Dysphagia
DOI 10.1007/s00455-009-9215-2

ORIGINAL ARTICLE

Maximal Tongue Strength in Typically Developing Children and Adolescents

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Abstract Evaluating tongue function is clinically important as the generation of adequate pressure by the anterior tongue against the hard palate is crucial for efficient oropharyngeal swallowing. Research in the evaluation of tongue function in pediatric populations is limited due to questions about the reliability of children's performance on objective measures of tongue strength and the lack of comparative data from typically developing children. The present study examined tongue strength in 150 children and adolescents, 3–16 years of age, with no history of speech or swallowing disorders using the Iowa Oral Pressure Instrument (IOPI). Children as young as 3 years of age were able to tolerate the IOPI standard tongue bulb and were reliable performers on measures of tongue strength with an unconstrained mandible. Tongue strength measurements were elicited in blocks of three trials with a 30-s rest between the trials and a 20-min rest between blocks. Tongue strength increased with age with no consistent best trial across ages and participants. Males showed a slight increase in tongue strength over females at ages 14 and 16. This study suggests maximum pediatric tongue strength may be reliably evaluated using commercially available equipment and provides a limited sample comparative database.

Keywords Tongue · Tongue pressure · Children · Pediatric · Swallowing disorders · Deglutition · Deglutition disorders

All work was completed at Washington State University Spokane and the University of Wisconsin-Madison.

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Introduction

Evaluating tongue function is important in the assessment and rehabilitation of chewing and swallowing disorders in adults and children. Adequate lingual pressure is crucial for bolus clearance in the oral phase and indirectly in the pharyngeal phase of swallowing [1]. In older adults, maximal tongue strength is predictive of the amount of oral residue after the swallow [2], dysphagic tongue movements, and coughing at mealtimes [3]. In adults, 20–79 years of age, maximal tongue strength gradually decreases with increasing age, with a significant drop after age 60 [4].

Multiple terms have been used to refer to maximal tongue strength, including tongue pressure [2, 3], maximal tongue pressure [5], maximum tongue pressure [6], tongue strength [4, 7–13], peak isometric pressure [14], maximal tongue-to-palate pressure [15], and maximum isometric pressure [16]. While the present study uses the term tongue strength, it is important to consider that all the preceding terms refer to oral closure measured at the tongue because tongue strength is the result of muscle activation of the posterior genioglossus, mylohyoid, anterior belly of the digastric, medial pterygoid, masseter, and intrinsic tongue muscles [15].

In the pediatric population, tongue strength has been examined in relation to speech disorders, but there has been

Published online: 24 April 2009

limited research examining tongue strength in relation to pediatric swallowing disorders. In relationship to speech, there is no difference in tongue strength between typically developing children and children with speech delay errors [8]. However, across three published studies reporting tongue strength in children ages 3–12 with developmental motor speech disorders, 10 of the 12 participants showed decreased tongue strength compared to children with typical development and children with speech delay, suggesting that decreased tongue strength may be predictive of motor impairment [8, 11, 12].

A clinical concern with testing tongue strength is equipment availability, especially for young children. Previous pediatric tongue strength studies have measured tongue strength using a laboratory-designed 33-mm tongue bulb with 12 school-aged children [11], a 15-mm tongue bulb with 24 preschool-aged children [8], and an earlier version of the IOPI tongue bulb with 11 school-aged children [12]. The tongue bulb for the commercially available Iowa Oral Performance Instrument (IOPI) [17], which is often used to measure tongue strength with adults, is 35 mm long. Because tongue length (measured along the dorsal superior contour from the valleculae to tip) increases 37% between age 3 years and adult [18], the IOPI tongue bulb is in contact with 30% of the tongue surface in an adult compared to 50% of the tongue surface of a 3 year-old child, raising concern about young children's ability to tolerate the standard bulb [8].

Another concern in testing tongue strength is reliability (i.e., consistency) across trials. In adult populations, measures of tongue strength have been found to be reliable across trials [10]. The only published study examining repeated measures of tongue strength in children reported consistent performance across trials, albeit for a small sample ($N = 6$) of school-aged children [12].

A final clinical concern is the lack of comparative data. Research in pediatric swallowing disorders has been hampered by the lack of comparative data. There is a great need for meaningful objective quantitative measures to aid in the assessment and management of feeding and swallowing disorders in children [19]. As with adults, problems with tongue strength in the pediatric population have direct implications for the oral phase of swallowing and, thus, indirectly for the pharyngeal phase of swallowing [20]; therefore, establishing objective, quantitative measures of tongue strength in children and adolescents has the potential to aid in the assessment and treatment of pediatric dysphagia.

Tongue strength studies of adults with impaired swallowing use a single age- and gender-matched control for each clinical participant [21]. There are concerns about the accuracy of using a limited number of age- and gender-matched controls for comparing tongue strength in normal and impaired swallowing with pediatric patients as limb strength studies of children report significant strength differences among individual children of the same age due to factors such as height and weight associated with growth [22]. Earlier studies suggest that weight may influence hand strength more than tongue strength. In a small sample study ($N = 6$) of children ages 6–12 years, hand strength and weight were strongly correlated ($r = 0.76$) but tongue strength and weight were only weakly correlated ($r = 0.38$) [12]. However, due to the variation in weight across children of the same age, it is important to examine the relationship across tongue strength, age, and weight to determine the optimal basis for comparing children with swallowing disorders to their typically developing peers.

The objectives of this study were (1) to determine if commercially available equipment could be used to test young children, (2) to examine the number of trials needed to determine maximal tongue strength in children and adolescents, (3) to determine whether tongue strength was best compared by matching for age or weight, and (4) to provide comparative data for tongue strength in children and adolescents.

Method

There were three parts to the study. Part I: Preschool Feasibility examined the feasibility of testing tongue strength in preschool-aged children using standard tongue bulbs [23], Part II: Preschool Multiple Sessions examined the reliability of tongue strength measures in preschool-aged children within and across testing sessions, and Part III: Preschool to Adolescence examined the development and the reliability of tongue strength across two blocks of trials within a single testing session in preschool through adolescent-aged participants.

Participants and Trials

A total of 150 participants were involved in this study. No participants were included in more than one of the three parts of this study. Participants ranging in age from 3 to 16 years were recruited from preschools and public schools in Wisconsin and Washington. In Part I: Preschool Feasibility, 50 participants (10 males and 10 females in the age groups [years;months] 3;0–3;11 and 4;0–4;11, and 5 males and 5 females in age group 5;0–5;5) completed a single block of three tongue strength and three dominant and nondominant hand strength trials with a 30-s rest between trials. In Part II: Preschool Multiple Sessions, 30 participants (5 males and 5 females aged 3;0–3;11, 3 males and 7 females aged 4;0–4;11, and 4 males and 6 females aged 5;0–5;11) completed three blocks of three tongue strength and three dominant and nondominant hand strength trials with a 30-s rest between trials. Blocks 1 and 2 were completed on the same day with a 20-min break between blocks. In Part III: Preschool to Adolescence, 70 participants (5 males and 5 females from the age groups 4;0–4;11, 6;0–6;11, 8;0–8;11, 10;0–10;11, 12;0–12;11, 14;0–14;11, 16;0–16;11) completed two blocks of three tongue strength and three dominant and nondominant hand strength trials with a 30-s rest between trials. Block 3 was completed on a subsequent day within a week of the first two blocks.

All participants performed within normal limits on an oral structure-function exam, including no overt swallowing difficulties on a dry swallow, scored within 1 standard deviation on the Goldman-Fristoe Test of Articulation-2, had never been referred for special educational services, and were making adequate progress in school as reported on parental and teacher questionnaires.

Procedures

All testing was completed by a speech-language pathologist with more than 20 years of experience working with speech and swallowing in neurologic populations (first author) or by speech-language pathology graduate students directly supervised by the first author. This project was approved by the University of Wisconsin-Madison (Part I: Preschool Feasibility) and Washington State University (Parts II: Preschool Multiple Sessions and III: Preschool to Adolescence) institutional review boards.

The standard tongue bulb and the air-and-silicone-filled hand bulb were used with the IOPI to measure tongue and hand strength, respectively. The examiner controlled the positioning of the tongue bulb, as young children have a tendency to try to bite the tongue bulb with their teeth. The tongue bulb was positioned immediately posterior to the central incisors; the bulb stem was held by the examiner immediately anterior to the participant's central incisors for consistent positioning of the bulb. The participants' mandibles were unrestrained. The children were asked to raise their tongues and squeeze the bulb against the palate as hard as they could for approximately 3 s. The examiner encouraged the participants to produce maximal effort during the trial by saying, "Squeeze really hard. Squeeze harder. You can do it." The examiner removed the tongue bulb from the participant's mouth, allowing 30 s of rest between trials. The highest value of all trials was defined as the maximum tongue strength for each participant. For testing hand strength, a mark on the hand bulb was used to insure consistent orientation within the participant's hand as anecdotally variations in measurements have been reported due to bulb orientation (E.S. Luschei, personal communication, November 25, 2003). Body weight was measured using a Taylor Lithium Electronic Scale. IOPI calibration was checked weekly, as recommended by the manufacturer, to ensure accurate measurement.

Data Analysis

Descriptive statistics (mean, standard deviation, and minimum and maximum values) are provided for the trial with the greatest pressure within each block for tongue and hand strength. Reliability of the tongue strength measures across blocks within session and across sessions was computed using Cronbach's alpha. Two separate two-way analyses of variance (ANOVAs) were used to examine the effects of trial, gender, and age for tongue and hand strength. Planned comparisons were conducted between age groups using Fisher's least significant difference (LSD). Partial correlations, controlling for age, were used to examine the relationships between tongue strength, hand strength, and weight. *Post-hoc* analysis was conducted between age groups using independent *t* tests. Backward stepwise multiple regression was used to identify the set of strongest predictors of tongue strength. An alpha level of 0.05 was set. All computations were made using SPSS v16.0 (SPSS Inc., Chicago, IL).

Results

Of the 150 participants, 148 (99%) tolerated the tongue bulb. One 3 year old refused and one 3 year old began to gag when the tongue bulb touched the tongue tip. Preschool children (Part II: Preschool Multiple Sessions) were reliable performers across blocks within a single session and across sessions completed on separate days (Cronbach's alpha = 0.93). Preschoolers-adolescents (Part III: Preschool to Adolescence) were reliable performers across blocks within a single session (Cronbach's alpha = 0.98). Across participants there was no consistent pattern of which trial produced the maximum tongue strength for Part II: Preschool Multiple Sessions (three blocks of three trials; $F_{8,216} = 1.17$; $p = 0.32$) or Part III: Preschool to Adolescence (two blocks of three trials; $F_{5,410} = 0.507$; $p = 0.48$). For example, examining participants ages 4;0–16;11 (Part III: Preschool to Adolescence), the maximum tongue strength was recorded 50% of the time during Block 1 (trial one 20%, trial two 17%, trial three 13% of the time) and 50% of the time during Block 2 (trial one 24%, trial two 11%, trial three 14% of the time). Although the first trial of each block did not consistently produce the greatest score for individual children, the first trial was the highest on average, followed by the second and third trials. Mean tongue strength by block and trial is shown in Fig. 1. When a third block of trials was included on a subsequent day with children ages 3;0–5;11 (Part II: Preschool Multiple

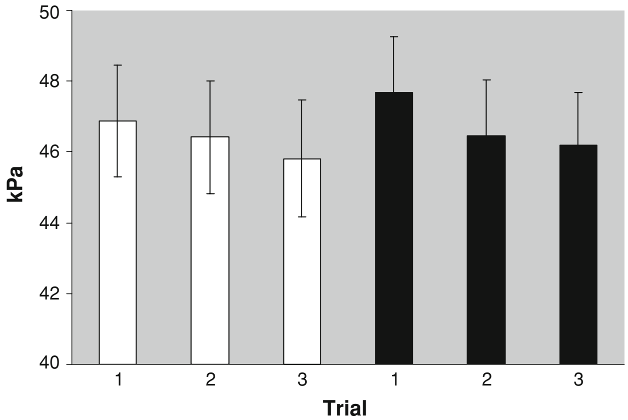

Fig. 1 Mean and standard error values for tongue strength plotted against trial. White bar = Block 1; black bar = Block 2

Sessions), most preschool children (70%) had slightly, but not significantly, lower maximum tongue strength on the second day (Block 3) compared to the first day of testing (Blocks 1 and 2).

Children's tongue strength increased with age ($F_{17,130} = 19.20$; $p < 0.001$). *Post-hoc* LSD showed significant increases between ages 3–4, 5–6, 6–8 years ($p < 0.001$, $p < 0.001$, $p = 0.04$, respectively). Young children, ages 3–6 years, showed greater inter-participant variability on maximum tongue strength measures compared to older children and adolescents, ages 8–16 years, as shown in Fig. 2. There was no overall difference in tongue strength across gender for children ages 3–14 years ($F_{1,130} = 0.70$; $p = 0.40$). In *post-hoc* analysis, using independent *t* tests, there were slight differences in tongue strength between males and females at ages 10, 14, and 16 years (Fig. 3). At age 10, girls' tongue strength was slightly, but not significantly, greater than boys' ($t_{1,8} = 2.14$; $p = 0.065$). At age 14, boys' tongue strength was slightly, but not significantly, greater than girls'

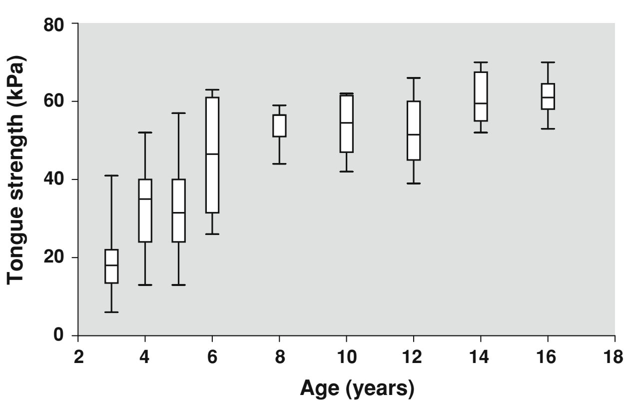

Fig. 2 Mean, standard deviation, and range for tongue strength plotted by age collapsed across gender. Bar = mean; box = standard deviation; range = whiskers

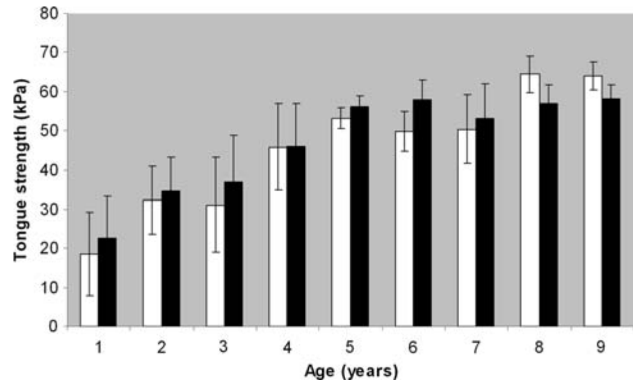

Fig. 3 Mean and standard deviation values for tongue strength plotted against age by gender. White bar = male; black bar = female

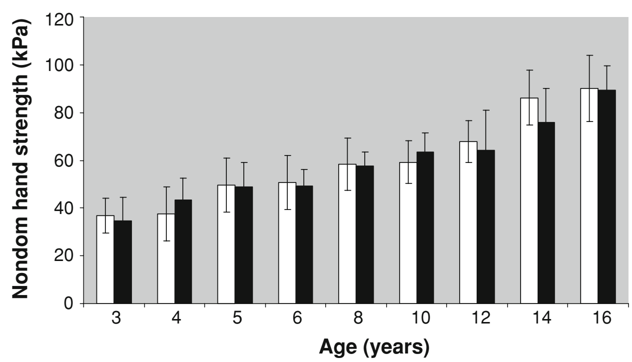

Fig. 4 Mean and standard deviation values for nondominant hand strength plotted against age by gender. White bar = male; black bar = female

($t_{1,8} = 2.25$; $p = 0.055$). At age 16, boys' tongue strength was significantly greater than girls' ($t_{1,8} = 2.42$; $p = 0.042$). There was no gender difference in dominant ($F_{1,130} = 0.35$; $p = 0.55$) or nondominant hand strength ($F_{1,130} = 2.56$; $p = 0.21$) for children ages 3–16 years (Fig. 4).

When controlled for age, tongue strength correlated with dominant ($r = 0.21$; $p < 0.05$) and nondominant hand strength ($r = 0.34$; $p < 0.001$) but not weight ($r = 0.005$; $p = 0.961$). Using backward stepwise multiple regression, the strongest predictor of tongue strength was nondominant hand strength followed by age ($F_{2,97} = 76.73$; $p < 0.001$).

Descriptive statistics for tongue strength by age and gender are shown in Table 1. Predicted means and 80 and 95% confidence intervals are shown in Fig. 5.

Discussion

Contrary to earlier reports, children as young as 3 years of age were able to tolerate the standard tongue bulb from the IOPI. Before this investigation there was concern that the

Table 1 Means, standard deviation, and minimum and maximum values for tongue strength (kPa) by age, gender, and number of participants

Age (years;months)	Gender	*N*	Mean	SD	Min	Max
3;0–3;11	Male	14	18.5	4.8	8	27
	Female	14	22.6	10.7	6	41
4;0–4;11	Male	18	32.2	10.7	16	49
	Female	22	34.6	8.7	18	52
5;0–5;11	Male	9	31.1	12.9	13	56
	Female	11	36.7	12.1	18	57
6;0–6;11	Male	5	45.8	17.5	26	61
	Female	5	46.0	11.0	35	63
8;0–8;11	Male	5	53.2	6.1	44	59
	Female	5	56.2	2.7	52	58
10;0–10;11	Male	5	49.8	6.9	42	58
	Female	5	58.0	5.1	51	62
12;0–12;11	Male	5	50.4	8.7	39	63
	Female	5	53.2	8.8	45	66
14;0–14;11	Male	5	64.4	5.7	56	70
	Female	5	57.0	4.6	52	64
16;0–16;11	Male	5	64.0	4	60	70
	Female	5	58.2	3.6	53	63

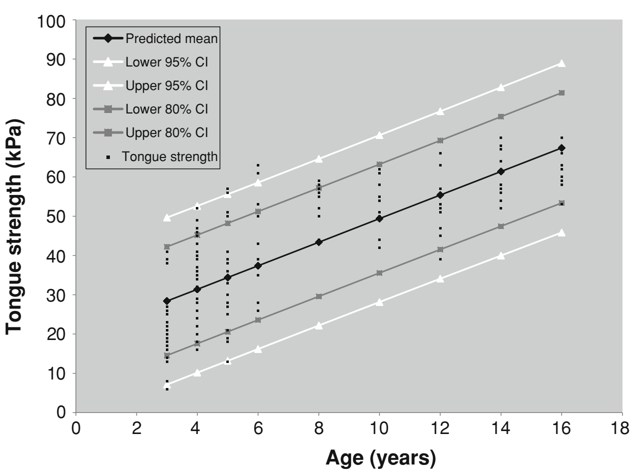

Fig. 5 Predicted means, 80 and 95% confidence intervals, and observed values of individual participants' tongue strength plotted against age

standard bulb from the IOPI would be too large for young children and a pediatric bulb [8, 11] would be necessary. However, this accommodation was not required as more than 99% of the children had no difficulty with the standard tongue bulb, allowing direct comparison across ages.

As predicted, children's tongue strength increased with age, with 16 year olds showing a threefold increase over 3 year olds. Integrating results from the present investigation with those of previous studies [6, 16], it appears that tongue strength increases rapidly across ages 3–8 years, then continues to increase at a slower rate with increasing age, until peaking in late adolescence to young adult-age prior to decreasing with increasing age during adulthood. The mean tongue strength for a 16 year old was 61.1 kPa compared with 62.02 kPa for adults aged 20–39 years in the Stierwalt and Youmans [21] study and decreasing to 55.01 in adults aged 60–91.

There was no significant overall difference in pediatric tongue strength across genders; however, a trend was seen with females showing greater tongue strength than males at age 10 years followed by males surpassing females and showing greater tongue strength at ages 14 and 16 years. Adult studies have differed on significant effect of gender. Youmans and Stierwalt [16] found slight but not significantly greater tongue strength in males aged 20–39 and 60–69 compared to females, while Utanohara et al. [6] found that males' tongue strength was significantly greater than females in their twenties, thirties, and forties, but not in their fifties, sixties, and seventies. The results of the present study support the Youmans and Stierwalt [16] statement that although males tend to have greater tongue strength than females, beginning in mid-adolescence, the difference is likely not clinically relevant.

The capability to objectively measure tongue strength allows for the diagnosis of lingual weakness in the evaluation of pediatric dysphagia and for the documentation of possible changes in tongue strength during treatment for pediatric dysphagia. In adults, decreased tongue strength is related to increased oral and pharyngeal residue after the swallow [24]. Isometric lingual exercise programs, utilizing the IOPI, have been effective in decreasing dysphagia symptoms. Ten of ten adults with dysphagia following a stroke significantly increased maximum tongue strength and swallowing pressures and decreased oral transit duration, pharyngeal residue, and the frequency of penetration and aspiration. It is likely that isometric lingual exercise may decrease symptoms of oral and pharyngeal dysphagia in the pediatric population. Future studies are needed to examine the effect of lingual exercise programs in the treatment of dysphagia in pediatric populations.

All children demonstrated some variability across trials; however, overall they performed reliably on multiple measures of tongue strength. The increased inter-participant variability in children ages 3–6 years, compared to older children and adolescents, likely reflects individual differences in biological and cognitive-strategic development [23]. The corticobulbar tract, which controls tongue elevation, increases conspicuously and nonlinearly in axon diameter and myelination during early childhood and continues to increase more gradually throughout childhood and adolescence, contributing to greater inter-participant variability in younger children [25]. Younger children also differ from older children in their performance awareness.

Older children and adolescents typically watched the display on the IOPI and, in addition to the examiner's encouragement, were intrinsically motivated to surpass their personal best on subsequent trials. Younger children often did not comprehend double-digit numerals and were motivated primarily by the examiner's encouragement.

Two concerns with measuring children's tongue strength in clinical and research settings centered on how many trials were required to reliably measure tongue strength and whether children improve their performance over time, indicating a significant learning or experience factor. When the tongue strength was measured in three blocks of three trials, two blocks on the first day of testing and one block of three trials on a subsequent day within a week of the initial test, maximum tongue strength measurements were obtained 70% of the time on the first day. This finding suggests that there is no practice effect for maximum tongue strength measurements across multiple days. Tongue strength may be accurately measured in typically developing children in two blocks of three trials within a single session, with a rest between blocks. The first trial of the second block most frequently yields the maximum tongue strength; however, this is not consistent across children or adolescents. The decrease in best trial within each block suggests that 30 s may not be adequate time for recovery between trials.

Studies of tongue strength in children and adults have differed on whether the mandible should be unrestrained or stabilized in a standard position using a bite block during tongue strength testing. In the adult population, greater pressure is generated and biomechanical positioning is optimized without a bite block [7] allowing for the best estimate of maximal strength reserve available during deglutition [15]. The present investigation did not restrain the mandible as the goal was to investigate the tongue-to-palate muscular system as a whole to assess maximal strength available during deglutition.

The increase in tongue strength across ages is best explained by the increase in nondominant hand strength followed by age, indicating that children and adolescents are strong or weak across effector systems [23]. The strong relationship between tongue strength and nondominant, but not dominant, hand strength likely reflects biological differences due to increased experience using the dominant hand [23]. Although tongue strength and hand strength are closely related in the typically developing pediatric population, tongue strength cannot be inferred from nondominant hand strength in the pediatric population with neurologic disorders. Robin et al. [12] reported that hand strength did not differ from the typically developing controls with the two children who had decreased tongue strength and motor speech disorders. Multiple regression analysis showed that unlike lower-extremity strength [22], tongue strength in children and adolescents is not closely related to body weight, in agreement with Robin et al. [12] based on a sample of six children. These findings suggest that when comparing the tongue strength of children and adolescents with impaired swallows to those with normal swallows, matching by age will be acceptable, without consideration of gender or weight.

A limitation of this study was the relatively small number of participants within each age group. To provide comparative data for clinical application, predicted means with 80 and 95% confidence intervals (CI) are given in addition to observed means, standard deviations, and ranges. Eighty-five percent of observed tongue strength measurements fell within the 80% CI, with seven (4.6%) tongue strength measurements falling below the lower CI and 15 (10.0%) exceeding the upper CI. Ninety-five percent of observed tongue strength measurements fell within the 95% CI, with two (1.3%) tongue strength measurements falling below the lower CI and 5 (3.3%) exceeding the upper CI. The data from the present study suggests that for comparing tongue strength in children with impaired swallowing to typically developing peers, maximum tongue strength measurements may be attained from six trials (two blocks of three trials) and compared to the 80% CI.

The assessment of tongue strength, which typically has been assessed subjectively, is an important component of pediatric dysphagia evaluations [20]; however, subjective judgments of tongue strength vary across examiners and may not be sensitive to small changes in strength observed during treatment [9]. Objective measures of tongue strength are consistent across examiners and sensitive to small changes but are limited to measuring only anterior tongue elevation, while subjective judgments may also provide information about lateral tongue strength. We propose that a thorough dysphagia evaluation should include both objective and subjective measures of tongue strength.

Although the importance of adequate tongue strength and the use of tongue strengthening exercises to improve swallowing has been documented in the adult population, the role of tongue strength and the use of tongue strengthening exercises to improve speech production is controversial [14, 24, 26]. Decreased tongue strength may be suggestive of neurologic impairment; however, in children and adults, tongue strength is not related to the severity of speech sound impairment, providing little evidence to warrant tongue strengthening exercises to improve articulation [27].

The findings from this study show that tongue strength may be objectively and reliably assessed using commercially available equipment, such as the IOPI, with children and adolescents and provide a limited sample size comparative database of typically developing controls for use in the evaluation and treatment of pediatric dysphagia in children and adolescents ages 3–16 years.

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