Relationships between Abdominal and Around-Lip Muscle Activities and Acoustic Features when Playing the Trumpet

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ABSTRACT

When playing the trumpet, embouchure and breath control are the most important factors in achieving stable performance. To investigate these factors in greater detail, we asked 11 amateur trumpet performers to play tones of different pitches, intensities, and durations and analyzed the variations of the activities of their abdominal muscles and the muscles around their lips, which were measured via surface electromyography at the participants' abdominal oblique muscle (AOM) and depressor anguli oris muscle (DAO). The measurements were conducted during the periods of preparing and sustaining the tones. Our main experimental results are as follows. (1) As the pitch increased, the activities of both the DAO muscle and AOM increased during both the preparation and sustain periods. (2) As the intensity increased, only the activity AOM increased in both periods. (3) As the tone length increased, the AOM activity increased, while the DAO muscle was not affected. (4) The DAO muscle and AOM activities were lower and higher, respectively, during the sustain period than they were during the preparation period.

1. INTRODUCTION

Both embouchure and breath control are important in playing brass instruments but most of existing studies focused only on embouchure [1, 2]. Embouchure refers to the use of the facial muscles to shape the lips to the mouthpiece of a brass instrument. The sound of the instrument is driven by the vibration of the lips, which are created by the rapid flow of breath from the gap between the two lips. Embouchure plays a significant role in creating the proper lip vibrations. Therefore, many researchers have investigated the activities of the muscles around the lips when playing a brass instrument [2-9].

Breath is also an important factor and is controlled by the activity of abdominal muscles. In particular, breathing during performance differs from breathing at rest due to the fact that larger volumes of the lungs must be used while performing. Player's abdominal muscles therefore work more actively to support the breath during performance. However, brass players' abdominal muscles have been investigated in only a few studies. Cossette *et al*. reported the relationship between lung capacity and muscular activity during flute performance [10], but they did not focus on brass instruments.

Nonetheless, it is informative to investigate brass players' abdominal muscles since the abdominal muscle activity begins before the instrument starts to sound. Rather, the activity during the preparation phase is important. Generally, performers prepare to exhale just before playing to achieve the proper tone pitches or intensities, which requires the use of the abdominal muscles. Consequently, the abdominal muscle activity during preparation is important in producing correct tones.

In this paper, we discuss the relationships between trumpet players' muscle activities and the acoustical features in the following regards: (1) how the activities of the abdominal oblique muscle (AOM) and depressor anguli orins muscle (DAO) change relative to variations in the acoutical features (e.g. pitches, intensities, and durations), (2) the differences between the activities of these muscles during the periods of preparing and performing a tone, and (3) whether these changes have different tendencies between the AOM and DAO. We aim to provide evidence regarding breath control while playing a brass instrument based on our analysus of the objectively measured muscle activities.

2. RELATED WORK

White and Basmajian reported on the relationship between trumpet performance proficiency and the activities of the orbicularis oris muscles in the upper and lower lips, the levator anguli oris muscle, and the DAO muscles of 18 trumpeters [4]. According to their study, muscle activity varied when the pitch or intensity changed, regardless of the player's proficiency. In addition, it was observed that the beginners had greater degrees of muscle activity in their upper lips than in the lower lips. The muscle activities of the novice players were also found to vary widely in general.

Matsukata et al. also analyzed the muscle activity around the lips during trumpet playing [5]. The amount of muscle activity was found to be greater when playing high pitches than when playing low pitches. In addition, the players who could perform over wider pitch ranges exhibited smaller muscle activity differences between the high and low pitch ranges.

Hirano et al. studied the skin surface movement and muscle activity around the lips before and after tone production in horn playing [6]. Ten proficient horn players were asked to played sounds of various pitches, intensities, and durations while wearing markers and electrodes around their lips. The authors analyzed the positions of the markers and electromyography (EMG) signals and found that the performers had great control over both their muscle activities and skin surface movements (i.e., that these activities and movements were performed with high stability), resulting in no differences between before and after tone production. These results suggest the importance of proper embouchure before tone production.

Moreover, Bianco et al. investigated the temporal evolution and interrelationships among intraoral pressure, mouthpiece force, and activity in two groups of facial muscles [7]. Three professional players were asked to perform 10 isolated C5 quarter notes and a series of 10 concatenated C5 quarter notes, using pp, mf, and ff dynamics. The results showed that the experimental conditions affected the amount and locations of the variations that occurred during performance as well as the intraoral pressure during tone production.

3. EXPERIMENT

3.1 Participants

Eleven amateur trumpet players (seven men and four women) with more than 4 yr (mean, 8.5 yr) of training in playing brass instruments participated in this study. Informed consent was obtained from all the participants, and the experiment was approved by the institutional review board at the University of Tsukuba.

3.2 EMG and sound data recording

We collected EMG signals from the DAO muscle and AOM on the right side of each player by using a wireless EMG logger (Logical Product Co.), myoelectric sensor (Oisaka Electronic Equipment Ltd.), and disposable electrode (Nihon Kohden Co.). Considering the area of each participant's face, the electrodes used to measure the participant's DAO muscle were cut to the appropriate sizes.

To perform EMG on each participant's DAO muscle, we attached electrodes obliquely from the jaw to below the corner of the mouth of the participant. To conduct EMG on the AOM in each case, electrodes were attached to each subject at the intersection between the umbilicus and the anterior axillary line, where the layer portions of the external and internal oblique muscles are located.

We also recorded the performed sounds by using a microphone with an audio interface (both by Harman International Japan Co., Ltd.). The microphone was placed 1 m from the bell of the instrument in each case. We detected the onsets of the performed sounds and used the onset data to extract the relevant EMG data periods.

3.3 Tasks

The participants played in a semi-anechoic chamber using the instruments that they usually played. Our stimuli consisted of six sequences, which covered the following pitches, intensities, and durations:

- pitch: B♭3 (233.08 Hz), F4 (349.23 Hz), B♭4 (466.16
- Hz), F5 (698.46 Hz), and B♭5 (932.33 Hz)
- intensity: pp, mf, and ff
- duration: short note (one beat), long note (eight beats)

The sounds in each sequence were arranged randomly. Each participant played the set of six sequences three times. The order of the sequences was randomized in each set and for each participant. The tempo was set to 80 beats per minute and was shown to each participant by an illuminated electronic metronome (Yamaha). Each participant started playing when given a cue.

4. ANALYSIS OF EMG AND SOUND DATA

4.1 EMG signals

We removed the DC offset of each EMG signal and then filtered the signal using a fifth-order Butterworth band-pass filter, which had a pass-band of 30–400 Hz. Next, we calculated the root mean square (RMS) of the signal, using a window width of 300 ms.

We computed the mean EMG data during periods of 375 ms before the onset of sound production and 750 ms starting 3 s after the onset. In the following paragraphs, the former and latter periods are referred to as the "preparation" and "sustain" periods, respectively (Fig. 1). In each one-beat case, we computed the mean EMG data only for the preparation period.

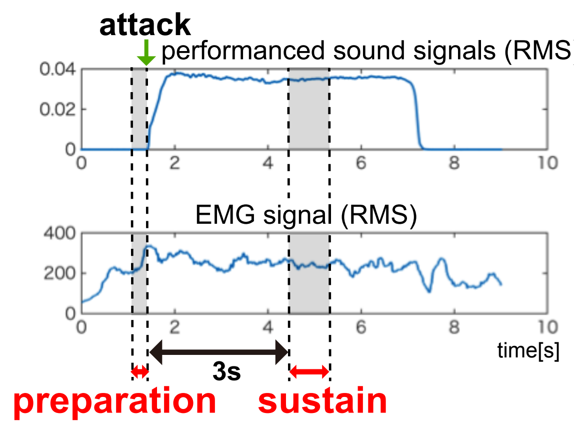

Figure 1. Preparation and sustain periods.

The EMG data were normalized to the muscle activity at the time of maximum voluntary contraction. In this report, we refer to the normalized values as %EMG values.

We calculated the average %EMG values using three trials for each participant and inspected the differences between these averages due to the variations of features such as pitch and intensity during the preparation period in the one- and eight-beat cases and during the sustain period in the eight-beat cases. In addition, to verify the variations caused by changes in duration, we compared the average %EMG values during the preparation period in the one- and eight-beat cases.

4.2 ANOVA

Three-factor analysis of variance (ANOVA) was used to examine the effects of pitch, intensity, and duration, and their interactions during the preparation period. Two-factor ANOVA was conducted to examine the effects of pitch and intensity during the sustain period. Furthermore, for the preparation and sustain periods in the eight-beat cases, three-factor repeated-measure ANOVAs were performed to examine the effects of pitch, intensity, and period (preparation and sustain). As mentioned in Section 3.3, the pitch and intensity categories were defined by performance instructions, rather than physical measures. Finally, post-hoc analyses with multiple comparisons, namely, t-tests with Holm's adjustments, were conducted.

5. RESULTS

Since the entire analysis is comprehensive and too lengthy to describe in its entirety in this paper, four key findings are described in the following sections.

5.1 Pitch and muscle activities

As the pitch of the performed sound became higher, the DAO muscle and AOM activities significantly increased during tone production just before and during the sustain period ($p < 0.001$ in each case). This trend is illustrated for the AOM in Fig. 2. Thus, the higher the pitch, the more active both the muscles around the lips and the abdominal muscles are.

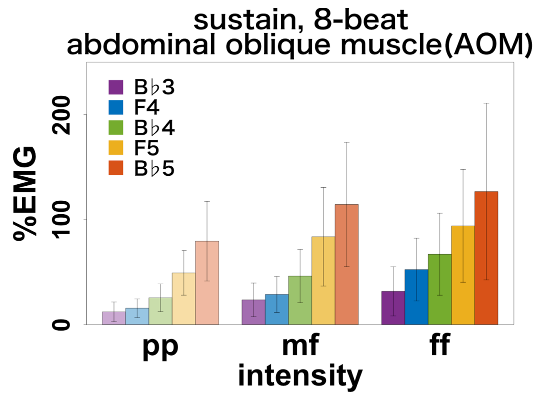

Figure 2. Mean and standard deviation (SD) %EMG values for the AOM during the sustain period in the eight-beat cases.

5.2 Intensity and muscle activities

As the intensity of the performed sound increased, the AOM activities changed, although the DAO muscle didn't increase during both the preparation and sustain period. This trend is observable for the AOM in Fig. 2. The intensity only significantly affected the AOM activity during both the preparation ($p < 0.01$) and sustain ($p < 0.001$) periods. This result suggests that performing a tone with a greater intensity requires more abdominal muscle activity than does performing a tone with a lower intensity, although the activities of the muscles around the lips are not affected by intensity changes.

5.3 Duration and muscle activities

When the duration of the performed sound increased, the activity of the DAO muscle did not change during the preparation period, while that of the AOM decreased with statistical significance ($p < 0.05$), as shown in Fig. 3. These findings suggest that only the abdominal muscles are activated while performing longer tones, but that the muscles around the lips are not affected by the tone duration.

5.4 Muscle activities during preparation and sustain periods

The DAO muscle activity was found to be greater during the preparation period than during the sustain period, while that of the AOM was greater during the sustain period than during the preparation period. In the long-tone cases, the AOM activity differed significantly between the sustain and preparation periods ($p < 0.001$ in each case), while also being affected by the

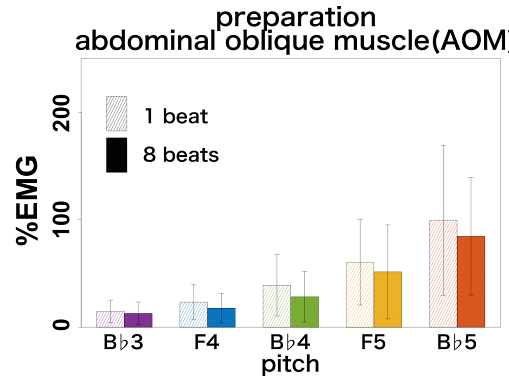

Figure 3. Mean and SD %EMG values for AOM during the preparation period in the one- and eight-beat cases.

pitch and intensity. In addition, interactions were observed between pitch and intensity ($p < 0.01$) and between intensity and period ($p < 0.001$). The pitch, intensity, and period all significantly affected the DAO muscle activity as well (with $p < 0.001$, $p < 0.05$, and $p < 0.01$, respectively).

These results suggest that when performing long tones, the abdominal muscles are relaxed during the preparation period and activated during the sustain period. On the other hand, the muscles around the lips are activated during the preparation period and relaxed during the sustain period.

6. DISCUSSION

6.1 Muscle activity variations with tone pitch

The muscle activity differences observed when the participants performed different pitches would have been caused by the corresponding intraoral pressure changes. Intraoral pressure refers to (1) the feeling of resistance caused by breath flowing out rapidly from the gap between the lips that is reflected from the mouthpiece, or (2) the pressure applied to the oral cavity in order to open the lips against the pressure from the air column inside the instrument.

When performing a high-frequency tone, the oral cavity pressure must be greater than it is when performing a low-frequency tone [9]. The increase in pressure inside mouth causes the AOM and DAO muscle to become more active. It seems that to realize a greater flow of breath, the AOM must support the diaphragm more strongly, resulting in a higher oral cavity pressure. Meanwhile, the DAO muscle becomes active to maintain stable embouchure by tightening the cheeks against the increasing oral cavity pressure.

We observed less activity in both the AOM and DAO muscle when lower pitches were played than when higher pitches were played, in order to realize the same interval differences. In other words, more muscular activity (i.e., more energy) is required in higher pitch ranges to perform the same jump between pitches than is required in lower pitch ranges (e.g., a jump from B ♭ 4 to B ♭ 5 requires more muscle activity than a jump from B ♭ 3 to B ♭ 4 does). Therefore, the muscle activity required for performance is considered to increase exponentially (yet within the realistic range) as the pitch increases.

6.2 Muscle activity variations with tone intensity

The muscle activity differences observed when the participants played tones of different intensities would also have been affected by the corresponding intraoral pressure changes. When playing a tone on a brass instrument, the performer's intraoral pressure depends on the intensity with which the tone is played [6, 7]. Specifically, the intraoral pressure increases as the intensity of breathing increases. Consequently, the AOM activity must be greater to support stronger breathing.

The amount by which the sound intensity of a brass instrument changes depends on the expiratory volume. A larger difference in sound intensity requires a larger expiratory volume than a smaller difference in sound does, resulting in a more rapid decrease in lung volume. The AOM contributes to realizing this decrease in lung volume by pushing up the diaphragm.

6.3 Muscle activity variations with tone duration

Significant variations were not observed in either the DAO muscle or AOM activity, but the mean %EMG value for the AOM was greater in the short-tone cases than in the long-tone cases. We suspect this difference was caused by the participants' consciousness of the required tone duration. Many of the participants reported in follow-up interviews that the degree of psychological stress involved in playing the target sounds differed between the short- and long-tone cases. Higher psychological stress was involved in performing the short tones. We suspect that the AOM activity during the preparation period was higher when the psychological stress was greater.

6.4 Muscle activity differences between before and after production

The DAO muscle activity during the sustain period was less than it was during the preparation period. This finding contradicts that of Hirano et al., who observed no differences between the preparation and sustain periods in horn performance [6].

Unnecessary straining while sustaining a tone leads to fatigue, making it difficult to perform long tones [7]. Therefore, it is desirable to minimize the amount of muscle activity during the sustain period when performing.

Moreover, we observed that the AOM activity was greater during the sustain period than during the preparation period. This difference could have been caused by the AOM being used to push up the diaphragm to squeeze the last remaining air out from the lungs.

7. CONCLUSIONS

In this study, we focused on the activities of the DAO muscle in embouchure and the AOM in breathing during trumpet playing and analyzed the relationships between the levels of muscle activity and acoustic features such as the pitch, intensity, and duration of the performed sound. Based on the experimental results, the following conclusions can be drawn:

1. As the pitch of the performed sound increases, both the muscles around the lips and the abdominal muscles become more active.
2. As the intensity of the performed sound increases, the abdominal muscles become more active. However, the activity of the muscles around the lips does not change with the intensity.
3. When performing longer tones, the abdominal muscles become more active, while the muscles around the lips are not affected.
4. When performing long tones, the abdominal muscles are relaxed during the preparation period and activated during the sustain period. On the other hand, the muscles around the lips are activated during the preparation period and relaxed during the sustain period.

We wonder if performers were aware of these complex muscle activity patterns themselves. Since performers need to conduct sequences of such coordinated movements smoothly, we anticipate that EMG measurements would be beneficial to performers, since such measurements would enable performers to recognize their own muscle activities and make connections between their physical movements and the resulting sounds. Thus, EMG feedback systems for practice sessions may be useful to performers who wish to understand their sound production processes more objectively.

ACKNOWLEDGMENTS

This work was supported by JSPS KAKENHI Grant Numbers 16K16180 and 26240025. We would like to thank to the people who participated in the experiment.

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