Orofacial Muscular Activity and Related Skin Movement During the Preparatory and Sustained Phases of Tone Production on the French Horn

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This study investigated activity of the embouchure-related orofacial muscles during pre- and postattack phases of sound production by 10 trained French-horn players. Surface electromyogram (EMG) from five selected facial muscles, and related facial skin kinematics were examined in relation to pitch and intensity of a tone produced. No difference in EMGs and facial kinematics between the two phases was found, indicating importance of appropriate formation of preattack embouchure. EMGs in all muscles during the postattack phase increased linearly with an increase in pitch, and they also increased with tone intensity without interacting with the pitch effect. Orofacial skin movement remained constant across all pitches and intensities except for lateral retraction of the lips during high-pitch tone production. Contraction of the orofacial muscles is fundamentally isometric by which tension on the lips and the cheeks is regulated for flexible sound parameter control.

Keywords: surface facial EMG, dynamics control, pitch control, embouchure formation, advanced players

Human facial muscles are basically built and developed for speech, mastication, and expressing affections and emotions. The same muscles also play a vital role in singing and playing musical instruments. While playing a brass instrument, such as the trumpet, French horn, trombone, or tuba, muscles located in the middle-to-lower front of the face, throat, and tongue act together to form a playing-related face/lip configuration adjusting to the mouth piece, the so-called “embouchure”.

The facial muscles related to embouchure may include the orbicularis oris superior (OOS), the orbicularis oris inferior (OOI), the buccinator (BUC), the levator anguli oris (LAO), the depressor anguli oris (DAO), the zygomaticus major (ZYG), the risorius (RIS), the levator labii superioris (LLS), the levator labii superioris alaeque nasi (LLSA), the zygomaticus minor (ZYGmn), the depressor labii inferioris (DLI), the mentalis (MET), and other deep and small muscles. These

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Embouchure Control in French Horn Playing

Muscles can be classified into some groups based on insertion and function. The OOS and OOI muscles are the sphincter muscles around the mouth, which closes the mouth, and puckers the lips. The ZYG, BUC and RIS muscles insert into the modiolus, which draws the angle of the mouth into an outward motion. This action results in the appearance of a smile. The DAO muscle also insert into the modiolus, which pull the angle of the mouth downward. The LAO, LLS, LLSA, and ZYGmn muscles insert into the upper lip. Upon contraction of these muscles, the upper lip is elevated. The DLI and MET insert into the lower lip, and the DLI muscles are lower-lip depressors, while the MET muscles are lower-lip elevators.

There have been some attempts to study the functional role of some of these embouchure-related muscles. Using needle electromyography (EMG), White and Basmajian (1973) investigated the activation of the OOS, OOI, LAO, and DAO while advanced players of the trumpet produced tones at different pitches and varying intensities. Photographic records of the EMG data were visually and subjectively categorized into 4 levels of activity. On the basis of this categorization, they reported that the EMG data increased in all of these muscles during the production of higher and louder tones. Interestingly, in a follow-up needle-EMG study conducted by the same group of researchers, a sound property-related modulation of facial muscle activity was no longer observed because of large inter- and intrasubject variability of the data (Isley & Basmajian, 1973). One reason for these differences in results can be the use of needle EMG, which examines activity of a specific and limited location in activated muscles. To observe a general activation pattern of muscles, a surface type of EMG may be better suited (Basmajian & De Luca, 1985).

In response to the need for a surface EMG study of facial muscles, Heuser and McNitt-Gray (1991) recorded surface EMGs from bilateral DAO and ZYG while 10 successful trumpet players produced a sustained long tone and a staccato short tone. On the basis of subjective evaluation of the EMG records, they reported that there was a rise in the EMG activity before the intended time of attack: the initiation of a musical tone commonly referred to by musicians. On the other hand, a drop of the EMG activity and the tone completion occurred nearly simultaneously. These on-off patterns of EMG activity related to tone commencement and cessation were more evident for the players with longer formal trumpet training. Nevertheless, within each player and within each task, the spatial and temporal patterns of EMG activity in all muscles examined were fairly constant. In the same study, they compared a typical EMG pattern from the successful players with those of two players who were having difficulty in playing proper pitches of various tones. They found poor synchronization of preattack EMGs in these two players among the four muscles examined. Heuser and McNitt-Gray (1994) reported that a trumpet player with attack difficulty improved to produce a temporally coupled activation pattern in embouchure muscles when his difficulty of tone commencement was alleviated after intensive training. Unfortunately, only qualitative EMG data were dealt with in these EMG studies, and thus there was no statistical testing of the results. Quantitative EMG data before tone commencement and during tone production could explain the control of muscular tension for pitch and intensity modulations. In addition, simultaneous investigations of facial muscle activity and accompanying skin movement can evaluate the dynamics of facial muscle contraction, and explain the aspects of facial muscle function for brass instrument playing in detail. These results could provide further information on proper facial/
lip configuration for pitch and intensity modulations, and could aid the development of brass instrument pedagogy.

The purpose of the study was to investigate the relationship between the two sound parameters of pitch and intensity, and the two parameters of facial muscle activity and facial skin movement during two phases of sound production: before tone commencement and during tone production. More specifically, surface EMGs were recorded from LLS, ZYG, DAO, DLI, and RIS with BUC (RIS/BUC) of trained French horn players while preparing and producing a long tone at different levels of pitch and varying intensities. Movement of the skin over the embouchure muscles, an estimate of the dynamics of facial muscle contraction and facial/lip configuration, was simultaneously recorded using a 3D motion capturing system during the execution of the task.

**Methods**

**Participants**

Two professional and eight semiprofessional players of the French horn (5 males and 5 females, mean age \( \pm SD = 24.2 \pm 8.2 \) years) with more than 7 years (mean = 12 years) of brass instrument training served as participants in the current study. The semiprofessional players were performance-major undergraduate and graduate school students at local music universities. Their mean weekly duration of playing was 29.0 \( \pm 9.0 \) hr. None of the players reported that they had suffered from any playing-related neurological and orthopedic disorders in the past. Informed consent was obtained from all participants, and the study was approved by the ethics committee at the Graduate School of Arts and Sciences in the University of Tokyo.

**Experimental Task**

Using his/her own French horn with the mouthpiece, each participant performed four sets of three successive 6-s sustained tone productions at different levels of sound intensity twice with a 3-s rest period in-between, and 1–2 min rest period between sets to minimize the effects of fatigue. A light-emitting metronome without sound was used to keep the playing tempo constant. Each set had a target pitch randomly selected from Bb1, F3, F4, and Bb4 tones, which are all from the open harmonic French horn tones with resonance frequencies of 58, 175, 349, and 466 Hz, respectively. Before the experiment, the participants were given scores of the notes indicating weak (pp), medium (mf), or strong (ff) intensity of sound to be produced (see Figure 1A for an example). The level of intensity was graded by each participant at each pitch level. In addition to these, the participants performed sustained production of an F5 tone (698 Hz), which is near the highest pitch in all participants at ff. EMG and kinematic data obtained from this high pitch with strong intensity were used for reference for the subsequent normalization of all EMG and kinematic data.

**EMG and Kinematic Data Acquisition Methods**

Surface EMG signals from the LLS, ZYG, DAO, DLI, and RIS/BUC muscles on the right side of the player’s face were collected using an 8-channel EMG record-
ing system (EMG-AMP04, Harada Co.). RIS and BUC were groups here because electrodes located on a narrow bundle of RIS fiber also detected electrical signals from a relatively large muscle of BUC running underneath RIS. The signals were amplified 500 times, and band-pass filtered between 10 and 1000 Hz on-line. They were then stored in a personal computer via an A/D converter (MP150, BIOPAC Systems Inc.) sampled with 16 bits at 1000 Hz. Earlier studies confirmed near bilateral symmetry of activity in the embouchure muscles during brass instrument playing (White & Basmajian, 1973; Heuser & McNitt-Gray, 1993). Figure 1B shows placement of the EMG electrodes. For EMG, pairs of Ag/AgCl surface electrodes (9 mm diameter) were placed over the belly of the target muscle while keeping the electrodes parallel to the muscles with a 19 mm center-to-center difference. The electrode positions on these muscles were basically determined on the basis of the information given by Lapatki, Stegeman, and Jonas (2003). Briefly, the electrodes for LLS were placed at the side of the ala nasi baseline at the level of the alar curvature point. The ZYG electrodes were placed midway between the ZYG’s origin and cheilion. The electrodes for the RIS/BUC were placed midway between the cheilion and the edge of the masseter muscle. The DAO electrodes were placed midway between the modiolus and the inferior border of the mandible, and the DLI electrodes were placed midway between the vermilion border and the mentolabial sulcus near the border of the mental soft tissue. The border of the mental soft tissue was determined by asking the participants to contract the mentalis muscle. A ground electrode was placed over the right clavicle.

We examined signal selectivity of these target muscles while estimating the amount of crosstalk from adjacent muscles using a method introduced by Lapatki et al. (2003) who also used surface EMG with 5 mm diameter electrodes and 10 mm interelectrode distance. Each of the present participants performed a series of five discrete facial poses, as shown by Lapatki et al. and contracted a target muscle with his/her maximum effort while recording EMGs for 5 s. RMS values of EMG were then calculated for the duration of 2 s. Based on the equations given by Lapatki et al. selectivity index (SI) and crosstalk ratio (CR) values were further computed individually for each facial pose. Lapatki et al. reported that median SI values for LLS, ZYG, DAO, and DLI were 4.4, 2.2, 2.5, and 2.8, respectively. The corresponding values in this study were 2.0, 1.9, 2.0, and 2.7 (RIS/BUC = 1.7), and thus we had smaller SI values. Lapatki et al. also provided the data of CR minima in accordance with the concept that the amount of crosstalk would be estimated from coactivation by taking the most selectively executed pose into account. The CR minima for ZYG from LLS and RIS/BUC in this study were 0.09 and 0.20, respectively. The corresponding values for RIS/BUC from ZYG and DAO were 0.23 and 0.09, respectively, and those for DAO from RIS/BUC and DLI were 0.19 and 0.10, respectively. The CR minima for LLS from ZYG and for DLI from DAO were 0.18 and 0.29, respectively. Lapatki et al. reported that none of their CR minima exceeded 0.25, and thus our value in DLI from DAO was larger than their value. Our EMG data therefore had slightly lower muscle selectivity and slightly greater cross-talk problems due possibly to the use of larger electrodes with larger interelectrode distance than the Lapatki et al.’s recommendation, which could be a limitation of the current study.

For the kinematic analysis of facial configuration, reflecting markers (diameter = 1 mm) were attached to the skin over each of the target muscles in the left side of the face (Figure 1B and C). The video image of the face was recorded using two
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high-speed digital cameras (HAS-220, DITECT Co.) positioned approximately 1.5 m apart and perpendicular to each other, with each camera approximately 1 m from the participants. The data were sampled at 50 Hz for 30 s during the execution of the experimental tasks. The camera-face distance setting allowed the spatial resolution of the digitized marker data to be less than 0.2 mm. The markers were placed at a

![Figure 1](image_url)

**Figure 1** — The score of the F3-tone (175 Hz) production task (A). The order of intensity within each pitch was randomized for each participant. The symbol of “♩ = 80” indicates musical tempo of 80 bpm. EMG electrodes were attached on the right side of the face, and kinematic markers were attached on the left side of the face (B). Marker-to-marker distance for each muscle. a = LLS, b = ZYG, c = RIS, d = DAO, e= DLI (C). A wooden holder attaching the sound-level meter was set to the French horn bell (D).
point approximately midway between the origin and insertion of the muscle, and approximately at the point of insertion near the vermillion border of the muscle.

Using a sound-level-meter (NL-22D, Rion, Japan) mounted on a wooden frame with styrene foam cushions attached to the side of the French horn bell (Figure 1D), a sound signal was collected simultaneously with the EMG into a personal computer. A flat type of frequency weighting with a DC mode was used for the current sound-level-meter setting.

Following the electrode and marker placement, the participants were asked to practice the experimental tasks until they were comfortable with the electrodes and markers attached to their face.

**Analysis of Sound, EMG and Kinematic Data**

The sound data stored were used for the detection of the moment of attack. In a MATLAB environment, this was accomplished by computing the mean and standard deviation of the 2-s background-noise signals while the participant was quietly waiting for a vocal cue to start each experimental task. The attack moment was then identified as the time point when the sound signal exceeded the mean of the background-noises plus 2 standard deviations for more than 30 consecutive samples.

The EMG data were rectified and digitally low-pass filtered at a cut-off frequency of 50 Hz off-line. This filter was the second-order Butterworth filter programmed in a MATLAB environment. A movement artifact at a low frequency (< 10 Hz) was also removed by the feature of EMG recording system (band-pass filtered between 10 and 1000 Hz on-line). The mean value of the EMG and kinematic data for the duration of 375 ms before the onset of sound production (the “pre-attack phase” in Figure 2) and the duration of 750 ms 3 s after the onset of sound production (the “sustained phase” in Figure 2) were computed. Findings from a pilot study using trained players revealed that the sound and facial EMGs were most stable at around the middle of the 6-s long tone production, and therefore the central 750-ms period was chosen as the sustained phase in this study. The 375 and 750 ms corresponded to half and all of a quarter-note at the current 80 bpm tempo, respectively. The EMG data were then normalized by dividing by the mean rectified EMG value of a sustained F5 tone at ff, and expressed in percent of F5 value (%EMG) for the subsequent statistical analysis. The F5-tone production at ff demanded near maximum effort in all of the current participants. We also attempted to measure maximum voluntary contraction of each muscle during a series of facial poses as introduced by Lapatki et al. (2003). The data obtained from this measurement were in many cases clearly less than those for strong F5 tone production. Therefore, we used only the normalized data based on the F5 tone production as assumed maximum contraction. As reported by Lapatki et al., this was perhaps due to difficulty in making specific facial poses in some individuals.

For the analysis of the kinematic data, a direct linear transformation from 2D digitized data to 3D coordinate data were executed using motion analysis software (DIPP Motion Pro, DITECT Co.). From the acquired 3D data, the linear distance between the two targeted markers for each muscle was computed during the period defined as the preattack and sustained phases. The distance data were then normalized by dividing by the distance data obtained during the F5 tone production. The
percent value of the distance (%distance) was used for the subsequent statistical analysis.

Statistical Analyses

A three-way multivariate analysis of variance (MANOVA) with repeated measures was used to examine the effects of phase, intensity, and pitch as well as their interactions. The dependent variables for MANOVA were five muscle data or five marker-to-marker distance data. A post hoc univariate test was performed if significant main and interaction effects were present. The statistical significance was set at $p < .05$.

Results

Sound Data Around Tone Commencement

Figure 3A shows mean time-history curves of sound signals during tone commencement for the three intensity conditions. These curves were made of averaged signals at four pitches examined for all participants. Note that the signals increased sharply from the onset toward the level of each target sound pressure level (SPL). Using the first time derivative of the SPL data, SPL rate was calculated to evaluate the forcefulness of pressure application to the horn. Figure 3B shows a distinct unimodal profile of SPL rate with its peak increased with intensity. ANOVA test
revealed a significant difference in peak SPL rate among three levels of intensity ($F(2, 18) = 14.92, p < .01$). These findings suggest that the initial increase in sound was accomplished by a blast of air pressure with its volume corresponding to the intended intensity.

**EMG Data**

Figure 4 shows mean time-history curves of sound and rectified EMG pooled across all pitches as each level of intensity for all participants during a 1-s period before tone commencement followed by 6 s tone production and 1-s rest period. Bursts of activation in all muscles commonly started about 750 ms before the tone commencement (see Figure 4, and also Figure 2 in a single participant). For example, the mean values of the preattack activity duration for DLI at pp, mf, and ff were 760 ± 56, 723 ± 108, and 766 ± 189 ms, respectively. The muscular activation reached a level similar to that in the sustained period before the tone commencement. Before the tone commencement, all muscles exhibited an intensity-dependent increase of activity, which was maintained for about 6 s of the aimed tone production period. The muscular activity ceased rapidly at the end of this period. These findings indi-
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cated that all muscles examined participated in embouchure formation. In contrast
to the sharp increase of sound onset, a sound offset that started from the moment of
muscular activity cessation took about 2 s to drop to the baseline. This may have
been due to the horn’s reverberation.

MANOVA performed on the %EMG data revealed significant main effects of
intensity (Wilks’s Lambda = .070, p < .001) and pitch (Wilks’s Lambda = .107, p
< .001). The phase effect and all of the interaction effects were nonsignificant. Post hoc univariate tests for each muscle revealed a main effect of intensity for ZYG
(p < .001), DAO (p < .001), LLS (p < .001), DLI (p < .001), and RIS/BUC (p < .001) (e.g., ZYG, DAO, and LLS in Figure 5). The univariate tests also revealed a
significant pitch effect for ZYG (p = .030), DAO (p < .001), DLI (p = .017), and

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Figure 4 — Time-history curves of the mean sound signal and EMG signals across all pitches for five muscles examined at pp (-), mf (--), and ff (——) for all participants.

Figure 5 — The mean and SD values of %EMG (% of sustained F5-tone EMG value at ff) for ZYG, DAO, and LLS at pp, mf, and ff for the preattack (△) and sustained (●) phases. The vertical bars indicate +1 SD for the preattack period data and -1 SD for the sustained period data.
RIS/BUC ($p < .001$), but not for LLS ($p = .406$) (Figure 6). Note that the %EMGs for all muscles examined except for LLS were increased nearly in proportion to the level of pitch in frequency.

**Facial Marker Data**

MANOVA on the interfacial-marker distance as a percent of the resting distance revealed a significant main effect of pitch (Wilks’s Lambda = .310, $p = .013$). Main effects of intensity and phase and their interaction effects were nonsignificant. Univariate tests for each muscle revealed a significant pitch effect only for the markers placed on RIS/BUC ($p = .006$), which decreased from 111% at Bb1–103% at Bb4.

The markers placed on the other muscles remained nearly constant across all pitches, and therefore no change in the marker-to-marker distance (see e.g., ZYG and RIS/BUC in Figure 7).

**Discussion**

**Preparatory Embouchure Muscle Control**

The present findings confirmed that preattack setting of muscular activity and accomplished skin movement were equivalent to those used during actual production.
of a tone at varied pitches and intensities. In line with the observation by Heuser and McNitt-Gray (1991), all muscles examined except for LLS showed increased preattack activity at a higher pitch level. A sound error commonly committed by brass players is unintended pitch of tone commencement, known as an “off-pitch” tone attack. Because this error breaks the harmony of the musical sound, it is a major issue for the players. Successful tone production at the intended pitch requires brass players to set their lip tension properly by moving the lips toward their teeth. The proper lip tension can be accomplished by the cooperative contraction of the orbicular oris muscles, and the group of perioral facial muscles. The clear pitch-related preparatory activity of ZYG, DAO, DLI, and RIS/BUC in the current study explains this phenomenon for the perioral facial muscles.

Related to the facial kinematics, the skin over RIS/BUC was shortened in parallel with increased muscular activation during the higher pitch preparation. Contraction of RIS/BUC is known to retract the corners of the lips laterally. With shortening of the skin, the lips would form a smiling posture. The present findings thus seem to indicate that so-called “smiling embouchure formation” plays an important role in the subsequent production of a higher tone. Interestingly, post-study interviews revealed that none of the present participants was aware of this embouchure formation change.

The present study confirmed that tone intensity is also a preparatory parameter of embouchure muscles. Common problems associated with intensity control among less experienced players are production of sound error such as an unintended explosive attacking tone for an expected soft tone and a delayed tone commencement in a high-intensity range. These could occur if the prepared embouchure setting and the BP were mismatched (Farkas, 1956; Heuser & McNitt-Gray, 1991). Isometric preattack muscular activity that was modulated with the level of BP was thus expected before tone commencement. In agreement with this hypothesis, all muscles examined in the current study showed an intensity-dependent change in preattack facial muscle activity. The kinematic analysis of the facial markers further indicated
no intensity-related change for all muscles examined. In addition, peak attacking SPL rate, which should reflect the preattack BP, was clearly dependent on aimed intensity. Therefore, these findings confirmed that expected sound intensity was a variable associated with muscular contraction for preattack embouchure formation.

The duration of preattack facial EMGs from the tone commencement was also around 750 ms for all activated muscles, regardless of pitch and intensity parameters. Studies of the leg or arm muscles activated before the impact moment from jumping off a platform (Santello, 2005; Mrdakovic, Ilic, Jankovic, Rajkovic, & Stefanovic, 2008) or while catching a ball dropped from different heights (Lacquaniti & Maioli, 1989; Savelbergh & Whiting, 1992) revealed that their durations were commonly much shorter (100–300 ms) than the duration of preattack facial muscle activity in the current study. A search for candidate information sources for estimating the impact moment in these studies showed involvement of visual, somatosensory, and vestibular functions, and the memory of timing experience. Our finding of 750 ms, on the other hand, corresponds to a quarter-note when performing at the current 80 bpm tempo. This suggests that a musical tempo, and thus the paced auditory cue from a metronome, most likely played a major role in the specification of the onset of muscular activation. Indeed, in a follow-up experiment to test the effect of different tempi in one trained French horn player, we found a clear tempo-related change of the preattack EMG duration. This preattack EMG duration decreased to about 300 ms at 140 bpm, and it remained nearly constant at higher tempi, suggesting that 300 ms may be a minimum preattack duration for the embouchure muscle setting. Respiration in synchrony with the metronome sound, and somatosensory information from foot movement to keep timing or movement of other body parts, could also have contributed to the onset determination of the embouchure muscle activations.

**Midsounding Embouchure Control**

White and Basmajian (1973) used needle electrodes to examine the effects of pitch and intensity of a sustained tone on OOS, OOI, LAO, and DAO activity during trumpet playing. On the basis of subjective categorization of the EMG records, they stated that both pitch and intensity influenced the level of their muscular activity. The present study first time used objectively quantified surface EMG data recorded from the muscles from a wider orofacial area than those examined by White and Basmajian. In addition, to test the effects of pitch and intensity, as well as their interaction on a combination of all muscular activities assessed, we employed parametric statistics using MANOVA.

As expected, the pitch and intensity effects were significant; the level of midsounding activity in all muscles except LLS was increased at a higher tone and with stronger dynamics. Unlike our expectation, however, there was no pitch x intensity interaction in any of the muscular activity, indicating that the present trained players were able to modulate the activity of the orofacial muscles with pitch totally independent from that with intensity, and vice versa. Our kinematic data further showed no pitch- or intensity-dependent modulation in the marker-to-marker distance except for RIS/BUC during pitch control. Since MANOVA also revealed no phase difference in any of the kinematic data, the pitch-related change in RIS/BUC distance had already been made during the preparatory phase, and not
during the sustained phase. Together with the findings of White and Basmajian, it is possible to state that sustained tone production at a higher pitch or stronger intensity basically demands stronger isometric contraction of the muscles for embouchure formation. It has been shown that the level of isometric EMG activity is nearly proportional to tension developed in skeletal muscles including those in the face (Kim, Oh, Lee, & Chung, 2009; Lippold, 1952; Lawrence & De Luca, 1983; Petrofsky & Laymon, 2005).

Our findings indicated that the pitch-related modulation in the level of activity in the ZYG, DAO, DLI and RIS/BUC muscles was approximately linear, suggesting that the relationship between resonance frequency (RF) of the lips and tension developed around the lips could also be linear. This information is novel and valuable when understanding a physical model of player’s lips proposed by Fletcher and Tarnopolsky (1999). That is, the brass player’s lips act as an acoustic generator within a narrow frequency band quite close to their natural mechanical RF. The RF of the player’s lips may then be simulated by a simplified mass-spring model as $RF = (MT/EM)^{1/2}$, where MT is tension of the lip, and EM is effective (vibrating) mass in the lip. From a measurement of mouthpiece pressure while producing various tones at different pitches, and estimated average volume flows and average opening of the lips, Elliott and Bowsher (1982) deduced that vibrating lip mass should be inversely proportional to vibrating frequency. It is then possible to postulate that RF of the player’s lips is modulated in proportion to MT (Adachi & Sato, 1996; Fletcher & Tarnopolsky, 1999). Our empirical data showing the linear relationship between pitch and lip tension from the orofacial EMG activity supported this postulation within the range of tones examined.

LLS failed to show a pitch-dependent increase in its activity. While LLS is an elevator of the upper lip, it is a vital facial expression muscle. Its strong activation leads to a frowning face, which opposes the widely held belief that the brass embouchure musculature should remain as motionless as possible. Therefore, we speculate that, to maintain a motionless face, our advanced players have deliberately regulated the level of LLS activity constantly at all pitches.

There are a variety of opinion among teachers, players, and researchers of brass performance concerning embouchure for control of tone intensity. Some stated that the lips themselves should be more relaxed, concentrating muscular tension in other muscles, while others advocate the opposite (e.g., Farkas, 1962; Fuks & Fadle, 2002; Gallagher, 2002; Kleinhammer, 1996; Tuckwell, 1983; Yancich, 1971). As mentioned above, in trumpet playing White and Basmajian (1973) noted that the amplitude of OOS, OOI, LAO, and DAO activities was greater while producing a louder tone. However, they did not discuss this finding. The present study confirmed statistically that at each level of the pitch examined, the amplitude of activity in all five orofacial muscles increased with intensity without changing their length. It has been shown that intensity of a tone produced is adjusted by changing the rate of air volume blown into the instrument and a corresponding change in BP (Bouhuys, 1968; Fréour, Causse, & Cossette, 2010). The louder the tone is, the greater the BP due to an increased rate of air blown into the instrument. Fletcher and Tarnopolsky (1999), and Fréour, et al. further demonstrated that this intensity-related increase in BP became stronger during the production of higher notes, which was also the case in our EMG-SPL relationship (see e.g., RIS/BUC in Figure 8). This suggests that isometric contraction of the orofacial muscles is closely linked to BP resulting
from preparation and production of a tone at an intended intensity. It is most likely
that tension developed by this isometric contraction can provide properly regulated
stiffness in the walls of the oral cavity in relation to changing BP. A benefit of this
control is to maintain a constant space in the oral cavity by preventing puffing out
of the cheeks at high notes with strong dynamics where BP becomes extraordinary
high. Another benefit is physiological efficiency. Musical performance often lasts
hours in trained players, adjusting activity of the orofacial muscles flexible to
resulting BP is essential to reduce their fatigue.

**Implications and Limitations of the Present Findings**

The present findings have several important implications for brass pedagogies
as well as music medicine for brass players. Firstly, a model performance by the
present advanced French horn players exhibited preattack elevation of the facial
muscle activity commensurate with intended pitch and intensity of an upcoming
tone. Accurately setting the preattack contraction of the embouchure muscles to that
required for sustained tone production can be a key to successful tone commence-
ment. This seems to be little emphasized in brass teaching and poorly explained
in the textbooks of brass playing.

Secondly, expert opinions on the embouchure muscle contraction vary from
keeping relaxed to moderately tensed at all levels of tone requirements, or gradually
tensed in relation to the level of pitch and intensity. The present findings clearly
support the latter opinion. All facial muscles examined were activated continuously
from the preattack phase to the end of tone production, and their activation levels
were pitch- and intensity-dependent. Facial muscles need to be tensed to increase
lip tension for higher-pitch-tone production, and to stiffen the wall of oral cavity

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**Figure 8** — SPL-dependent changes in mean %EMG (% of sustained F5-tone EMG value
at ff) for the RIS/BUC muscle. %EMG values are shown in logarithmic scale.
for louder-intensity-tone production. This fact of tensing the orofacial muscles may need some caution when giving an oral instruction to beginner brass students since they often react more than necessary. Kinds of instructions for relaxing are sometimes necessary for the beginners.

Thirdly, the present kinematic analysis of facial skin movement demonstrated clear pitch-related shortening of the skin over RIS/BUC. This information is novel since none of the previous researchers examined facial skin movement directly during brass instrument playing. Many brass authorities agree that the mouth corners should be kept firm while playing a brass instrument. However, there is still much disagreement in terms of embouchure formation, such as puckered configuration, smiling configuration, or intermediate between these configurations. Our data indicate that advanced players, without recognizing it themselves, are clearly relying on a facial configuration only for control of pitch similar to the smiling configuration. This should enable the creation of strong lip tension when generating a higher pitch tone.

Lastly, the level of activation in all muscles examined during the strong high-tone production exceeded 50% of the assumed maximum contraction, and in some cases, above 70%. Professional brass players are known to practice or perform on their instruments for 3–4 hr daily (Flores-Franco & Limas-Frescas, 2010; Roset-Llobet, Rosines-Cubells, & Salo-Orfila, 2000; Zetterberg, Backlund, Karlsson, Werner, & Olsson, 1998), which was also the case in our participants. Clearly, fatigue from prolonged practice or performance is possible, which may result in overuse injuries. A growing amount of research asserts that one major cause of focal task-specific embouchure dystonia among brass players is overuse resulting in a disorder in the brain’s sensory feedback system (Lim, Altenmüller, & Bradshaw, 2001), which often ends professional careers (Hirata, Schulz, Altenmüller, Elbert, & Pantev, 2004; Satoh, Narita, & Tomimoto, 2011). Care must be exercised for extensive, repetitive, and prolonged practice of higher and louder tone production. The fact that a fairly strong muscular contraction is needed for high-pitch-tone production also suggests that a well-developed embouchure musculature is essential for smooth and successful high-pitch-tone production. One reason for brass instrument beginners having difficulty producing a high pitch tone can thus be a lack of properly developed embouchure muscles. This fact should be recognized by brass instrument teachers.

One limitation of the current study was that we only used advanced players as subjects. White and Basmajian (1973) reported that beginners of the trumpet had greater activation of OOS than OOI during simple tone production tasks whereas no such difference was observed in advanced players. The beginners also had a larger range of variation in OOS, OOI, LAO, and DAO activity than the advance players during performing some technical passages, such as small-interval lip slurs, slurred and tongued arpeggios, and short-spaced repeated tones. We reexamined our EMG and kinematics data by separating two concert professional players from other 8 players with less training experience. However, there was no clear trend indicating the skill-level difference in any of these data. We conjecture that the present experimental tasks of simple long tone production at pitches between Bb1 and Bb4 with different dynamics are too fundamental for the horn-major students with more than 7 years of dedicated training. A future study thus should include more complex and technically demanding skills of tone production so that the level of
skill would reflect on muscular activity and/or configuration forming embouchure even among advanced horn players.

References


