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JSLHR

Research Note

Effects of Age, Sex, and Body Position on Orofacial Muscle Tone in Healthy Adults

Angela M. Dietsch,[a,b] Heather M. Clark,[c] Jessica N. Steiner,[a] and Nancy Pearl Solomon[a]

Purpose: Quantification of tissue stiffness may facilitate identification of abnormalities in orofacial muscle tone and thus contribute to differential diagnosis of dysarthria. Tissue stiffness is affected by muscle tone as well as age-related changes in muscle and connective tissue.
Method: The Myoton-3 measured tissue stiffness in 40 healthy adults, including equal numbers of men and women in each of two age groups: 18–40 years and 60+ years. Data were collected from relaxed muscles at the masseter, cheek, and lateral tongue surfaces in two positions: reclined on the side and seated with head tilted.
Results: Tissue stiffness differed across age, sex, and measurement site with multiple interaction effects. Overall, older subjects exhibited higher stiffness coefficients and oscillation frequency measures than younger subjects whereas sex differences varied by tissue site. Effects of body position were inconsistent across tissue site and measurement.
Conclusions: Although older subjects were expected to have lower muscle tone, age-related nonmuscular tissue changes may have contributed to yield a net effect of higher stiffness. These data raise several considerations for the development of accurate normative data and for future diagnostic applications of tissue stiffness assessment.

Abnormalities in muscle tone, the background activity within a resting muscle, may accompany dysarthria and underlying neuromuscular impairments. The accurate identification and classification of muscle tone abnormalities may, therefore, contribute to differentiation between dysarthria types. Hypertonicity, for example, is typically associated with spastic and hypokinetic dysarthrias, whereas hypotonicity may accompany flaccid dysarthria. Furthermore, abnormalities in muscle tone may contraindicate some treatment strategies; strengthening exercises in spastic dysarthria could exacerbate the underlying neuropathology and worsen the dysarthria. Effective management of these disorders depends on accurate diagnosis. To this end, the establishment of reliable measurement tools and relevant normative data for resting tone in orofacial musculature may enhance clinical decision making.

There is reasonable evidence that factors such as sex and age may influence muscle tone measures and thus must be considered when developing normative data for clinical purposes. For example, Blackburn, Bell, Norcross, Hudson, and Kimsey (2009) identified lower muscle tone in the hamstrings of women compared to those of men. No published measures have directly assessed orofacial muscle tone by age and sex, so presumptions of lower muscle tone are based largely on what is known about orofacial muscle strength and bulk (Dugdale, 2012; Minaker, 2011). The strength of orofacial muscles is lower in women than men and in older than younger adults (Adams, Mathisen, Baines, Lazarus, & Callister, 2013; Clark & Solomon, 2012). Furthermore, perceptual ratings of masseter muscle tone were significantly associated with masseter thickness and occlusion force, both of which differed between men and women (Ohara et al., 2013).

Sarcopenia, a normal age-related loss of skeletal muscle mass and strength (Visser, 2009), has been demonstrated in limb and torso musculature (Lauretani et al., 2003) as well as the tongue (Adams et al., 2013; Vitorino, 2010; Youmans & Stierwalt, 2006; Youmans, Youmans, & Stierwalt, 2009). The associated weakness and muscle atrophy is intuitively related to lower muscle tone in aging although this presumption seems to contradict the targeted effects of facial rejuvenation practices that use botulinum toxin to reduce the resting tone and contractile strength

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of facial muscles (Le Louarn, Buthiau, & Buis, 2007). This disparity highlights gaps in our understanding of mature musculature and suggests that other factors may contribute to age-related changes in the stiffness of orofacial tissues.

Although muscle atrophy and changes in muscle fibers with aging are expected to reduce muscle tone, several other age-related changes in tissue composition may contribute to increased tissue stiffness in elderly persons. *Fibrosis* and *lipomatosis* are accumulations of excessive connective tissue and fatty cells, respectively. Both were observed to increase progressively with age in histological examinations of tongue tissue across the life span (Bassler, 1987; Bennett, van Lieshout, & Steele, 2007; Rother, Wohlgemuth, Wolff, & Rebentrost, 2002). In addition, cadaveric tongues of people over 60 years of age contain deposits of waxy proteins and polysaccharides called *amyloidosis* (Yamaguchi, Nasu, Esaki, Shimada, & Yoshiki, 1982). All of these nonmuscular tissues exhibit higher stiffness than muscle and thus may cause age-related reductions in orofacial tissue compliance that could confound measures of muscle tone.

Another issue that could affect stiffness measures is body position at the time of testing. Previous work exploring orofacial muscle tone has been conducted with participants in either upright (Clark & Solomon, 2010; Dietsch et al., 2014) or reclined positions (Dietsch et al., 2014; Solomon & Clark, 2010). It is unknown how changes in gravitational forces and muscle tension associated with variations in positioning might affect measures of orofacial muscle stiffness. Such data are needed to develop standardized procedures for collection of normative data and clinical assessment of orofacial muscle tone.

In the past, motor speech evaluation protocols that include information about muscle tone have relied on subjective impressions made on the basis of passive stretching, palpating tissue, or presumed correlates of muscle tone, such as facial droop or ptosis (Duffy, 2013; Marchesan, Berretin-Felix, & Genaro, 2012). All these indicators of tone rely on the clinician's judgment and experience rather than normalized objective data. Furthermore, studies indicate poor correlation between clinician ratings of tone and instrumental measures of spasticity in the limbs, undermining the validity and reliability of perceptual ratings of muscle tone (Malhotra et al., 2008). Instruments designed to measure tissue resistance offer opportunities for quantification of muscle tone or correlates thereof.

The purpose of the present study was to compare measurements of tissue stiffness in healthy adults across age groups, sexes, and body positions. Investigators hypothesized that neurologically normal older adults would exhibit lower orofacial stiffness measures than younger counterparts (H_1). Furthermore, women were expected to have lower orofacial stiffness measures than men (H_2). Last, in the absence of clear evidence to support a directional hypothesis of position-related changes in orofacial stiffness measures, no differences in upright versus reclined positions were expected (H_3).

Methods

Participants

Participants included 40 adults, 20 in each of two age ranges (18–40 and 60+ years of age). There were 10 women and 10 men per age group. Exclusion criteria included body mass index (BMI) in the obese ($\geq$30 kg/m^2) range, history of neurological disorder or speech/swallowing impairments, and use of medications with muscle relaxant properties. All participants provided written informed consent as approved by the Institutional Review Board at Walter Reed National Military Medical Center.

Instrumentation

The Myoton-3 (V6.7, 2005, Müomeetria, Estonia, EU) is one of few instruments available to quantify tissue stiffness in orofacial musculature (Dietsch et al., 2014; Solomon & Clark, 2010). This precalibrated, handheld device uses a small cylindrical probe (length 7 cm, diameter 3 mm), which is lowered perpendicular to the tissue site until a pulse perturbation of fixed duration (default = 10 ms) is triggered at a known force. The pulse deforms a small area of tissue, the movement of which is sensed by an accelerometer, generating an acceleration curve. Outcome variables of oscillation frequency, logarithmic decrement, and stiffness coefficient are derived from the curve. Higher frequency of oscillation (in Hz) is indicative of greater tone. The logarithmic decrement of damped oscillation is a reflection of elasticity, such that decrement values typically decrease as tone increases. The stiffness coefficient (in N/m) corresponds to the linear displacement of tissue as a result of the known force of the perturbation, with higher coefficients suggesting greater tone (Myoton Muscle Diagnostics, 2011).

Investigators using an early version of the Myoton identified concerns about data quality, which led to modifications in the perturbation parameters and analysis algorithm, yielding robust sensitivity, reliability, and position shift tolerance measures in lab settings (Myoton Muscle Diagnostics, 2011). Since then, a number of studies have demonstrated the validity and reliability of Myoton measures in limb and trunk musculature across healthy and disordered populations, extended periods of time, and multiple users (Agyapong-Badu et al., 2013; Aird, Samuel, & Stokes, 2012; Chuang et al., 2013; Chuang, Wu, & Lin, 2012; Marusiak, Jaskólska, Koszewicz, Budrewicz, & Jaskólski, 2012). We recently reported on the validity and reliability of Myoton-3 measurements in orofacial musculature, noting that Myoton-3 measures obtained in its triplescan mode were stable for tissue thicknesses greater than 10 mm (Dietsch et al., 2014). Triplescan utilizes an internal algorithm that compares three acceleration curves obtained in rapid succession and saves measures from the curve closest to the arithmetic mean. In unpublished preliminary work, we compared measures derived from individual trials to those obtained via triplescan. Based on the satisfactory results of these trials and the desire to minimize data

collection time (and thereby potential variability in precise location and body position between measurements), the triplescan setting was used in this study to collect data from each tissue site. These values were downloaded from the device to a laboratory computer for further analysis.

Procedures

Data were obtained bilaterally from the skin overlying the masseter, cheek, and lateral tongue. Participants sat upright with the head tilted toward the side contralateral from that being measured (see photographs of data collection in this position in Dietsch et al., 2014) and also reclined in a side-lying position such that the tissue to be measured was as parallel to the floor as possible (see photographs in Solomon & Clark, 2010). To identify measurement sites while accounting for individual differences in facial contours, participants were asked to contract (e.g., "clench your jaw," "contract your tongue," "tighten your cheek against your teeth like this" with visual and tactile confirmation by the investigator) then relax the target muscle; the examiner identified the midsection of the muscle bulk while avoiding surface tissue buckling or wrinkling. The examiner marked the masseter and cheek sites with a small ink dot to ensure consistent probe placement for repeated measures across body positions; the small indentation left on the tongue between measures ensured precise relocation of the probe across the three triplescan trials, which typically lasted less than 5 s total per tissue site. As pictured previously (Solomon & Clark, 2010), a wooden tongue blade was positioned between the ipsilateral buccal tissue and teeth to support the cheek during measurement. For lingual measures, the blade rested vertically between the teeth on the contralateral side to create a platform for the relaxed tongue. Throughout all data collection trials, participants were encouraged to let their muscles relax and were specifically reminded to "let your tongue/face/jaw relax" as indicated; the examiner visually verified the muscle's resting posture. Data were collected in counterbalanced order from each tissue site in each position within a single session lasting 5–10 min.

Data Analysis

Instrumental determination of stiffness, frequency, and decrement for each tissue site was downloaded from the Myoton-3 and imported to SPSS (IBM Corporation, Armonk, NY) for further analysis. After confirming normality and homoscedasticity, two-way analyses of variance with age group and sex as between-subjects factors were calculated to assess participant demographics, using an α level of .05. Two sets of three-way analyses of variance compared the effects of group characteristics (using tissue site, age group, and sex) and data acquisition methods (using tissue site, body position, and side) for each Myoton-3 outcome variable. To correct for family-wise error among the related Myoton-3 outcome variables, an α level of .0167 was established for statistical significance of the Myoton-3 data.

Results

BMI did not differ significantly by age group ($p = .177$) or for an Age × Sex interaction ($p = .796$; see Table 1). BMI was significantly higher for men than women (25.1 and 22.9, respectively), $F(1, 36) = 6.041$, $p = .019$, $\eta_p^2 = .144$. As expected, main effect of tissue site was statistically significant for all three outcome measures, $F(2, 467) = 53.236–153.276$, $p < .001$ for each, $\eta_p^2 = .186–.396$.

Data were collapsed across side and body position to assess for age (H_1) and sex (H_2) differences in Myoton-3 measures. A statistically significant three-way interaction between site, age, and sex, $F(2, 467) = 5.164$, $p = .006$, $\eta_p^2 = .022$, was observed for frequency, wherein the masseter measurements were significantly higher for older women than for all other cohorts and tissue sites; see Figure 1. Two-way Site × Age interactions for stiffness, $F(2, 467) = 9.300$, $p < .001$, $\eta_p^2 = .038$; frequency, $F(2, 467) = 11.395$, $p < .001$, $\eta_p^2 = .047$; and decrement, $F(2, 467) = 52.442$, $p < .001$, $\eta_p^2 = .183$, were associated with greater age disparities at the masseter (and cheek for decrement only) compared to the other structures. As confirmed by main effects for age, stiffness, $F(1, 467) = 72.532$, $p < .001$, $\eta_p^2 = .134$; frequency, $F(1, 467) = 50.927$, $p < .001$, $\eta_p^2 = .098$; and decrement, $F(1, 467) = 160.410$, $p < .001$, $\eta_p^2 = .256$, values were higher for older than younger participants (H_1). Of the 42 outliers across all outcome measures in Figure 1 (some points overlie others), 33 were from older participants; these data were included in all analyses.

In addition to the previously described three-way interaction, sex differences (H_2) were observed in site-specific interactions for stiffness, $F(2, 467) = 13.454$, $p < .001$, $\eta_p^2 = .054$; frequency, $F(2, 467) = 18.304$, $p < .001$, $\eta_p^2 = .073$; and decrement, $F(2, 467) = 14.441$, $p < .001$, $\eta_p^2 = .058$, such that values were greater at the masseter for women and at the cheek and tongue for men. There were no statistically significant main effects of sex for any of the three outcome measures ($p = .068$ to $.749$).

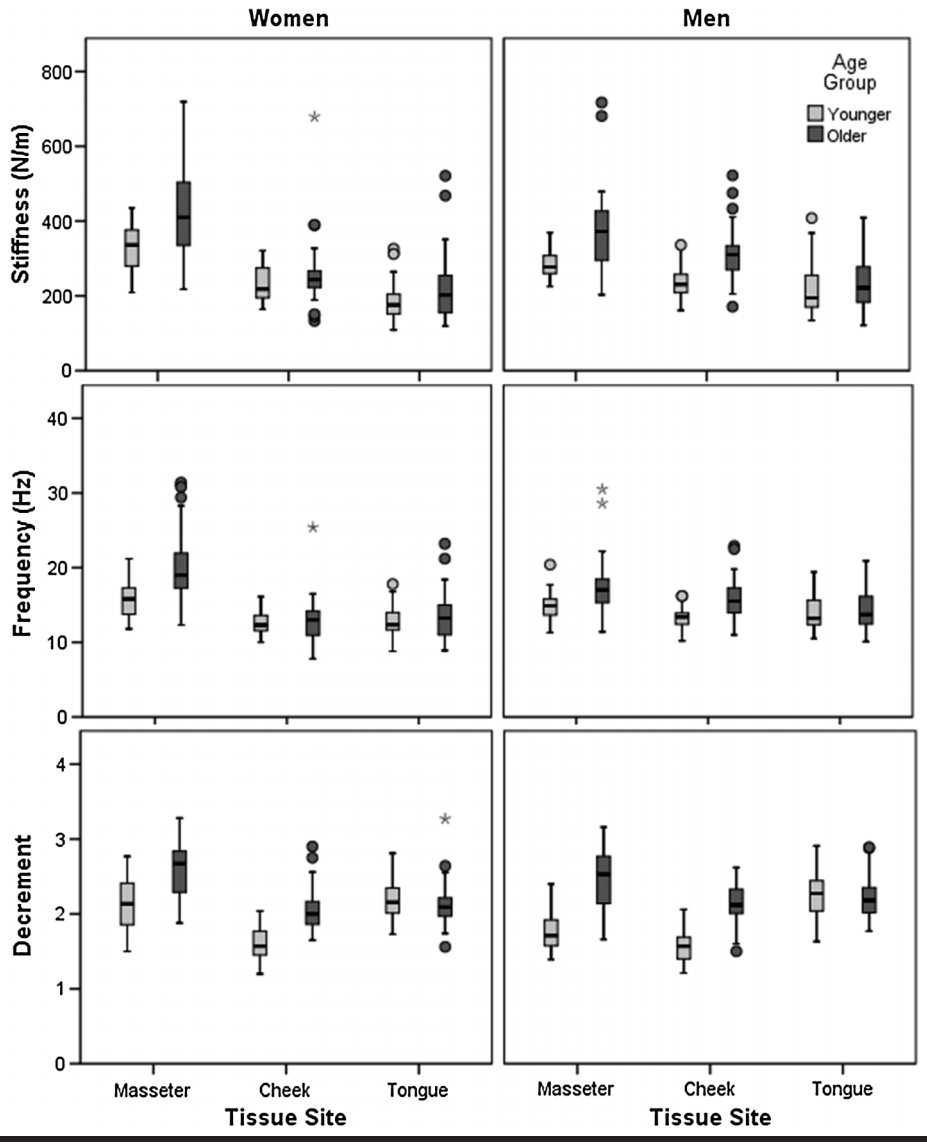
To determine whether body position or side affected Myoton-3 measurements (H_3), data were collapsed across groups. There were no significant main or interaction effects

Table 1. Summary statistics for demographic data of participants.

Variable	*N*	Younger		Older	
		Mean	Range	Mean	Range
Age (years)					
Women	10	27.1	22–37	70.7	61–90
Men	10	29.4	23–40	74.7	62–98
BMI (kg/m^2)					
Women	10	22.2	20.0–27.4	23.7	20.4–29.1
Men	10	24.6	19.4–28.4	25.6	17.9–29.5

Note. BMI = body mass index.

Figure 1. Stiffness coefficient (N/m), oscillation frequency (Hz), and logarithmic decrement of damped oscillation for tissue site by age group and sex. Horizontal lines = median; boxes = ± 1 quartile around the median; whiskers = 1.5 interquartile range (QR), approximately 95% CI; ○ = outliers (>1.5 QR); * = extreme outliers (>3 QR).



involving side (left vs. right) for any outcome measure (p = .387 to .939). Stiffness and frequency measures yielded no significant main or interaction effects for body position (upright vs. reclined, p = .038 to .980, see Table 2). Decrement values were higher for masseter and cheek and lower for lateral tongue when reclined compared to upright, resulting in an interaction between body position and tissue site, $F(2, 467) = 5.232$, $p = .006$, $\eta_p^2 = .022$, and a main effect for position, $F(1, 467) = 9.750$, $p = .002$, $\eta_p^2 = .020$.

Table 2. Summary statistics for Myoton-3 measures of stiffness coefficient (N/m), oscillation frequency (Hz), and logarithmic decrement of damped oscillation for tissue site by body position.

Variable	Tissue site	Upright		Reclined	
		Mean	*SD*	Mean	*SD*
Stiffness (N/m)	Masseter	384.3	105.04	370.0	107.28
	Cheek	225.1	49.47	259.0	82.50
	Tongue	206.4	105.04	201.1	68.66
Frequency (Hz)	Masseter	18.1	4.43	17.6	4.34
	Cheek	12.1	1.92	13.3	2.51
	Tongue	13.2	2.72	13.2	2.40
Decrement	Masseter	2.2	0.38	2.5	0.43
	Cheek	1.8	0.32	1.9	0.36
	Tongue	2.2	0.28	2.1	0.25

Discussion

Decreased muscle tone with advancing age is a logical extension of what is known about strength and muscle

atrophy across age and was the hypothesized outcome of this study (H_1). At first glance, the hypothesis was not supported as the present results revealed increased tissue stiffness with advancing age with small-to-medium effect sizes across the different Myoton measures. Although stiffness was intended to reflect muscle tone, the competing effects of sarcopenia, fibrosis, and lipomatosis may account for these findings. Older participants exhibited greater variability and a larger number of outliers than younger counterparts. This mirrors reports of greater variability with age in acoustic and kinematic measures of speech (Bennett et al., 2007; Dromey, Boyce, & Channell, 2014; Liss, Weismer, & Rosenbek, 1990; Weismer, 1984; Wohlert & Smith, 1998). The interplay of multiple factors affecting aging tissue could be responsible for differences in tissue stiffness and must be considered as a potential confounder to the development of normative data.

In addition to tissue properties, other potential sources for the unexpectedly higher tissue stiffness measures in older participants may be related to an inability to relax completely and tissue thickness. There is no reason to believe that the older participants maintained muscle contraction during voluntary relaxation, but electromyographic monitoring of resting muscle activity could be used in future studies to confirm this assumption. Although tissue thickness was not measured in these participants, age-related decreases in tissue thickness have been demonstrated in the human tongue (Sonies, Baum, & Shawker, 1984) and other skeletal musculature (Baumgartner, 2000; Frontera, Hughes, Lutz, & Evans, 1991; Moore et al., 2014), and thinning of subcutaneous tissues (Zoumalan & Larrabee, 2011) and shifts in fat distribution (Le Louarn et al., 2007; Zoumalan & Larrabee, 2011) are recognized contributors to age-related changes in facial appearance. Preliminary experiments in our laboratory suggest that cross-sectional tissue thickness contributes to the validity of Myoton-3 measurements, such that values from tissues thinner than 10 mm may be confounded by stiffness properties of the underlying substrate (Dietsch et al., 2014). Thus, the thinner orofacial tissues of older subjects may have been more susceptible to measurement interference from the underlying bone or wooden tongue blade in the calculation of outcome measures. This is consistent with the present results, in that the masseter showed greater age-related differences in the stiffness coefficient and oscillation frequency compared to cheek and tongue sites, which do not immediately overlay bone.

The sex-related differences in tissue stiffness reported here partially supported the associated hypothesis (H_2) and also may pertain to differences in tissue composition and thickness. Rother et al. (2002) demonstrated an interaction effect between sex, age, and lipomatosis in the tongue. In men younger than 50, fatty deposits increased linearly with age and were more abundant than in women. In later years, women exhibited more adipose accumulation whereas men's values diverged, falling below women's on average (Rother et al., 2002). Applied to the current cohort, such trends would be expected to yield relatively more fatty deposits (and thus higher tissue stiffness) in older women compared to the other three groups, which is consistent with study results. In addition, women exhibit lesser muscle bulk compared to men across ages and tissue sites (Banks, 2006; Moore et al., 2014; Voss, 1971) and therefore may be more vulnerable to thickness-related measurement confounds (Dietsch et al., 2014). Limited prior reports of sex-related differences in muscle tone did not control for tissue bulk or muscle strength (Blackburn et al., 2009) or found that these factors were interrelated (Ohara et al., 2013).

The Myoton-3's stiffness coefficient and oscillation frequency measures were robust to the tested changes in body position, partially supporting the third hypothesis (H_3). Logarithmic decrement of damped oscillation values, however, were marginally higher when upright compared to reclined. This measure, associated with tissue elasticity, may have been more susceptible to stretching of the soft tissue of the cheek, tongue, and masseter during the head tilt used in seated trials. Furthermore, postural reflexes in the jaw-closing musculature exert greater tonic activity when upright compared to other body positions (Lund, Nishiyama, & Moller, 1970). On the basis of these results, Myoton-3 measures of tissue stiffness and oscillation frequency may be more useful metrics when a reclined body position cannot be implemented in clinical settings.

In the present study, advanced age and being a woman appear to be associated with higher in vivo orofacial tissue stiffness as measured instrumentally. Effect sizes for the age- and sex-related differences were small to moderate, and data were derived from healthy individuals with normal speech production. Thus, these data must be considered too preliminary to reflect true and meaningful disparities in normal tissue stiffness and/or muscle tone. If confirmed in larger cohorts, the present findings could provide a foundation for the development of accurate normative data to facilitate clinically meaningful discrimination of abnormalities in orofacial tissue stiffness that may guide management of dysarthria.

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