Research Article

Tongue Strength in Children With and Without Speech Sound Disorders

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Purpose: The purpose of this cross-sectional investigation was to expand the comparative database of pediatric tongue strength for children and adolescents with typical development, ages 3–17 years, and compare tongue strength among children with typical development, speech sound delay/disorders (SD), and motor speech disorders (MSDs).

Method: Tongue strength was measured using the Iowa Oral Performance Instrument in a total of 286 children and adolescents, 228 with typical development, 16 with SD, and 42 with MSDs, including classic galactosemia, a known risk factor for MSD ($n = 33$) and idiopathic MSD ($n = 9$).

Results: For all groups, tongue strength increased rapidly from 3 to 6.5 years of age and then continued to increase with age at a slower rate until 17 years of age. Children with SD's tongue strength did not differ from their typically developing (TD) peers. Children and adolescents with MSDs had decreased tongue strength compared to children with typical development or SD. Tongue strength was not related to severity of speech sound disorders in SD or MSD.

Conclusion: Weak tongue strength does not appear to contribute to speech errors in children with speech sound delays but does appear to be related to speech sound disorders that are neurologic in origin (developmental MSD).

Since the first report of an attempt to measure tongue strength by Fere in (1889), scientists have been interested in objectively measuring tongue strength, resulting in a long intense controversy over possible clinical significance between tongue strength and speech (Adams, Mathisen, Baines, Lazarus, & Callister, 2013; Fere, 1889; Solomon, Makashay, Helou, & Clark, 2017; Weismer, 2006). The majority of tongue strength studies have focused on the adult population, with a limited number of studies examining pediatric tongue strength, most with relatively small sample sizes. Research comparing the tongue strength of children with and without speech sound disorders over the past 75 years has reported contradictory findings. Some earlier studies reported that children with speech sound disorders had weaker tongue strength than their typically developing (TD) peers (Dworkin, 1978; Palmer & Osborn, 1940), others reported that only children with motor speech disorders (MSDs) had weaker tongue strength (Bradford,

Murdoch, Thompson, & Stokes, 1997; Murdoch, Attard, Ozanne, & Stokes, 1995), and still others reported no difference in tongue strength between children with and without speech sound disorders (Dworkin, 1980; Dworkin & Culatta, 1985; Fairbanks & Bebout, 1950; Stierwalt, Robin, Solomon, Weiss, & Max, 1996). In this article, we present potential reasons for the equivocal findings between tongue strength and speech sound disorders based on our study of 288 children.

Instrumentation for Measuring Tongue Strength

Historically, many different instruments have been developed for measuring tongue strength. All studies have used some type of meter attached to a device placed on the tongue to measure elevation or placed immediately anterior to the tongue to measure protrusion. Tongue devices have included a tray attached to springs (Fere, 1889), a steel disc (Dworkin & Culatta, 1985; Fairbanks & Bebout, 1950), a Lucite cup (Dworkin, 1978, 1980), a rubber ball (Palmer & Osborn, 1940), an air-filled latex bulb (Bradford et al., 1997; Murdoch et al., 1995; Robin, Somodi, & Luschei, 1991), or an air-filled silicone bulb (Iowa Oral Performance Instrument [IOPI], IOPI Medical). All recent studies have used some form of a soft air-filled bulb. The advantage of a soft air-filled bulb is that the tongue muscle and tissue can mold around the bulb without discomfort. Because the

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tongue is a hydrostatic organ, pushing the tongue against the rigid edges of a hard surface may cause tongue tissue shearing and discomfort, resulting in less than maximal effort (Hiemae & Palmer, 2003; E. S. Luschei, personal communication, March 24, 2009).

The terms used to refer to tongue strength differ across articles and authors. In this article, we have chosen to use the term *tongue strength* to refer to the task in which a participant squeezes the bulb between the tongue and hard palate with maximum effort. Other terms for the same measure include *maximum pressure* (Solomon et al., 2017) and *maximum tongue pressure* (Utanohara et al., 2008). In this article, we use the term *tongue pressure* to refer to the force exerted by the tongue during speech or swallowing, as these are not maximal strength tasks.

Tongue Strength Across Age

The findings across pediatric and adult studies show tongue strength increases across childhood, peaking in early adulthood, remaining stable or slightly decreasing through middle age, then showing a gradual decline after the age of 60 years, with a steeper decline during the late geriatric period of life (Clark & Solomon, 2012; Crow & Ship, 1996; Fei et al., 2013; Maeda & Akagi, 2015; McAuliffe, Ward, Murdoch, & Farrell, 2005; Nicosia et al., 2000; Potter & Short, 2009; Robbins, Levine, Wood, Roecker, & Luschei, 1995; Stierwalt & Youmans, 2007; Youmans, Youmans, & Stierwalt, 2009). In adults, tongue strength has been examined using an anterior placement, with the tongue bulb placed between the tongue and hard palate just posterior to front incisors, and a more posterior placement toward the tongue dorsum. Because of the smaller oral cavity, especially in young children, only an anterior placement, with the tongue bulb placed on the alveolar ridge just posterior to the front incisors, is possible. When depressed, the IOPI bulb is about 4 cm long, which covers most of a young child's hard palate. The average hard palate length for a 4-year-old is just over 5 cm (Vorperian et al., 2009). Examining tongue strength across studies using the IOPI in an anterior placement, mean maximum tongue strength is about 18 kPa at the age of 3 years, peaking at about 75 kPa in 20-year-olds, then decreasing to 60 kPa in older adults with minimal or no difference between sexes (Adams et al., 2013; Clark & Solomon, 2012; Potter & Short, 2009; Youmans et al., 2009).

A question raised in the literature addresses whether tongue strength would be best compared by age or by sex because body mass and strength develop in tandem (Kent, Kent, & Rosenbek, 1987). In adults, age is the obvious metric to use for tongue strength comparison because tongue strength differs significantly by age with little or no difference by sex, although men typically weigh more than women. This study will address this question for the pediatric population.

Speech Sound Disorders

Pediatric speech sound disorders can be divided into the two broad categories, speech sound delay/disorders

(SD) and MSDs (Binger, Ragsdale, & Bustos, 2016; Shriberg et al., 2010). Children with SD typically have consistent speech sound errors primarily affecting consonant sounds, with errors showing little variation across multiple repetitions of the same word. SD typically normalizes by the age of 9 years with speech therapy (Shriberg et al., 2010). Subcategories of SD include articulation and phonological disorders. Children with MSDs have a neurogenic speech sound disorder with inconsistent or atypical speech sound errors, including both consonant and vowel errors, that may not normalize even with intensive speech therapy. Subcategories of MSD include childhood apraxia of speech, childhood dysarthria, and a subcategory of MSD that does not fit the typical speech profiles for childhood apraxia of speech or childhood dysarthria, currently termed *motor speech disorder—not otherwise specified* (American Speech-Language-Hearing Association, 2007; Shriberg, Potter, & Strand, 2011). Standardized assessment of pediatric MSD is a topic in progress, along with firm diagnostic criteria for the three subcategories. In a review of published tests, McCauley and Strand (2008) reported that no standardized tests validly and reliably diagnosed or distinguished between pediatric MSD (McCauley & Strand, 2008). However, there continues to be advancement toward more accurate and consistent diagnosis of pediatric MSD (Davis, Jakielski, & Marquardt, 1998; Murray, McCabe, Heard, & Ballard, 2015; Shriberg et al., 2010; Strand, McCauley, Wiegand, Stoeckel, & Baas, 2013). For most children with MSDs, the cause of their speech sound disorder is idiopathic, but a number of populations have been identified to be at increased risk of pediatric MSD. One known population, included in this study, is classic galactosemia (CG), a rare recessive genetic disorder with a 180-fold risk of an MSD compared to the general population (Shriberg et al., 2011).

Tongue Pressure in Speech and Swallowing

The tongue is active in both speech and swallowing, but the strength requirements widely differ for the two functions. In adults, speech production typically uses 20% or less of the maximum tongue strength (Kent, 2015; Kent et al., 1987). Also in adults, tongue strength does not appear to be directly related to speech intelligibility, but there may be a critical tongue strength threshold required for normal speech. In a study of 110 adults, half with dysarthria, anterior tongue strength was lower in the group with dysarthria compared to the neurotypical controls (Solomon et al., 2017). For the group with dysarthria, tongue strength was weakly to moderately correlated with auditory perceptual measures of speech, including intelligibility and articulatory precision. Interestingly, individuals with severely weak tongues had moderate to severe speech imprecision, but half had acceptable speech intelligibility, indicating that speech intelligibility is not a sensitive measure of speech impairment.

Swallowing in the adult population typically uses 45%–60% of maximum tongue strength, dependent on bolus size and viscosity (Youmans et al., 2009). Adults

with decreased tongue strength are at risk for dysphagia and aspiration. In one study, 76% of the adults with maximum tongue strength below 20 kPa, measured using the IOPI, exhibited oral phase dysphagia (Clark, Henson, Barber, Stierwalt, & Sherril 2003). No known studies to date have reported tongue pressures during speech or swallowing in children.

Nonspeech Tasks

The use of nonspeech orofacial movements, including tongue strength, in the diagnosis or treatment of speech sound disorders has been debated and criticized for more than two decades because speech and nonspeech tasks use the same structures for different actions. For example, the tongue strength task and speech production both recruit the internal and external tongue muscles, but the neurological underpinnings that drive the specific performance of the actions are largely separate and independent (Kent, 2015; McCauley, Strand, Lof, Schooling, & Frymark, 2009; Wilson, Green, Yunusova, & Moore, 2008; Ziegler, 2003). Debate continues on the topic of whether specific nonspeech tasks, such as tongue strength, may facilitate differential diagnosis and lend insight into the function and dysfunction of the motor system for speech production (Ballard, Robin, & Folkins, 2003).

Purpose of the Study

This study assesses the largest published comparative database for pediatric tongue strength and will provide a foundation for comparing swallow pressures to tongue strength in children with and without swallowing disorders. The goals of this study are to (a) expand the limited comparative data for tongue strength in children and adolescents; (b) examine if age or weight is a better metric to use for tongue strength comparisons; (c) determine if the tongue strength is related to the presence and type of the speech sound disorder by comparing rate of increase and tongue strength means across age for children with typical development, SD, and MSDs of known (CG) and idiopathic origin; and (d) compare tongue strength of children with CG with and without reported swallowing problems.

Method

Study Design

The present case-control study of children and adolescents with typical development, SD, and MSDs includes novel data and aggregated data from previously published studies by the first author (Potter, Kent, & Lazarus, 2009; Potter, Nievergelt, & Shriberg, 2013; Potter & Short, 2009; Shriberg et al., 2011). Novel data include participants in the control group ($n = 20$), the SD group ($n = 16$), and the idiopathic MSD (MSD-I) group ($n = 9$). Aggregated data include controls reported in Potter and Short (2009; $n = 150$), with a subset from Potter and Short (2009) included in Potter et al. (2009; $n = 50$) and a different, nonoverlapping

subset in Potter et al. (2013; $n = 70$). Additional aggregated data in this study, not included in Potter and Short (2009), include a separate nonoverlapping set of controls in Potter et al. (2013; $n = 60$) and the participants in the MSD-CG group ($n = 33$).

Participants

All participants were between 3 and 17 years of age and had (a) English as a first language, (b) no significant hearing loss (defined as > 30 dB bilaterally assessed by a pure-tone screening test performed in a nonsoundproof room), and (c) no significant craniofacial anomalies, such as cleft palate. All participants were assessed by the first author, a speech-language pathologist with more than 30 years of experience in motor speech and dysphagia or speech-language pathology graduate students supervised by the first author. Assessors were not blinded to the speech or genetic diagnoses.

Participants With Typical Development

TD participants ($n = 228$) were the first individuals to meet criteria and volunteer in each age and sex category from preschools and public schools in Washington and Wisconsin and were recruited by teachers and speech-language pathologists employed in the children's school districts and through e-mails and printed announcements. Participants were tested individually in a quiet room. A total of 232 TD individuals initially volunteered. Four 3-year-olds could not be tested; two refused to attempt the tongue strength measurement, and two others gagged when the tongue bulb was placed in or near their mouths.

Participants With MSDs and CG (MSD-CG)

The participants with CG ($n = 33$) were identified during the newborn period and recruited through e-mail, websites, postal announcements to two support groups with online presence, Galactosemia Foundation and Galactosemic Families of Minnesota, and through metabolic clinics across the United States (Shriberg et al., 2011). All participants had a history of speech sound disorders and had previously received or were currently receiving speech therapy. All participants with CG were tested in their homes in 17 different states across the United States. In the CG group, families of 63 children initially volunteered, but 30 were excluded for one or more of the following reasons: (a) were diagnosed with CG but did not have a history of receiving therapy for speech sound disorders ($n = 18$), (b) lived outside the United States or their first language was not English ($n = 6$), (c) had cleft palate or moderate-profound hearing impairment ($n = 3$), (d) were not within the target age range ($n = 6$), or (e) were unable to be scheduled due to date and time constraints ($n = 7$). Ten of the volunteers, above, were included in two different exclusion categories. All participants with CG were diagnosed with an MSD using a preliminary version of the Madison Speech Assessment Protocol (MSAP;

Shriberg et al., 2010). Diagnostic criteria for the MSD-CG group are discussed in Shriberg et al. (2011).

Participants With Idiopathic Speech Sound Disorders

A total of 26 participants with idiopathic speech sound disorders were recruited from public preschool speech programs. Sixteen children had developmental speech sound errors consistent with a diagnosis of SD. Nine children were identified by their speech-language pathologist and confirmed by the first author as having an MSD using current diagnostic criteria at the time of data collection (2006; Davis et al., 1998). These children's speech errors were characterized by inconsistent speech sound errors on multiple repetitions of the same word or phrase and exhibited eight or more of 11 speech characteristics consistent with a diagnosis of MSD-I as defined by Davis et al. (1998). The children with MSD-I were assessed prior to the development of the preliminary version of the MSAP.

Procedure

All participants passed a pure-tone hearing screen at 30 dB for 1000, 2000, and 4000 Hz in each ear in a non-soundproof room. A brief case history was completed by parents or guardians that included a health history with questions about early speech development. The health history form was amended for the participants with MSD-CG to include questions about past or present signs or symptoms of dysphagia, defined as difficulty with chewing, swallowing, choking, or dietary texture or viscosity restrictions due to problems with swallowing. Parent report of the presence or absence of dysphagia signs and symptoms was confirmed during an in-person interview with the first author.

Tongue Strength

The examiner demonstrated the tongue strength task and permitted the participant to squeeze a tongue bulb with his or her fingers prior to the participant performing the task. The bulb was placed midline with the sealed edge just posterior to the front incisors. The examiner held the tubing anterior to the lips for the 3- and 4-year-old children. The older participants were allowed to place the tongue bulb and hold the tubing anterior to the lips with the examiner holding the tubing more distally. The maximum tongue strength measurement reported was the greatest maximum isometric force exerted by the tongue on the bulb in an anterior position across three encouraged trials, with 30 s of rest between trials, using the standard IOPI bulb with an unrestrained jaw.

Articulation

Articulation was assessed, and standard scores were obtained using the Goldman-Fristoe Test of Articulation—Second Edition (GFTA-2; Goldman & Fristoe, 2000).

The institutional review board of Washington State University or the University of Wisconsin–Madison approved

these studies. A parent of each participant provided written consent, children of ages 12 years and older provided written consent, and children of ages 11 years and younger provided written or verbal informed assent.

Data Analysis

Data were plotted and fitted with trend lines using MATLAB and the curve fitting toolbox (MATLAB R2016b, The MathWorks, Inc.). The angle-shaped curve was the only curve for which the residuals, weighted by the fourth root of tongue strength, passed all available statistical tests. The fitted angle curve suggested a significant change in the growth rate (slope) from 0.734 to 0.122 kPa/month at 79 ± 9 months. We used 77 months of age to separate all participants into two mutually disjoint groups, a “younger group” for all participants younger than 77 months of age (6;5 years; months) and an “older group” for all participants older than 77 months of age. The 77-month separation fit this data set well as all participants in the SD and MSD-I groups were younger than 77 months of age and no participants were 77 months of age. The separating age of 77 months also corresponds to the literature's age for the changes in the development of coordination at about 6 years of age (Green, Moore, Higashikawa, & Steeve, 2000; Green, Moore, & Reilly, 2002). Within each age group, the data were further separated into subgroups according to sex and diagnoses. Descriptive statistics were calculated for articulation standard scores and maximum tongue strength measures to examine the distribution characteristics by group membership, age, and sex.

All tests of differences between groups, or between subgroups, and all the test results reported here were computed with MATLAB's functions for descriptive statistics, Pearson product-moment correlation, and tests of difference such as the two-way *t* test. Within each subgroup, the residuals between the data and the line of least squares regression for the subgroup passed tests of randomness, normality, and heteroscedasticity (except for the subgroups of seven younger participants with CG and nine participants with MSD-I, whose sample sizes, 7 and 9, were too small for the test of heteroscedasticity). For all tests, an uncorrected α -criterion of 0.05 was used.

Reliability

To evaluate intrasubject test-retest reliability, 56 of the children, ages 3–6 years, completed two sessions with three maximum tongue strength measurement trials per session within a 2-week time period. Intrasubject test-retest reliability was very high for the control group ($r^2 = .89$, $n = 30$), the SD group ($r^2 = .80$, $n = 17$), and the MSD-I group ($r^2 = .87$, $n = 9$).

Results

How Did Tongue Strength Increase Across Age?

Tongue strength increased rapidly from age 3;0 to about age 6;5 (mean increase of 0.734 kPa/month across

all participants) and then continued to increase at a slower rate until 17 years of age (mean increase of 0.122 kPa/month), as shown in Figure 1. From the present data, the change in the rate of increase for tongue strength was between ages 5;10 and 7;3. We chose to use age 6;5 (77 months of age) to separate the older and younger participants so that all the children with SD were included in the younger group, as the oldest child included in the SD and MSD-I groups was 76.88 months of age. There were no differences detected in rate of increase in tongue strength among the different speech diagnoses in younger or older age groups ($p > 0.05$), but additional data may bear on this finding as there was a relatively large error term in the rate of increase for the SD, MSD-I, and MSD-CG groups with relatively small numbers of participants. Table 1 provides a summary of participant tongue strength by age group and speech sound diagnosis.

In the younger TD group, female participants had, on average, slightly greater tongue strength than male participants, $t(128) = 2.17$, $p = .03$. No sex differences were evident in tongue strength within any of the other groups ($p > 0.05$).

Should Tongue Strength Be Compared by Age or Weight?

Because children of the same age vary in size, we questioned if a comparative database for tongue strength should be presented by age or weight. This same concern was raised by Kent et al. (1987), who stated that oral strength is typically compared by age as participants' body weights are rarely reported in speech studies (Kent et al., 1987). To determine which factor, age or weight, was most closely associated with an increase in tongue strength, we recorded weight for 217 of the participants and performed regression analyses. Tongue strength was better predictor by age ($r^2 = .512$) than weight ($r^2 = .474$) for tongue strength for all participants combined as measured by the correlation coefficients.

Do Children With SD or MSDs Differ From Their TD Peers on Tongue Strength?

Children with SD had, on average, slightly greater tongue strength compared to the younger TD group, $t(128) = 2.38$, $p = .0189$. There was no difference in tongue strength

Figure 1. Maximum tongue strength by age and diagnosis. We separated the younger from the older groups at 77 months, represented by the dashed vertical line. Tongue strength increased rapidly from 3 to about 6.5 years of age (77 months) and then continued to increase at a slower rate until 17 years of age. Participants were grouped by typically developing (TD), classic galactosemia (CG), speech sound delay/disorders (SD), and idiopathic motor speech disorder (MSD-I). Coefficients of determination and probability values by group are as follows: young TD ($r^2 = .38$, $p < .001$), young SD ($r^2 = .31$, $p = .024$), young MSD-I group ($r^2 = .22$, $p = .20$), young MSD-CG ($r^2 = .16$, $p = .79$), older TD ($r^2 = .28$, $p < .001$), older MSD-CG ($r^2 = .002$, $p = .83$).

Table 1. Tongue strength measured in kilopascals by age group and sex.

Age in years	Sex	TD			SD			MSD-I			MSD-CG		
		<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>	<i>n</i>	<i>M</i>	<i>SD</i>
3	M	20	18.42	6.57	3	32.00	7.00	4	17.50	9.33			
	F	20	22.74	9.90	2	30.50	2.12	2	13.00	9.90			
4	M	18	31.78	10.74	2	33.50	2.12	2	15.50	0.71	2	13.50	4.95
	F	22	34.64	8.69	2	41.00	4.24				1	12.00	—
5	M	14	32.07	11.23	2	39.00	7.07	1	25.00	—	2	12.00	2.83
	F	16	38.50	11.03	3	43.33	6.66				1	9.00	—
6	M	5	45.80	17.48	2	44.00	24.04				2	12	2.83
	F	5	46.00	11.00									
7	M	5	52.40	5.98							3	42.67	25.93
	F	5	51.60	7.57							2	21.50	6.36
8	M	5	53.20	5.98							6	24.17	9.54
	F	5	56.20	6.14							3	20.00	12.17
9	M	5	57.00	6.63							1	34.00	—
	F	5	53.00	5.15									
10	M	5	49.80	6.87							2	11.00	9.90
	F	5	58.00	5.15							1	42.00	—
11	M	5	54.40	6.19									
	F	5	61.60	6.23							1	27.00	—
12	M	5	50.40	8.71							1	30.00	—
	F	5	53.20	8.84							1	15.00	—
13	M	5	57.40	7.70							1	32.00	—
	F	5	59.00	4.85									
14	M	5	64.40	5.77							1	21.00	—
	F	5	57.00	4.58							1	36.00	—
15	M	5	61.20	10.43									
	F	5	65.00	1.87									
16	M	5	64.00	4.00							1	39.00	—
	F	5	58.20	3.56									
17	M	5	69.20	9.93									
	F	5	69.60	10.29									
Total <i>n</i>		230			16			9			33		

Note. Em dashes indicate data not available. TD = typically developing; SD = speech sound delay/disorders; MSD-I = idiopathic motor speech disorder; MSD-CG = motor speech disorder—classic galactosemia; M = male; F = female.

between the MSD-I and younger MSD-CG groups, $t(14) = 1.46$, $p = 1.66$, but both MSD groups had decreased tongue strength compared to their peers in the SD and younger TD groups. Specifically, the tongue strength of the MSD-I group was lower than the SD group, $t(23) = 5.72$, $p < 10^{-5}$, and the younger TD group, $t(121) = 3.24$, $p = .0016$. The MSD-CG group's tongue strength was lower than the SD group, $t(21) = 6.98$, $p < 10^{-6}$, and the younger TD group, $t(119) = 3.86$, $p < 10^{-3}$. The older MSD-CG group's tongue strength was lower than the older TD group, $t(138) = 14.32$, $p < 10^{-29}$.

Figure 1 illustrates that, with the exception of two participants with MSD-CG, whose tongue strength was in the 50–60 kPa range, all participants with MSD-I and MSD-CG had tongue strength at or below 40 kPa, which was well below that of their age-matched peers with SD or TD. The two MSD-CG exceptions had short terms of speech therapy during their preschool years, but their speech improved and both were dismissed from speech therapy before they entered elementary school. At the time of this study, both had mild residual speech errors with /r/ or /s/ and some differences from the TD group on the MSAP, so they were not excluded from the MSD-CG

group (Shriberg et al., 2011). No other members of the MSD-CG or MSD-I groups were dismissed from speech therapy before entering elementary school.

Did Articulation Standard Scores Differ Between Groups?

As expected, the children with SD had lower standard scores on the GFTA-2 compared to the children in the younger TD group, $t(138) = 17.11$, $p < 10^{-34}$. The children with MSD-I also had lower GFTA-2 standard scores compared to the younger TD group, $t(121) = 13.95$, $p < 10^{-26}$, as did the younger children with MSD-CG, $t(119) = 13.73$, $p < 10^{-25}$. The GFTA-2 standard scores for the SD group did not differ from the MSD-I group, $t(23) = 0.17$, $p = .864$, nor from the younger MSD-CG group, $t(21) = 0.61$, $p = .551$. The older MSD-CG group's GFTA-2 standard scores were lower than the older TD group, $t(138) = 15.62$, $p < 10^{-39}$.

There was a trend toward lower GFTA-2 standard scores for the older compared to younger TD groups, which may be explained by the test metrics in which standard scores for no speech errors on the GFTA-2 decrease with increasing age. Tongue strength was not

correlated with the GFTA-2 standard scores ($r^2 = .07$, $p > 0.05$) in any of the groups of children. Table 2 provides a summary of mean tongue strength and GFTA-2 standard scores by group membership.

Tongue Strength and Dysphagia

Parents or guardians of 10 of the 33 children in the CG study reported that their child had a history of dysphagia beyond his or her toddler years with frequent choking or coughing when eating and avoidant-restrictive food intake based on texture. There was no difference in age between the MSD-CG participants with and without dysphagia ($M_{\text{age}} = 8;9$), but the mean tongue strength of the 10 participants with MSD-CG and a history of dysphagia (18.3 kPa) was lower compared to the participants with MSD-CG and no reported history of dysphagia (26.1 kPa), $t(31) = 10.01$, $p < 10^{-10}$. Seven of the 10 participants with MSD-CG and a history of dysphagia had tongue strength at or below 20 kPa. Eight of the 23 participants with MSD-CG with no history of dysphagia had tongue strength of less than 20 kPa. Parents or guardians in the other groups were not asked specific questions about dysphagia symptoms.

Discussion

This study shows that tongue strength increases rapidly during early childhood then continues to increase, at a slower rate, throughout later childhood and adolescence. Children with SD have similar tongue strength compared to their peers with typical development, but children and adolescents with MSD, of known and unknown origin, have significantly weaker tongue strength compared to their age-matched peers with typical development or SD.

Developing a Comparative Database

One goal of this study was to expand the scientific literature on pediatric tongue strength of children and adolescents, ages 3–17 years. This study reports the largest published comparative pediatric database to date with

tongue strength measures from 228 TD individuals. Looking across age, children's tongue strength increases rapidly between the ages of 3;0 and 6;4. From about age 6;5 to 17;11, tongue strength continues to increase with age, but at a slower rate, with no difference between sexes. The older TD group's tongue mean strength was 57 kPa, which is consistent with anterior tongue strength of 56 kPa reported in a study with 68 young adults, ages 18–29 years (Clark & Solomon, 2012). In an earlier report, using a partial data set now included in this study, Potter and Short (2009) stated that tongue strength increased most rapidly between the ages of 3 and 8 years; however, with the increased number of participants and expanded age range of children between 3 and 17 years, the change in the rate of increase with age appears earlier than previously reported (Potter & Short, 2009). We also show in this study a theoretically motivated and empirically evident change in the trajectory of tongue strength development around age 6;5. Of course, development of motor abilities such as tongue strength are expected to be gradual temporal processes within any individual and are expected to show some degree of individual variation.

The increase in tongue strength across age is due to gains in both muscle mass and coordination. Studies of skeletal muscle development across age show that, as children develop, skeletal muscle mass and muscle strength increase in tandem (Kohl & Cook, 2013). If the strength–mass increase observed in limbs is estimated in the tongue strength and muscular development, the mean tongue strength of a 6-year-old would be about 80% of the adult tongue strength because, by 6 years of age, the tongue and the hard palate are about 80% of the adult mass (Vorperian et al., 2009). However, in this study, the mean tongue strength of 6-year-olds was only 65% of the average young adult tongue strength (Youmans, Youmans, & Stierwalt, 2009). This apparent lag in tongue strength development may be explained by the differences in muscular composition and development of coordination across effector systems. Tongue muscles have a heterogeneous fiber composition with slow-twitch Type I muscles predominant in the tongue dorsum and multiple variations of fast-twitch Type II muscles predominant in the anterior tongue (Daugherty,

Table 2. Age, mean tongue strength, and mean Goldman-Fristoe Test of Articulation–Second Edition (GFTA-2) scores by group membership.

Group	<i>n</i>	Mean age in months (<i>SD</i>)	Mean tongue strength (<i>SD</i>)	Mean GFTA-2 standard score (<i>SD</i>)
TD (younger)	116	53 (10.47)	30 (12.41)	108 (9.64)
TD (older)	114	146 (40.19)	58 (8.72)	103 (2.51)
SD	16	56 (12.28)	38 (9.23)	59.7 (15.61)
MSD-I	9	48 (7.15)	17 (7.59)	58.5 (15.84)
MSD-CG (younger)	7	62 (6.94)	12 (2.99)	53.5 (16.67)
MSD-CG (older)	26	117 (30.19)	27 (13.38)	70 (22.47)

Note. TD = typically developing; SD = speech sound delay/disorders; MSD-I = idiopathic motor speech disorder; MSD-CG = motor speech disorder–classic galactosemia.

Luo, & Sokoloff, 2012; Kent, 2015; Saigusa, Niimi, Gotoh, Yamashita, & Kumada, 2001). The tongue muscles are organized in small homologous bundles as opposed to skeletal muscles, which are primarily Type I and organized in parallel fiber strands (Hiimae & Palmer, 2003). The heterogeneous tongue muscle fibers are more variable in rates of contraction and in force production capabilities compared to skeletal muscles (Kent, 2015). Muscle control and coordination for nonspeech tasks are also more variable and develop later in the tongue compared to performance on the same task using skeletal muscles (Potter, Kent, & Lazarus, 2009).

Because tongue mass is related to tongue strength and children of the same age vary in body weight, our second study goal was to determine if the comparative data should be presented by age or weight (Robbins et al., 2005). Regression analysis showed that age and weight were both strong predictors of tongue strength, but that age was slightly stronger.

Are Speech Sound Disorders Related to Weak Tongues?

The third goal of this study was to examine the relationship between speech sound errors and tongue strength. A survey by Lof and Watson (2007) reported that 85% of speech-language pathologists have children perform nonspeech oral motor exercises to increase tongue strength with the assumption that speech errors are, at least in part, due to weak tongues (Lof & Watson, 2008). This assumption was not supported by the results of this study. Children with SD who had speech errors had tongues that were just as strong as their TD peers.

Children with MSDs in this study had a 43%–60% decrease in tongue strength compared to their peers with typical development and SD. Both the MSD-I and younger MSD-CG groups had much weaker tongue strength compared to age- and sex-matched participants in the SD and TD groups, as did the older MSD-CG group compared to the older TD group. These differences were so pronounced that there was no overlap among the tongue strength between the individuals with MSD-I and MSD-CG compared to the TD or SD groups, with the exception of the two participants with MSD-CG who had only minor residual speech sound errors and had been dismissed from speech therapy during their preschool years. Interestingly, the rate of increase in tongue strength across age was similar for all groups, but values were markedly lower in the groups with MSDs.

The co-occurrence of an MSD and decreased tongue strength is likely indicative of motor planning, execution, or coordination difficulty due to widespread bilateral neural network disruption. MSDs are neurological speech disorders that result from dysfunction in the brain, nerves, and muscles (Duffy, 2013). In developmental MSD, both idiopathic and known origin including CG, the disruption of neural networks is widespread throughout the white matter tracts in both cerebral hemispheres and cerebellum, negatively affecting both speech and tongue strength (Hughes

et al., 2009; Liégeois & Morgan, 2012; Shriberg, Potter, & Strand, 2011; Timmers et al., 2015). Developmental MSDs differ from acquired MSDs, which are often the result of focused left hemisphere or cerebellar dysfunction affecting speech production but not typically affecting tongue strength in children, adolescents, and adults (Solomon et al., 2017; Stierwalt et al., 1996).

Is the Severity of the Speech Sound Disorder Related to Tongue Strength?

This study did not reveal an association between articulation standard scores and tongue strength. There were no differences in the mean articulation standard test scores among the groups of children with SD and MSD-I and younger children with MSD-CG, even though tongue strength was markedly different. It was evident that tongue strength was related to the type of speech sound disorder, but not the severity of the disorder.

Controversy of Tongue Strength and Speech

There is a prolonged debate on whether nonspeech tasks provide valuable diagnostic information, not available through speech tasks, for differentially distinguishing MSD from SD. This debate is of interest in this study because tongue strength is a nonspeech oral motor task. Clinicians and researchers supportive of an integrative model approach consider nonspeech oral motor tasks valuable diagnostic indicators for the differential diagnosis of MSD (Ballard, Solomon, Robin, Moon, & Folkens, 2009). Other clinicians and researchers question the utility of nonspeech tasks for the following three reasons: (a) nonspeech tasks are driven by different neural networks than functional speech tasks, (b) nonspeech tasks have too much overlap between the cases and controls, and (c) nonspeech tasks lack clear reference values and have greater variances compared with speech tasks (Staiger, Schölderle, Brendl, & Ziegler, 2017). Tongue strength may be an exception to the substantial case–control overlap and the lack of clear reference value arguments. Our findings show little overlap between the tongue strength of TD and SD controls and the MSD cases. In addition, we are providing reference data and demonstrating that children as young as 36 months of age are relatively consistent in their performance on tongue strength measurements across trials and across days (Potter & Short, 2009).

Clinical Implications

The results of this study support the incorporation of tongue strength, as an objective measure, into a comprehensive speech assessment. Our findings support that a 40% or greater decrease in tongue strength differentiates between a developmental MSD and a severe SD diagnosis. This finding of decreased tongue strength in developmental MSD was also supported in previous studies with small participant numbers (Bradford et al., 1997; Murdoch et al., 1995).

Eliciting Cooperation From Children

One of the reasons for the dearth of pediatric tongue strength studies compared to those with adults may be the challenge of eliciting reliable participation and cooperation with large numbers of children. We offer what we have learned by testing our population to assist clinicians and researchers in measuring pediatric tongue strength. Nearly all the children, including those as young as 36 months of age, successfully completed the three trials with fewer than 2% of the children refusing to attempt the task. We acclimated the children to the task by encouraging them to first squeeze a practice bulb between their thumb and index finger prior to performing the tongue strength task. This intermediate step was important to facilitate familiarity, especially with the youngest children, as eliciting cooperation for novel task can be challenging. Previous studies examining force regulation with 3- and 4-year-olds have had dropout rates as high as 40% due to children's refusal to perform the task (Blank, Heizer, & von Voss, 1999).

The IOPI Medical user manual warns examiners to hold the tongue bulb tube during use (IOPI Medical, 2013). Children, 3–4 years of age, typically needed the examiner to carefully place the tongue bulb, hold the bulb stem firmly just anterior to the lips, and repeat instructions to squeeze the bulb with the tongue in order to prevent the child from biting the bulb. Most children, 5 years and older, were able to complete the tongue strength task, placing the bulb and holding the stem with their own hands without shifting the IOPI bulb toward their teeth. This allowed the examiner to hold the stem at a more distal location. Observationally after collecting tongue strength measures on more than 250 participants, the examiner noted that children were more willing to open their mouths wide enough to accept the tongue bulb on the first attempt during the task when they were allowed to assist with tongue bulb placement.

Limitations

Although the study described here is the largest reported to date for pediatric tongue strength, it did have limitations. The groups with speech disorders were relatively small, and the examiners were not blinded to the speech or genetic diagnosis of the participants at the time of the assessment. The participants were not retested by a different examiner to look at intrarater reliability. Also, specific information about early signs and symptoms of dysphagia was collected retrospectively and only from the CG participants.

Summary

This study provides the largest published comparative database on tongue strength measurements in children and adolescents with and without speech sound disorders to date. The conflicting views that speech sound disorders are associated with decreased tongue strength and the opposing view that speech sound disorders are not associated

with decreased tongue strength are both partially supported by our findings. We did not find evidence that weak tongue strength was related to the severity of speech disorders, nor did we find that children with SD had weaker tongues than their TD peers. We did find, in our sample, that most children and adolescents with MSDs had a 43%–60% reduction in tongue strength compared to their TD peers. Based on the results, we propose that a decrease in tongue strength of 40% or greater, compared to their age-matched peers, is a valuable metric to add to a motor speech assessment to differentially distinguish between severe SD and developmental MSDs in the pediatric population. Future studies with pediatric tongue strength should include measurements during speech and swallowing in addition to maximum tongue strength to determine the margin of functional reserve required for TD and disordered populations.

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