An Investigation of Abdominal Muscle Recruitment for Sustained Phonation in 25 Healthy Singers

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Summary: Objectives. The purpose of this study was to investigate the baseline muscle thickness and recruitment patterns of the transversus abdominis muscle (TAM) and the internal oblique muscle (IOM) during semisupine phonation in a group of healthy performers.

Study Design. This was a 2 × 3 × 2 within-group, repeated-measure study in which 25 professional vocalists—12 male and 13 female performed a series of sustained pitches in differing vocal qualities. Measurements were taken with ultrasound (Sonosite Micromaxx Ultrasound System) of the baseline thickness and % recruitment during voicing, of two deep abdominal muscles—TAM and the IOM. Correlations between TAM and IOM absolute change scores, TAM and IOM percentage change scores, and changes in muscle thickness (absolute and percentage) and age were examined using Spearman's correlations. Gender differences in the four types of change scores within each combination of pitch and quality were conducted with one-way analysis of variances. Differences in muscle thickness change 1) absolute scores and 2) percentage change in TAM and IOM, by pitch and quality (and their interactions) were analyzed using linear mixed models, using restricted maximum likelihood estimations, employing a Toeplitz variance-covariance matrix structure in *SPSS* (IBM, 2011). Post hoc analyses for independent variable group differences used Sidak's correction for multiple comparisons. Alpha level was set to 0.05.

Results. In terms of absolute contractions (changes in the actual millimeter thickness of the muscle), the IOM was greater than the TAM. However in terms of percentage changes in muscles during phonation, the TAM was always greater than the IOM. The TAM as a percentage change was recruited preferentially and significantly in most vocal qualities tested. Although there were differences in muscle mass and recruitment patterns between genders, and males had thicker muscle mass at rest, differences due to muscle mass were not conclusive.

Conclusions. Overall this study supports the argument that the peri-abdominal muscles do indeed play a role in supporting the "performing" or athletic voice in healthy subjects, and will hopefully act as a database for further research in individuals with healthy and injured voices.

Key Words: Transversus abdominis–Internal oblique–Phonation–Voice–Ultrasound.

INTRODUCTION

Opera and musical theaters require supported singing.[1] Such singing is often powerful, dramatic, and capable of being projected over orchestras and choirs. Supported singing has traditionally been difficult to learn and teach.[2,3] There are many issues relating to interpretation[3] understanding, terminology, language, and all manner of psychological and physiological idiosyncrasy.[2,4–6] Some pedagogists have looked toward support through the core muscle groups (the major such groups generally being recognized as those of the erector spinae, multifidus, peri-abdominal muscles, hip flexors, gluteus muscle group, and hip adductors).[7]

There are now many accredited programs and techniques that have as one of their aims the strengthening of some or all of the core muscles (eg, Pilates,[8] Alexander Technique[9]). Still others such as the Accent method[10] look to gain singing support through recruitment of some core muscles that specifically facilitate efficient and easy breathing. Many of the programs available for core muscle strengthening also have more general applications to posture, muscle strengthening, and general well-being.[11]

The more recent pedagogies of supported singing techniques have shown considerable interest in the peri-abdominal muscles. These muscles include the rectus abdominis, external and internal obliques, and the transversus abdominis muscles (TAMs) (Figure 1). Rolf[7] in 1977 emphasized the rectus abdominis muscle, in her book on Rolfing. More recent interest, particularly among Pilate's practitioners, has focused on the TAM. Research into the function of the TAM includes the TAM's independence from other abdominal muscles during simple actions[12]; its role in spinal stiffness[13,14]; its preferential recruitment during respiration or posturing[15–18]; its interactions with other muscles involved in singing.[19] These researches often draw reference to the potential impact the TAM has on expiratory breath flow and/or control for athletic performance.

The use of ultrasound as a safe tool for observing abdominal wall muscular activity is well-documented[20–22] and has previously been used by our team,[23,24] and Rowson and Blake, unpublished data, 2009.[25] It is useful for real-time phonatory research. Recent studies[23,24] have used ultrasound technology and have investigated the function of the TAM and internal oblique muscle (IOM) in small groups of healthy and dysphonic individuals. However, this type of research is still in its infancy and a database of normals is requisite to the development of sound management strategies. Therefore, this study is an attempt to develop such a database, using real-time

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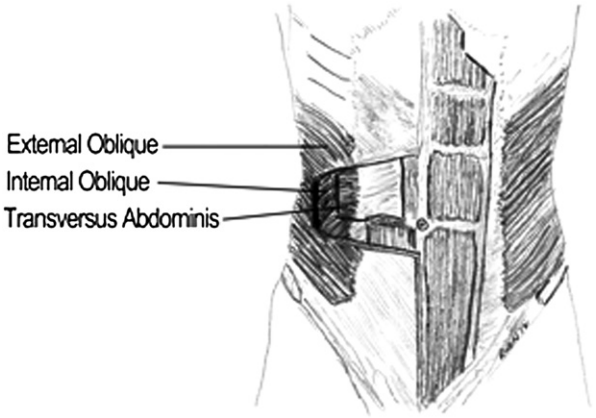

FIGURE 1. Anterior view of the abdominal muscles.

ultrasound in a group of vocally healthy singers and studying two of the large peri-abdominal muscles, the TAM and the IOM.

METHODS

Study design

This study examined changes in the thickness of TAM and IOM just prior to vocalizing a simple vowel (/a:/) and the absolute changes in millimeters and the percentage change measures calculated for three voice qualities (modal, opera, and belt), and at two pitches (low and medium, Table 1). This resulted in a 2 × 3 × 2 within-group, repeated-measure study. Age and Gender effects on TAM and IOM percentage change scores were also examined. We looked at a third (higher) pitch, but found it to be difficult to perform by a number of the subjects and thus have not included it.

Ethical approval

This study received ethical approval from the University College London Ethics committee.

Equipment

Muscle thickness was measured with the Sonosite Micromaxx Ultrasound System with C60e/5-2 transducer (probe), which shows a transverse image of the peri-abdominal musculature and subcutaneous fat (Figure 2). Working from a frozen M mode trace calipers allows for very specific measurement in millimeters. The M mode in ultrasonography is a diagnostic ultrasound presentation of the temporal changes in echoes in which the depth of echo-producing interfaces is displayed along one axis and time is displayed along the second axis, recording motion of the interfaces toward and away from the transducer.

TABLE 1.
Pitches Used in the Study

Sex	Low Pitch	Middle Pitch
Male	C3 = 130.81 Hz	Eflat = 311.13 Hz
Female	A3 = 220 Hz	A4 = 440 Hz

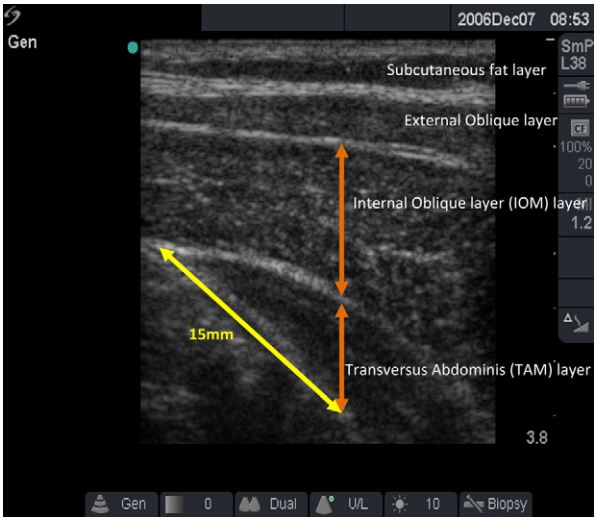

FIGURE 2. US images of the abdominal layers.

The transducer was placed transversely across the abdominal wall on a point between the inferior angle of the rib cage and the iliac crest and 10 cm from the umbilicus. This position was then adjusted by slightly moving the transducer head to ensure that the anteromedial aspect of the TAM, including its medial edge, was visualized. Additionally, some gentle pressure was applied to the transducer head over the abdominal wall to ensure that the orientation of the muscle fibers was perpendicular to the transducer head avoiding possible errors due to artifact anisotropy (as per Costa et al[26]). The images were then frozen and measurements taken at rest and during voicing. This is a well-documented process demonstrating acceptable intra-tester reliability.[23,24,26,27]

The measurement procedure involved a caliper-based calculation of muscle thickness of the TAM and IOM. Muscle thickness (at rest and contraction) was measured at the junction between the most posterior fibers and the abdominal cavity. The caliper direction ran perpendicular to the skin to allow for measurements taken perpendicular to the auxiliary line drawn 15 mm from the aponeurotic joint that could be standardized for both rest and contraction in midphrase voicing. Safeguards against potential measurement errors included assessment of the testing clinician for intrareliability prior to the commencement of testing. Such training was performed explicitly in accordance with the testing procedure adopted by Costa et al.[26]

The percentage increase in thickness during function was ascertained and considered to be representative of the increase in activity. As there is a nonlinear relationship between muscle length and thickness[28] this may not represent an exact increase in muscle activity, however it is a very good approximation, was used throughout the study and has been used by our team previously[20] (see further discussion in Discussion section). For consistency, ultrasonography was always performed on the right side of the abdomen (Figure 2).

Demonstration

All participants were given a short demonstration and training in the vocal exercises and voice quality markers required prior