders and the resources available for intervention may contribute to under-reporting. Normative data for maximum anterior and posterior tongue pressures in the pediatric population are severely lacking, and current published data does not establish anterior-posterior pressure ratios.

Researchers for the current study hypothesized similar anterior and posterior pressures exerted by male and female four-year-olds with an anterior-posterior pressure ratio of one. No significant difference in pressures between sexes is expected for two reasons: male and female children are expected to achieve the same developmental milestones by the time they're four years old, and such findings would align with existing reports. A pressure ratio of one is expected because anterior lingual pressure in a four-year-old is less developed than that of an adult, secondary to the acquisition of articulatory coordination and accuracy. Therefore, it is unlikely that a four-year-old's lingual muscle fiber composition mirrors an adult's, resulting in a more continuous distribution of muscle fibers. This study does not investigate muscle fiber composition of the tongue; however, it aims to:

- Establish normative data for anterior and posterior tongue pressures in healthy, typically developing, English monolingual children aged four years in the United States.
- Investigate sex differences in tongue pressure.
- Establish an anterior-posterior tongue pressure ratio for clinical assessment and treatment.

Method

The current investigation was adapted from the procedures, instrumentation, and dependent measures used by Youmans et al. (2008) and Potter & Short (2009). However, the study did not include boluses or measures of swallowing pressures. The University of Nevada, Reno institutional review board approved this study (IRBNet:2064821-6).

Participants

Researchers recruited 56 participants (30 females, 26 males) from six preschools in Reno and Sparks, Nevada and Tacoma, Washington. The director/principal of each school submitted a signed consent form allowing data collection to occur on-site. One additional site in Vaughn, Washington, provided signed consent, but parents did not return signed forms to participate. Recruitment was conducted via word-of-mouth, social media, and information packets. Flyers offering a brief explanation of the study's purpose and procedures were attached to permission slips and sent home with all students aged four years and zero months (4;0) to four years and 11 months (4;11). Parents were requested to return the signed permission slips if they consented to their child participating. Consent forms included a questionnaire (Figure 1) created by the researchers inquiring about health history, developmental milestone progression, feeding history, and food preferences. Information regarding food preferences was adapted from the SOS Approach to Feeding. Invitations and consent forms were sent home to parents at least one week before data collection. Signed forms were returned with the child and collected by their teacher. School directors and classroom teachers sent verbal and written deadline reminders to parents.

Each participant completed one five-repetition training period followed by official data collection consisting of one one-minute break, three anterior tongue pressure readings separated by 10-second breaks, one two-minute rest period, and three posterior tongue pressure readings separated by 10-second breaks. Measurement conditions (anterior versus posterior) were counterbalanced to mitigate condition effects.

Inclusion criteria were typically developing, monolingual English speakers aged four years with positive health status and no history of swallowing, speech, respiratory, neurologic, or other related disorders that may compromise swallowing function and safety or inhibit tongue function (i.e., head and neck cancer), confirmed by parent/caregiver report. Participants passed an oral-peripheral examination (OPE) and a brief articulation screen conducted by a speech-language pathology graduate student researcher. The purpose of the OPE was to identify anatomical and/or physiological abnormalities of the mouth (i.e., tongue tie, cleft palate, hindered mobility) that may impede function. The articulation screen ensured that participants produced age-expected consonants.

The OPE (Figure 2) evaluated the appearance, coordination, and range of motion of the jaw, tongue, lips, and palate. The standardized Preschool Language Scales, 5th

Edition (PLS-5) articulation screening (Figure 3) ensured the participant's articulatory skills met age-expected standards. Participants identified nine pictures to elicit sounds expected by age 4;0-4;11 including p, g, m, k, t, f, sh, ch, l, and s. The PLS-5 protocol included developmental norms. The examiner instructed the participant, "I want you to tell me what you see, and I'll listen to your speech. What is this?". The examiner modeled the word for participants who could not name the picture (i.e., "This is a dog. Say dog."). Participants were asked to repeat themselves if their initial response was unintelligible. They earned one point per correctly produced consonant for a maximum possible score of 10. According to the PLS-5 protocol, a score less than 8 was considered failing.

Instrumentation

Researchers used the Iowa Oral Pressure Instrument (IOPI) Pro Model 2.3, an FDA-approved device created by IOPI Medical LLC to measure tongue pressure. The IOPI handheld pressure transducer measured and documented participant tongue strengths. An 11.5 cm connecting tube attached an air-filled tongue bulb to a pressure in-port. The tongue bulb, a pressure sensor, is 3.5 cm long and 4.5 cm in diameter. The device measures the maximum pressure a participant can produce by compressing the bulb. Maximum isometric tongue pressure results were displayed in kilopascals (kPa) on an LCD screen. The IOPI has been used in several published studies and is known to demonstrate test-retest reliability (Youmans et al., 2008; Youmans & Stierwalt, 2006).

Procedures

The following procedures were adapted from studies by Youmans et al. (2008) and Potter & Short (2009). Speech-language pathology graduate students completed all testing. Data collection occurred in well-lit environments, with participants seated upright in a straight-back chair. Preschool directors requested data be collected in the school hallway, so noise was sometimes unavoidable. Participant behavior suggested that seeing and hearing peers may have motivated instead of hindered performance.

Researchers collected two screenings and six tongue pressure readings from each participant. Tongue pressure readings were collected from each participant irrespective of screen results, but only data from children who passed the screens were included in statistical analysis. Refer to Figure 4 for the tongue pressure data collection form.

The examiner positioned the tongue bulb immediately posterior to the central incisors for anterior pressure measurements and approximately half the distance between the tongue tip and soft palate for posterior placement. The examiner placed and held the tongue bulb in the correct position during each trial to prevent tube biting or movement. For consistency, the examiner's gloved fingertips touched the vermillion ridge of the participant's lips while holding the bulb in place, and the tube was not released during the 10-second breaks.

Prior to bulb placement, the examiner used tactile cues (i.e., tongue depressor) to indicate the anterior and posterior regions of the tongue needed for bulb compression by asking the participant to lift the cued area of the tongue and push the tongue depressor. The procedure continued once region-specific elevation was confirmed. Participants underwent a one-time, five-repetition training period with the bulb before officially recording pressure measurements to ensure that each participant understood the instructions. The examiner placed the IOPI bulb in the participant's mouth and instructed them to use their tongue to squeeze the bulb against the roof of their mouth as hard as they could and then stop. The examiner used verbal reinforcements to encourage maximal exertion by saying, “Push, push, push, and stop.” Participants were offered visual feedback during the training period to improve their understanding of protocol. Visual feedback was not offered during official data collection.

With the bulb in place, the examiner directed the participant by saying, "When I tell you to, use your tongue to push the bulb against the roof of your mouth as hard as you can, just like we practiced. I will tell you when to stop. We will do this three times, take a break, do it three more times, and we’ll be done. Are you ready?". With confirmation from the participant, the examiner cued, “Push, push, push and stop.”. This was repeated twice more with a 10-second break between each trial. The researcher recorded all the attempts but only used the highest value of the three trials, MIP, for analysis. After a two-minute break, the examiner repeated this process in the second position. Table 1 represents the data collection schedule. Participants completed six trials (three anterior, three posterior), resulting in two MIP values (one anterior, one posterior) used to calculate an anterior-posterior MIP ratio. Results from the screening tools and tongue pressure measurements were sent home to parents on the same day (Figure 5). It was reiterated to parents that results from the screen were not definitive or diagnostic. Contact information for the UNR Speech & Hearing Clinic was listed on the form.

Data Analysis

Data was analyzed using descriptive statistics to compare MIP values. Researchers used the Statistical Package for the Social Sciences (SPSS) software to calculate an Independent Samples t-test to determine the relationship between sex and anterior and posterior pressure values and whether the differences were statistically significant. T-tests for Equality of Means determined two-sided *p* values and 95% confidence intervals for anterior and posterior pressures and differences between sexes. A *p*-value of equal to or less than .05 suggests that there is a high probability the results did not happen by chance. Confidence intervals evaluate the degree of certainty in the results for both anterior and posterior pressures. Descriptive statistics were used to establish average pressures by sex and anterior-posterior ratios.

Results

Researchers collected data from 56 participants (26 male, 30 female). Eight of the 56 participants were disqualified from statistical analysis due to violation of inclusion criteria: three (two female, one male) failed the articulation screen, two (one female, one male) failed both screens, two (both male) were reported, after completion of data collection, to have a history of speech services and one female was reported, after completion of participation, to have an existing neurological disorder. One male participant was reported to have a history of a neurological disorder (i.e., breath-holding seizures), but he remained eligible, as decided by the research team, because he hadn't had an episode in 1.5-2 years and was no longer receiving medication for the condition. Therefore, data from 48 eligible participants were analyzed. Every target age (4;0-4;11) for this study was represented by at least one participant; 4;5 being the most represented (10 participants) and 4;1, 4;4, and 4;10 the least (1 participant) (Table 2).

Results showed that 95.8% (46 of 48) of participants tolerated the bulb without gagging or displaying negative behaviors. After several attempts, it was determined by the researcher to discontinue data collection of posterior tongue pressure from two male participants (4.1% of sample size): one for multiple episodes of gagging and the other for continued discoordination of tongue elevation after several attempts. However, anterior pressure readings from both participants were included in the final analysis. Four participants, or 8.3% of the whole (two female, two male), gagged at least once while using the bulb.

The average anterior tongue pressure was 28.35kPa (*SD* = 7.807; 95% CI = [25.35-31.45]) for females and 28.41kPa (*SD* = 7.908; 95% CI = [25.1-31.7]) for males (Table 3). Independent Samples t-test comparing anterior pressures between male and female participants indicated no statistical significance ($p = .978$) (Table 4). The average posterior tongue pressure was 26.65kPa (*SD* = 8.231; 95% CI = [10.3-43.0]) for females and 27.75kPa (*SD* = 6.988; 95% CI = [14.1-41.4]) for males (Table 3). Independent Samples t-test comparing posterior tongue pressures between male and female participants indicated no statistical significance ($p = .628$) (Table 4). Based on the findings, the calculated average ratio of anterior-posterior tongue pressures in four-year-old females is 1.06 and 1.02 in four-year-old males. Table 5 reports male and female anterior and posterior MIPs and ratios. Table 6 offers a bar graph comparison of male and female anterior and posterior MIPs.

Discussion

The current study investigated the relationship among tongue pressures in monolingual English-speaking, typically developing children aged 4;0-4;11 in the United States. Results established normative anterior and posterior tongue pressures, calculated anterior-posterior tongue pressure ratios, and compared tongue pressures between male and female participants. Data suggested no significant difference in anterior and posterior tongue pressures between male and female participants.

The analysis of pressure values supports the researcher's hypothesis that there is no significant difference between male and female tongue pressures. Factors contributing to this power similarity may be the still-developing speech, fine and gross motor coordination, and oral processing in the target population. Unlike the histological results in the adult population, the calculated pressure ratios indicate a more consistent dispersion of muscle fiber types throughout the tongue of a four-year-old compared to an adult. However, the hypothesis is based on tongue strength, not histological data. Especially considering the anterior region of the adult tongue is generally stronger than the posterior region.

Additional research investigating tongue muscle fiber composition may shed light on this matter. Potter & Short (2009) reported the average anterior tongue strength of four-year-olds to be 33.4 kPa (*SD* = 9.7) and Vanderwegen et al. (2012) reported male and female anterior pressures to be 31.36 kPa and 37.73 kPa in Dutch multi-lingual speaking children. Both studies reported higher pressures than the current study, but within the standard deviation. Differing sample sizes and geographical locations may contribute to this discrepancy. Potter and Short reported a high percentage of participant compliance and a low occurrence of sensitive gag reflex, both supported by results from the current study. Results also align with findings from Youmans et al. (2009) and Potter & Short (2009), indicating no significant difference in tongue pressure between genders. Normative posterior tongue pressure measurements and the average anterior-posterior ratio established here are the first of their kind. Thus, a comparison to other research is unavailable.

Clinical Implications

Clinically, a comparative ratio greater than or less than one may indicate an imbalance between anterior and posterior muscle fibers of the tongue that may require further investigation.

Observations

The bulb's smooth, squishy texture and visual feedback from the transducer captured and maintained participant engagement. External motivators (e.g., wind-up toys, toy cars, and stickers) were effective tools for redirecting and maintaining attention. As requested by school personnel, data collection occurred in common hallways. Despite the researcher’s concern about inefficiency and distraction, participants appeared calm and eager to participate in their familiar environment. One participant wore a chew necklace daily for sensory stimulation and produced a tongue pressure larger than the calculated average. Additional research may indicate whether consistent necklace chewing contributed to his high-average tongue strength. It is unknown whether parents of kids who failed one or both screens sought intervention after receiving the results.

Limitations

A possible limitation was the large IOPI bulb relative to the oral cavity of a four-year-old, which made differentiation from anterior to posterior placement difficult. A sensitive gag reflex in two participants prevented the collection of posterior pressure readings, which may have affected the analysis. However, there were fewer occurrences of gagging than expected. Few participants were observed to be hyperactive, exhibiting stimming behavior. Due to the age of participants, it is possible that disorders such as autism spectrum disorder and attention deficit hyperactivity disorder were present but not yet diagnosed.

Prepositional instructions like lifting the front and the back of the tongue ‘up’ proved difficult for many participants, but tactile cues with a tongue depressor improved their understanding. Although parents confirmed honesty in answering the questionnaires, it is possible that diagnoses or history/current reception of speech services were not disclosed. A quiet environment was not always possible at data collection sites, which may have impacted a participant’s patience and attentiveness.

The duration of breaks during data collection varied slightly as redirecting attention was more difficult for some than others, causing slightly longer rest periods but never exceeding an additional 30-60 seconds. Longer practice times were required for some participants due to difficulties with attention or tongue coordination. Some practice sessions were discontinued prematurely due to the researcher’s concerns of cognitive fatigue indicated by the participant. Some participants were asked to produce additional trials because they displaced, bit, or sucked on the bulb. Unusually low pressures may be due to improper bulb placement unbeknownst to the researcher, misunderstanding of instructions, or compression of the bulb with incorrect tongue region by the participant.

This study analyzed a small sample size of 48 (26 female, 22 male) monolingual English-speaking four-year-olds in Reno and Sparks, Nevada, and Tacoma, Washington. Although race/ethnicity was not logged, based on observation, there was limited diversity. A larger, more diverse sample size would improve the generalizability of results. Additional research is also encouraged for non-English and bilingual speakers within and outside of the United States.

Future Implications

These results are intended to improve the quality of care for the pediatric population experiencing speech and swallowing disorders. Establishing expected tongue pressures in typically developing, monolingual English-speaking four-year-olds allows for comparison of pressures produced by children presenting with swallowing and speech disorders. These data contribute to the care team's creation of therapy plans, prognosis, and therapy duration. Research is needed to establish ratioed tongue pressure norms for the older pediatric population. Older children have a larger surface area of the palate and are more likely to understand the instructions and differentiate the regions of the tongue with which to push, likely making bulb placement easier and results more reliable.

Conclusion

The current study established baseline anterior and posterior tongue pressure measurements in four-year-olds. It is one of few that investigates anterior tongue pressure, the first to investigate posterior tongue pressure, and the first to establish an anterior-posterior maximum isometric tongue pressure ratio. Researchers recruited enough participants to draw generalizable conclusions, and the sex-balanced sample size adequately represented male and female tongue pressures. The information is valuable for treating and diagnosing patients of the demographic represented and will bring attention to the lack of research regarding normative data. Advancements will help clinicians understand the relationship between reduced tongue strength and swallowing deficits.

Tables

Table 1: Data collection schedule

Participants completed a five-repetition training period and a one-minute break prior to official data collection. Participants then completed three push-and-release trials separated by two 10-second breaks. After a two-minute break, researchers repeated the schedule with the bulb in the second location.

Training Period		Trial 1		Trial 2		Trial 3		*Repeat for set of trials on the non-tested location (anterior/ posterior)*
5 repetitions	**Break** 1-min	Push & Release	**Break** 10-sec	Push & Release	**Break** 10-sec	Push & Release	**Break** 2-min	

Table 2: Participant age dispersion by month (4;0-4;11)

At least one participant represented every month between 4-years-and-0-months to four-years-and-11-months. The most represented age was 4;5 (10 participants). The least represented ages were 4;1 (1 participant), 4;4 (1 participant), and 4;10 (1 participant).

Age (year;month)	Gender		Total
	Female	Male	
4;0	1	2	3
4;1	0	1	1
4;2	2	0	2
4;3	1	2	3
4;4	0	1	1
4;5	6	4	10
4;6	1	3	4
4;7	1	2	3
4;8	4	5	9
4;9	6	1	7
4;10	1	0	1
4;11	3	1	4

Table 3: Anterior and posterior MIP comparison by sex
The bar graph below illustrates the difference in anterior and posterior maximum isometric tongue pressures within and between male and female participants. In a direct comparison, males exhibited a stronger average anterior and posterior MIP. However, the statistical analysis determined these results not to be significant.

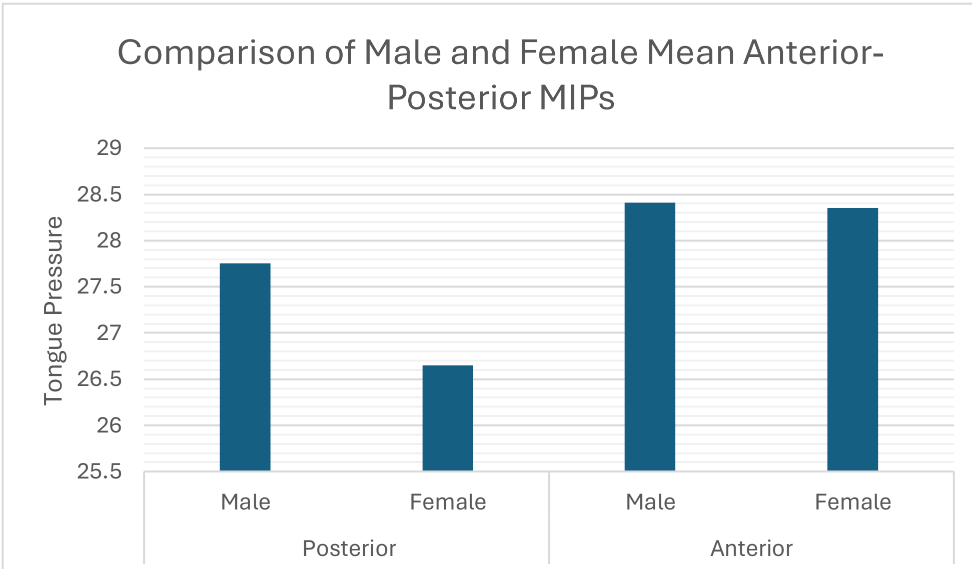


Table 4: Independent Samples t-test
Comparison of anterior and posterior MIP, standard deviation, 95% confidence interval, and p-value by sex. Results from the t-tests indicated no statistical significance between male and female anterior MIP (p=0.978) nor male and female posterior MIP (p=0.628).

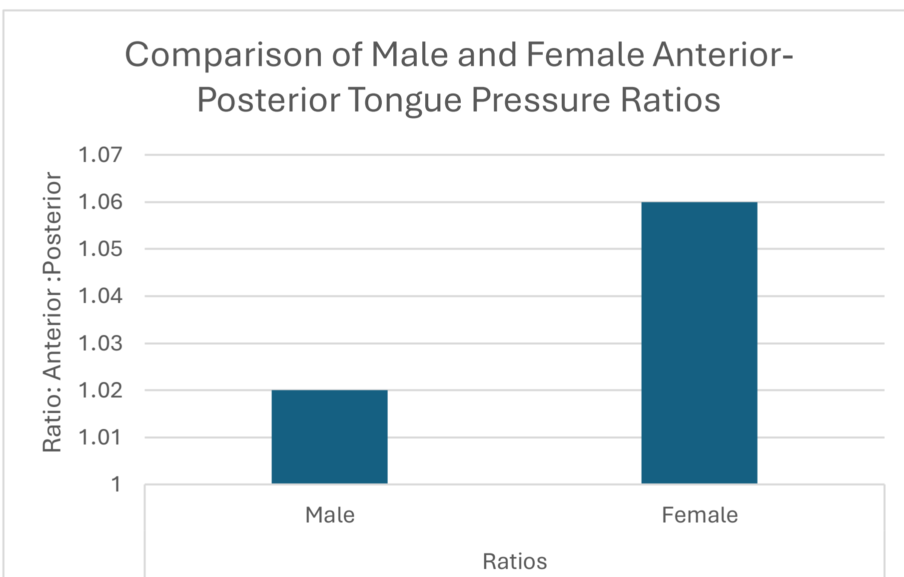
Sex	Anterior MIP (kPa)	Standard Deviation	95% Confidence Interval	*p* - value
Female	28.35	7.807	25.35-31.45	0.978
Male	28.41	7.908	25.1-31.7	

Sex	Posterior MIP (kPa)	Standard Deviation	95% Confidence Interval	*p* - value
Female	26.65	8.23	10.3-43.0	0.628
Male	27.75	6.988	14.1-41.4	

Table 5: Comparison of male and female MIP means and ratios
The calculated average ratio of anterior-posterior maximum isometric tongue pressures in four-year-old females is 1.06 and 1.02 for males.

Sex	Anterior MIP (kPa)	Posterior MIP (kPa)	Ratio
Female	28.35	26.65	1.06
Male	28.41	27.75	1.02

Table 6: Anterior-posterior tongue pressure ratio comparison
The bar graph below illustrates the comparison of ratios between male and female participants. Clinically, a comparative ratio greater than or less than one may indicate an imbalance between anterior and posterior muscle fibers of the tongue that may require further investigation



Figures

Figure 1: Participant Questionnaire

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PI: Kristine Galek, Ph.D. CCC-SLP
RA: Madeleine Daugherty, B.S.

Participant Questionnaire

Please complete the following questionnaire if you have signed the consent form. Please answer the following questions honestly.

Child name:

Date of Birth:

Age:

Question	**Yes/No** (circle one)	
Is your child a mono-lingual speaker? (English only)	Yes	No
Is there a history of complicated pregnancy and/or delivery?	Yes	No
Was your child born prematurely?	Yes	No
Is your child developing as expected and meeting all milestones by the appropriate age?	Yes	No
Does your child receive speech-language therapy services?	Yes	No
Does your child have a history of feeding difficulties? (i.e., difficulty latching, feeding tube)	Yes	No
History of head/neck injury and/or cancer?	Yes	No
History or current diagnosis of developmental, neurological, or other related disorders that may compromise speech or swallowing function, swallow safety or inhibit tongue function (i.e., oral surgery, cancer)?	Yes	No
How would you describe your child's eating style as 'picky' or avoidant?	Yes	No

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Below is a list of food textures/categories. Place a checkmark next to each category of food that your child eats *regularly*.

Check all that apply:	Texture	Examples
	Meltable Hard Solids	Baby cookies, fruit loops, graham crackers, popsicles, chocolates, snap pea crisps
	Soft Cubes	Avocado, overcooked squash, bananas, soft-boiled potatoes, soft cheese cubes
	Soft Mechanicals (Single Texture)	Small pasta, plain muffin, scrambled/hard boiled eggs
	Soft Mechanicals (Mixed Texture)	Mac & cheese, chicken nuggets, French fries, lasagna, blueberries
	Hard Mechanicals	Tortilla chips, carrots, steak, hard cookies, apples, cucumbers, pork chop, pretzel rods

Adapted from the SOS Approach to Feeding Program

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Figure 2: Oral-Peripheral Exam (OPE)

Oral-Peripheral Screening

ID#___________________

Instructions: *Circle pass (+) or fail (-) for each item. If any items earn a fail rating, the examinee has failed.*

Structures at rest		
Symmetry	+	-
Jaw control		
ROM	+	-
Labial function		
Lip spread /i/ symmetry	+	-
Lip round /u/	+	-
Lip closure at rest	+	-
Lingual function		
Protrusion to teeth	+	-
Retraction /k/	+	-
Lick lips	+	-
Lateralize to corners	+	-
Lateralize to buccal cavity	+	-
Elevation to alveolar ridge	+	-
Lowering of tip	+	-
Palatal function		
(movement/symmetry)		
Prolonged /a/	+	-

Final score (circle one): **pass** **fail**

Figure 3: PLS-5 Articulation Screen

Articulation Screening Tool
Preschool Language Scales, 5th Edition (PLS-5)

ID#__________________ **Pass/Fail** (circle one)
Instructions: Mark the appropriate box to indicate whether the child produces the bolded phoneme correctly or incorrectly.

Materials: *Stimulus pages*
Procedure: *Say, "Here are some pictures." Point to each picture and say, "What is this?". For the picture of teeth, ask, "What are these?". If the child is unable to name the picture (e.g., says "I don't know" or uses a synonym that does not contain the targeted sounds), you name it and tell the child to repeat the word (e.g., say, "It's a dog. Say dog.").*
Scoring: *The examinee must score at least 8/10 to 'pass.' Anything lower is a 'fail.'*

Sound	Correct	Incorrect
Pan/**p**ot	/p/	/p/
Do**g**	/g/	/g/
Mon**k**ey	/m/ /k/	/m/ /k/
Teeth	/t/	/t/
Feather	/f/	/f/
Shoe	/sh/	/sh/
Chicken	/ch/	/ch/
Hor**s**e	/s/	/s/
Lamp	/l/	/l/

Final score: /10
Circle one: **pass fail**

Figure 4: Tongue Pressure Data Collection Form

Tongue Pressure Data Collection Form

Participant code: _______________ Date: ____________________

Chronological age: ______________ Researcher initials: _________

Consent: yes no

Site #: 1 2 3

Location	Trial 1	Trial 2	Trial 3	Maximum
Anterior				
Posterior				
Spit Swallow				

Side effects: n/a gagging coughing vomiting

Compliant? **Yes** **no** Discontinued? **Yes** **no**

Notes:

Figure 5: Send-Home Data Collection Form

University of Nevada, Reno
School of Medicine

Kristine Galek, Ph.D. CCC-SLP
Madeleine Daugherty, B.S.

Dear parent(s)/legal guardian of _______________________,

Below are the results of how your child did on today's tests and the strength of their tongue. It's important to note that these screenings are just to see how things are going, **not** to diagnose anything. If your child didn't pass, you can look into seeing a speech-language pathologist for more information (refer below). We're studying what's normal for tongue strength, so your child's tongue strength results are just fun to know!

What do the scores mean?...

Mouth Exam: A 13/13 means everything looks normal
Speech Test: An 8/10 or above means their speech is on track.
Tongue Strength: Measured in pressure (kilopascals) – for now, we can't interpret what your child's tongue strength means.

Screener	Results	Notes
Mouth Exam	/13	
Speech Test	/10	
Tongue Strength	Front kPa Back kPa	

Please contact the UNR Speech & Hearing Clinic if you would like to schedule a speech evaluation.

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Thank you for helping with our research!
The Research Team
Principle Investigator: Dr. Kristine Galek, CCC-SLP
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