Fundamentals of Embouchure in Brass Players: Towards a Definition and Clinical Assessment

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Fundamentals of Embouchure in Brass Players

Towards a Definition and Clinical Assessment

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Brass players may experience problems producing an optimal sound (or range of sounds) in their instrument. Assessing and treating dysfunctional embouchure requires knowledge about functional embouchure, but peer-reviewed literature on dysfunctional and functional embouchure is scarce. **OBJECTIVE**: This study aimed to provide a narrative overview of embouchure based on information from different scientific and clinical fields. This should be regarded as a first step toward construction of a reliable, valid, and practical multi-item method to assess embouchure for brass players. **METHODS**: Literature reviews were conducted concerning: 1) the definition of embouchure, 2) physics and acoustics of embouchure, 3) functioning of embouchure-related structures, and 4) instruments to assess embouchure. In addition, embouchure experts (clinicians, scientists, and elite wind players) were consulted for information and discussion. **RESULTS**: A proposal for a new definition of embouchure, an overview of the relevant physics and acoustics, functions of embouchure-related body structures, and the main methods to measure embouchure in brass playing are presented. **CONCLUSION**: Peer-reviewed information about the fundamentals of dysfunctional embouchure is scarce and sometimes contradictory. A new definition for embouchure is proposed: embouchure is the process needed to adjust the amount, pressure, and direction of the air flow (generated by the breath support) as it travels through the mouth cavity and between the lips, by the position and/or movements of the tongue, teeth, jaws, cheeks, and lips, to produce a tone in a wind instrument. An integrative overview is presented, which can serve as a transparent foundation for the present understanding of functional and dysfunctional embouchure and for developments toward an evidence-based multi-item assessment instrument. *Med Probl Perform Art* 2016; 31(4):218–229.

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Wind players may experience problems producing an optimal sound or an optimal range of sounds in their instrument. This has a variety of causes, such as overuse (too much playing), misuse (wrong technique, for instance caused by incorrectly taught methods), and/or medical diseases/symptoms of the facial, oral, and dental areas and/or problems regarding breath support.[1,2] The prevalence of these embouchure problems is not precisely known. A literature search revealed only two studies.[1,3] Chesky et al.,[3] in their 2002 paper, reported up to 24% "loss of lip" in brass players, an unclear term and possibly a substitute for pain, fatigue, loss of control, or loss of power over the lips or embouchure-related facial muscles while playing a brass instrument. Steinmetz et al.,[1] in 2013, found a prevalence of 59% of "embouchure problems" in brass players.

Musicians, their teachers, and physicians and therapists consulted by musicians would benefit from a systematic approach to embouchure to prevent or resolve these problems. Up to now, no such integrated systematic approach has been available, despite the fact that there are several (dynamic) methods to observe embouchure (e.g., stroboscopy,[4–8] high-speed real-time MRI,[9–11] electromyography,[11,12] and fluoroscopy-video imaging[11,13]) and that some simple classification systems have been developed.[4–6] The most reliable methods to record embouchure, like high speed real-time MRI,[9–11] are not available in daily clinical practice, and there is no structured and agreed-upon way to interpret these recordings. Many expert opinions with respect to the analysis and treatment of embouchure problems have been put forward in the field of embouchure, sometimes contradicting each other. Knowledge of what is functional in embouchure is essential in order to understand and treat dysfunctional embouchure.

A wide range of complaints and symptoms can impede a wind player's embouchure.[1,2,14–16] These complaints may be interpreted in terms of injuries caused by "overuse" or "misuse."[2,15,17–19] They refer to a wide spectrum of soft-tissue related diagnoses such as tendinitis, tenosynovitis, (compression) neuropathies, and musician's dystonia.[17,20]

Various medical specialists interpret and label these situations with reference to different etiologies, according to their specific frame of reference.[21] Different approaches to the analysis, diagnosis, and treatment of embouchure problems are needed to reduce the number of wind players with dysfunctional embouchures and to improve the outcomes of treatment.

Unproven or unsubstantiated beliefs about the way sound is produced in a wind instrument are common, and these beliefs are the implicit foundation for educational methods to achieve good, i.e., functional, embouchure and for the educational or therapeutic approach to embouchure problems. A transparent and theoretically sound foundation for embouchure is clearly lacking, and this is hampering educational, artistic, and therapeutic effectiveness. There is thus a need for a theory-based overview of functional and dysfunctional embouchure and related issues. Theoretical development of a construct should be regarded as a first step in the scientific process of developing clinical assessment.[22] Like any motor performance, embouchure is subject to multiple individual variations and varying circumstances.[23] This leads to a wide spectrum of embouchure presentations. Hence, an overview must describe the main principles, regardless of these individual variations.

The objectives of this study were therefore:

1. to provide a definition of embouchure,
2. to provide an overview of the physics of embouchure and acoustics,
3. to provide an overview of the functions of embouchure-related structures,
4. to describe the main existing methods to assess embouchure at the level of body functions and body structures according to international medical standards, and their limitations.

METHODS

Our study consisted of three major stages: literature review, synthesis of results, and critical feedback.

Literature review: A literature review was performed by searching the Cochrane, Medline, Web of Science, and CINAHL databases. Search terms were: "Assessment-" and/or "Classification-" and/or "Observation-" and/or "Evaluation of embouchure," and the same terms in combination with "wind playing" instead of "embouchure." Since this strategy led to insufficient results, additional searches were conducted with a wide range of search terms; two in 2013[24,25] and three as ongoing searches (2014–2016). Searches focused on the study objectives. The first two searches[24,25] were performed on Medline and Web of Science with the search terms "embouchure" and ["brass playing" or "wind instrument(s)"].

Furthermore, embouchure-related literature collected by one of the authors (XXX) was searched for relevance, and articles that were suggested during the critical feedback stage and review process of the paper were searched for relevance and included when appropriate. During the review process, two additional databases specific for music literature were searched: the website of Oxford Music Online (www.oxfordmusiconline.com) and the German website Musik in Geschichte und Gegenwart (www.baerenreiter.com). <**AU pls give authors' initials**>

The definitions of embouchure found in the literature were evaluated using the following criteria:

1. They had to include an explicit description of the functional goal of embouchure.
2. They had to include an explicit description of the embouchure-related body structures involved.
3. They had to distinguish embouchure explicitly from the closely related mechanism of breath support.

The explicit description is necessary because it defines which body structures should be studied. It allows for an appropriate distinction between directly (primary) and indirectly (secondary) involved body structures. Embouchure refers to many aspects of wind playing that are involved in the sound production in a wind instrument. This paper considers only the directly involved body functions, not the indirectly involved functions concerning the process of breath support. Since embouchure can be seen as a functional construct (to produce an optimal tone), it is important to include this functional aspect explicitly in the definition. Breath support* is distinct from, but closely related to, embouchure (though beyond the scope of this paper).

Synthesis of results: Preliminary results were discussed among members of the study group and theoretical, practical, and clinical soundness and consistency were evaluated. Members of this study group represented the following scientific, clinical, pedagogical, and music-related disciplines: (music) physiatrists, a (music) physical therapist, a movement scientist, and an elite brass player.

Critical feedback: To facilitate discussion and invite feedback from embouchure experts, an online discussion was initiated on an open section of the website www.embouchure.nl. Additionally, conceptual definitions were presented in two poster presentations at an international conference. The final draft of this paper was sent to a wide range of experts (see Acknowledgments) to invite comments about the content. One of the requests explicitly invited critical feedback.

RESULTS

The first search in 2013 resulted in 0 useful references (in the sense of presenting a best-evidence-based clinically applicable instrument to assess embouchure). Searching on Oxford Music Online was not possible because it was not publicly accessible. The German website Musik in

*"Breath support" (USA) or "breathing support" (British) is the ultimate expiration force produced by an individual, resulting in vocalization or the production of a tone in a wind instrument.

Geschichte und Gegenwart resulted in 1 reference for the term "embouchure." All searches together resulted in 71 articles, posters, and publications on websites, which are presented in the reference list of this paper.

Definition

Our examination of the literature about definitions of embouchure resulted, after title-based selection of 118 potential articles, in 7 explicit definitions of embouchure.[2,19,26–32]

Although *embouchure* is a well-known term among wind players and in music medicine, there is no generally accepted definition of the concept. Several authors have proposed definitions,[2,19,26–32] but none of these met the criteria mentioned in the Methods section above. For example, many definitions did not clearly state if, and to what extent, the process of breath support,[33] such as the influence of the abdominal region, is included or excluded in the definition. The definitions by Porter[29] and Potter et al.[30] are the only ones that refer to the crucial role of the air, but they did not meet other criteria mentioned above.

We propose the following definition of embouchure: *embouchure is the process needed to adjust the amount, pressure,*† *and direction of the air flow (generated by the breath support) as it travels through the mouth cavity and between the lips, by the position and/or movements of the tongue, teeth, jaws, cheeks, and lips, to produce a tone in a wind instrument.*

Embouchure can be described in terms of "functional" and "dysfunctional." In "functional" embouchure, the wind player has the ability to efficiently create the intended tone (or range of tones) or sound in his/her wind instrument, without causing music- or practice-related physical complaints. "Dysfunctional" embouchure is the opposite: embouchure which does not, or insufficiently, create the tone (or range of tones) or sound and/or causes physical complaints related to wind playing. Dysfunctional embouchure can occur without apparent physical complaints, e.g., in "squeezed playing" with ineffective high muscle tension in the facial area that restricts the range of playable notes. Examples of possible consequences of dysfunctional embouchure include a limited range of tones (restrictions in playing low and/or high tones), poor dynamics (restrictions in playing loudly and/or softly), sound artifacts (squeezed tone, burred tone, superimposed sounds, diminished harmonics of the sound, noise caused by air escape, faulty intonation, or difficulties producing clear tonal intervals), difficulty playing long notes, pain, redness or swollen lips, and problems of "attack" (the starting or onset of the tone).

The judgment of "functional" or "dysfunctional" embouchure is directly related to the intended or desired level of performance; embouchure can be labeled as functional or dysfunctional depending on the level of intended quality or range of tones and sounds. For example, the (physical) demands are different for amateur musicians and professional musicians. In addition, embouchure is determined by a complex combination of individual factors and environmental circumstances. Deviations in a particular embouchure from the standard situation in this article can be very functional for an individual brass player; e.g., a brass player may compensate an asymmetry in the architecture of their incisors by lateral deviation of his/her instrument's position, in order to avoid painful compression of the lip between the prominent teeth and the mouthpiece. It is important to know these deviations in detail, because there are significant individual variations in morphology and pedagogy that lead to such a wide variation in embouchure presentations (both in functional and dysfunctional conditions).

Physics and Acoustics of Brass Playing

Assessing functional and dysfunctional embouchure in brass playing requires a thorough understanding of the physics and acoustics of brass instruments. The main aspects of the physics of brass instrument playing known so far are described below. These aspects are complex and still not fully understood.[34–40]

Playing music on a brass instrument can be described as a coupled aero-elastic dynamic system with a strong mutual influence between the brass wind player and the instrument.[34–36,40] It is the player's intention to initiate and maintain a vibrating air flow (as a generator) in the instrument. The instrument (as a resonator) contains an air column with a size and shape defined by the form and length of the tube (lead pipe), body, and bell of the brass instrument. The brass player must transfer sufficient vibrational energy to the air column in the instrument to let the column vibrate.[37,40] The air flow, shaped by the player's lips, is blown into the cup of the mouthpiece towards the lead pipe of the instrument. If there is sufficient vibration of the air column, a tone is generated in the instrument, corresponding to the resonance frequency of the instrument itself (the so-called natural or eigen-frequency). The brass player can create a series of natural tones (harmonics) by supplying extra energy to the vibrating air column. When played louder, the tone becomes more brilliant because of additional upper harmonics (= wider tone spectrum). The single tone becomes a sound (with a warm or clear timbre).[34,39–43]

A stable tone is created when there is a standing wave in the air column in the brass instrument. This standing wave is the sum of waves oscillating back and forth in the bore of the instrument, which cross each other at the same frequency.

The air column in all brass instruments behaves like an air column in a pipe closed at one end (the nearly closed mouth of the brass player).[34,35] Irregular, "unstable" blowing by the brass player creates irregularities in the vibrating air column in the instrument. As a consequence, the standing and crossing waves in the air column will be dis-

†Pressure is force divided by surface area, i.e., the opening of a reed or the equivalent of it in a brass instrument.

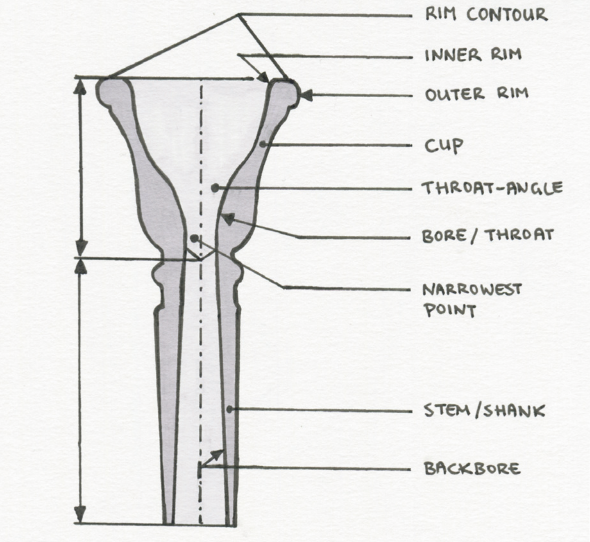

FIGURE 1. Anatomy of the mouthpiece.

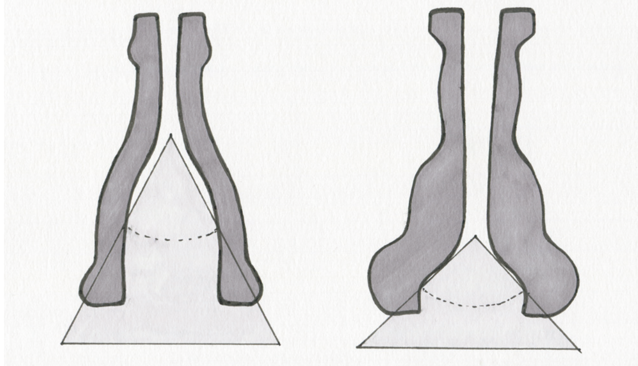

FIGURE 2. Mouthpiece with acute (*left*) and obtuse (*right*) vertex angle.

turbed, with jerky, doddery tones or extra (blurring) noises as the logical outcome.

The "physical aim" of the brass player is to create the necessary vibration in the air column of the instrument. This can be done more easily if the air stream passes a rim or edge. This physical principle is called the "edge tone principle" according to Richardson's law.‡ [42,44,45] The most important edges in this process to create a sound in the instrument are the frontal incisors, the lips, and in particular the refractive index/angle of the passage from the mouthpiece cup to the (back)bore of the lead pipe (Fig. 1). The form of the mouthpiece cup determines the angle of inclination and therefore influences the speed of the air flow and the direction of its transformation into air column turbulence; a dome-shaped mouthpiece with an obtuse vertex angle creates a harmonic full sound, but needs more effort to adapt the necessary air transformations, while a funnel-shaped mouthpiece with an acute vertex angle causes a sharp tone, created with less effort (Fig. 2).[34,41,42,44–46]

The mouthpiece and the rest of the brass instrument must be considered as one system. The mouthpiece of a brass instrument can be removed from the rest of the instrument, making it possible to change the mouthpiece of the instrument, instead of replacing the whole instrument, for the creation of a different sound. The shank of the mouthpiece must be inserted into the lead pipe of the brass instrument, which implies that the diameter of the pipe in this transition zone is therefore narrower (Fig. 3). Due to Venturi's and Bernoulli's principles¶ of the physics of flowing air,[31,33,39,47] this narrowing in the pipe causes extra turbulences in the air column due the accelerated flow and the reduction of the local air pressure. These differences in the air column produce extra harmonics in the sound.[34,41]

Bernoulli's principle: This principle states that the sum of the velocity of the air and the kinetic energy of the air flowing through a tube is constant. The greater the velocity, the lower the lateral pressure of the air on the wall of the tube.[33]

When a brass player actuates a tone, a small amount of air (called an "air packet") is sent into the mouthpiece cup. Most of this air is bounced back towards the now nearly closed lips (Fig. 4). As a result, the nearly closed lips are pressed back against the row of teeth, resulting in a second reflection back into the cup. Only part of the vibration of the air is transported into the bore of the leading pipe, and this produces a sound in the instrument. A very complex interaction between the lips, the bouncing air, and the cup takes place in the cup of the mouthpiece.[40] As a result of this interaction, an air packet with vibrational energy flows into the bore of the instrument. This cycle of air packets continuously repeats itself, within milliseconds, during playing. The main air flow flowing into the mouthpiece gradually diminishes and changes during one air packet cycle. In addition, each entering air packet is not an exact copy of its returned predecessor.[34] The interaction in the cup of the mouthpiece is sensitive to changes in intended pitch, as air pressure increases, and the wavelength of the airwaves decreases, exponentially when playing high and loud as compared to playing low and soft.[40,48,49] When playing loud, the input impedance on the air flow changes suddenly from linear sinusoidal into a nonlinear non-sinusoidal shock wave in the mouthpiece.[6,32]

The interaction between the lips and the mouthpiece is even more complex, as each brass player has their individual elasticity of the lips and surrounding soft tissues. More recent studies on artificial lips[38,39,48,50] have resulted in new insights into the motion of real players' lips. The lips have a tendency to favor an inward motion while playing high notes and outward when playing low notes. This changes

‡*Richardson's law/edge tone principle*: When air is directed at an edge, it does not divide smoothly, but tends to move to one side and form turbulences in the air (swirls and/or vortexes). This initiates and sustains a sound in a wind instrument or when whistling a tone.[44]

¶ *Venturi's principle*: This principle describes the inverse association between air pressure, velocity of flow, and restriction of passage. If there is a restriction in a tube, the related air pressure drop can be restored with a dilation of the tube distal to the narrowing.[33]

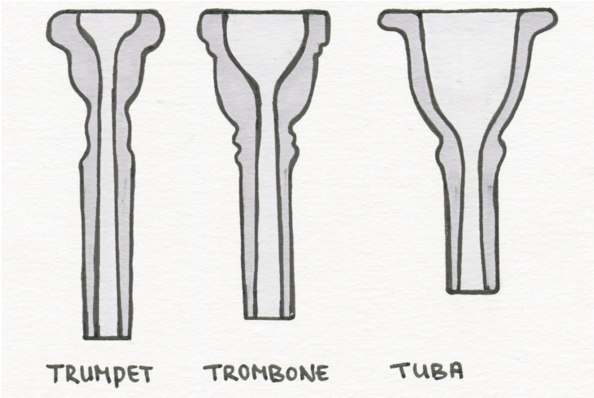

FIGURE 3. The throat-angle of the mouthpiece, showing different angles in different instruments: narrowing the bore of the instrument results in accelerated air flow.

the vibration frequency of the lips during playing, and this frequency is almost always higher than the corresponding air column resonance.[32,38,40] It is unknown if, and to what extent, the aspect of the vibrational frequency of the lips observed with a stroboscope while playing (see below) can be generalized to the situation of playing with a real instrument. Since the characteristics of the reflections depend on wavelength and pressure, different phenomena are likely to be observed in individual musicians playing the whole sound spectrum of the brass instrument.

Functioning of Embouchure-Related Body Structures

Our literature study about the functions of the embouchure-related body structures[24] yielded 10 to 15 more or less explicit descriptions of the function of the different structures in embouchure. A brief overview of the main functions of the embouchure-related body structures (the lips, cheeks, tongue, teeth, and mandible) is provided:

Lips

The lips consist of four zones of mobile mucous and epithelial membranes closely connected with the underlying facial muscles, which cause changes in lip configuration. A detailed description of lip anatomy is beyond the scope of this article. The lips and the immediately underlying orbicularis oris muscle generally consist of four main parts.[51-53] The parts of the lower lip have more fast-twitch muscle fibers, and the parts of the upper lip more slow-twitch, oxidative fibers.[51] The slow-twitch fibers facilitate the control of smaller movements over a longer time. From an anatomical viewpoint, the upper lip seems to be more suitable to perform the continuous small configurational changes needed in brass playing.

Both lips work together intensively for the ultimate control of the air stream velocity and air pressure. Two modes of lip opening can be observed,[38,40,54–56] one vertical "sliding-door" and one more horizontal "swinging-door" movement, like a valve blown open by the pressure of the air. The former movement acts in a plane parallel to the teeth and the rim of the mouthpiece, while the latter acts more at a right angle to this plane. These movements may be opposite in some individuals, influenced by the way they exhale the air (playing upstream or downstream) and the position of the mouthpiece in relation to the lips (whether more on the upper or lower lip), as has been found in the first published videos about embouchure.[39,40] The most frequently observed pattern is that the upper lip rolls inward, tightened over the teeth when playing higher pitched tones, to create an optimal sharp edge for the production of these tones according to the edge tone principle. The lower lip rolls out while playing low pitch tones, to create low frequencies or deceleration of the vibrating air column.[38,42,54,56,57] The position of the mouthpiece rim over the upper lip can be used to shorten the length of the upper lip,[38,57] just as upward fingering on a string instrument creates progressively higher pitched tones (Fig. 5).

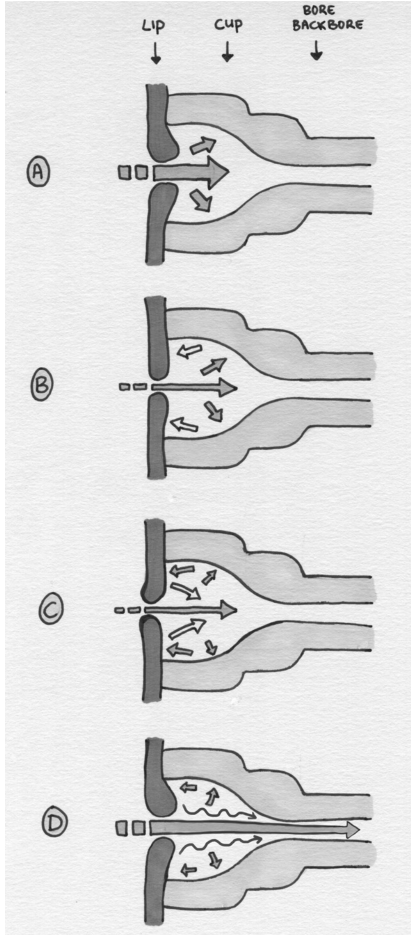

FIGURE 4. Reflecting and bouncing air flows in the mouthpiece and flow into the bore of the instrument. The air flow divides into three phases during one "air packet": ***A***, basal air flow into the mouthpiece; ***B***, reflecting waves in the mouthpiece; ***C***, bouncing air waves from the lips back into the mouthpiece and bore; and ***d***, resultant air flow (of *A*, *B*, *C*) into the bore consisting of air waves with different characteristics.

Stroboscopic videos[7,47,49,57–60] suggest that the role of the upper lip is different from that of the lower lip: the vertical cross-section of one lip behaves as a string and influences the vibration in the air stream towards the instrument, while the other lip (together with the lower jaw position) controls the amount and direction of the air and is kept more or less open[40,61] (Fig. 5).

Nothing could be found in the literature about the role of the layer of mucus on the lips. In our experience, the characteristics of this layer have a major influence on sound production; with wet lips (e.g., after drinking a cup of coffee), it is very difficult to create the same sound as with lightly moistened lips.

Brass players, clinicians, and researchers have different opinions about the above-mentioned functioning of the lips. One of the opinions is that there is a direct relationship between the lip vibration frequency and the tone produced in the instrument, because the lip trill is responsible for the pitch of the tone.[7,18,26] This misconception might be based on existing videos about lip vibration movements in brass playing. There are several arguments against this view. The main argument is that this is physically impossible: playing an A3 note would require an extremely high lip vibration frequency of 1760 Hz, and playing an arpeggio with a range of tones within a very small time window would demand a more rapid muscular action than is physically possible. This misconception is also disproved in practice, as is demonstrated by a video of playing an arpeggio on a brass instrument with a transparent mouthpiece, which shows no significant lip vibration.[29]

Teeth

The teeth have three functions in embouchure. The first and main function of the (top of the) incisors is that they act as a rim to the air column blown from the mouth cavity, according to Richardson's edge tone principle. The second is the influence on the direction of the expired air column induced by the inclination angle of the incisors to the opening of the lips. The third function of the incisors is to support the lips when the latter have to tighten while playing higher pitched notes.[24,26,29,42,57,62] The incisors (and canine teeth) thereby function as an anchoring point for the embouchure. The molars control the air flow by supporting the buccal mucosa and muscles. More detailed information, which is beyond the scope of this article, can be found in the series of papers by Porter,[62] Boschma,[63] and Hattori.[64]

Tongue

The tongue controls the direction and volume of air blown into the oral cavity and the frequency of quick staccato notes as in triplets.[11,13,65] The form of the tongue in the oral cavity has a major influence on the harmonics and resonance spectrum of the sounds finally produced in the instrument.[9,10,13,26,33] A flat tongue causes a much higher air flow velocity and air pressure than playing with a rounded, more relaxed tongue. The former situation is more suitable for loud and high-pitched playing, the latter for softer playing.[9,10,13,26,33] Figure 6 presents an overview of the different tongue forms, positions, and functions, based on dynamic MRI and video-fluoroscopy imaging.[11,13,42] The origin of the tongue is at the hyoid bone, a flexibly positioned bony structure at the level of the throat. Other muscles at the level of the throat, inserted at the hyoid bone, react secondarily to the air column as a consequence of the tongue activity and changes in the positioning of the hyoid bone. Various authors[56,66–70] have reported that elite wind players narrow the opening of the throat to enhance

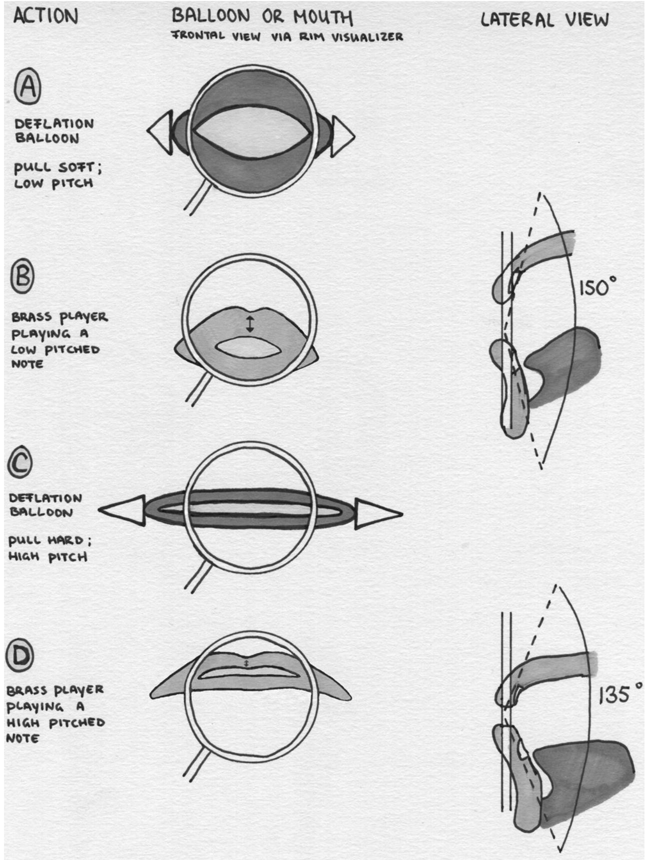

FIGURE 5. The mechanism of lip behavior, lip thickness, and width of the mouth opening explained by the metaphor of deflating an inflated balloon. Different degrees of pressure exerted on the tubular part of the balloon near its opening produce different pitches of sound:
A, Production of a low tone by the spontaneous deflation of a balloon with little pressure.
B, Frontal view of the brass player's mouth while playing a low tone; the lips are thick and relaxed. The (vertical) thickness of the lip acts as a long vertical string (see ↕ in *panel B*).
C and ***D***, Production of a high tone with a balloon and a brass player's mouth, respectively. The width of the opening and the "lips" decrease, and the distance between the edges increases (a louder sound with a balloon is only possible with higher pressure on the inflated balloon itself, comparable to the process of breath support). The (vertical) narrowness of the lip acts as a short vertical string (see ↕ in *panel D*). In panels *A* and *C*, ▷ = place of pressure exerted by the hands.

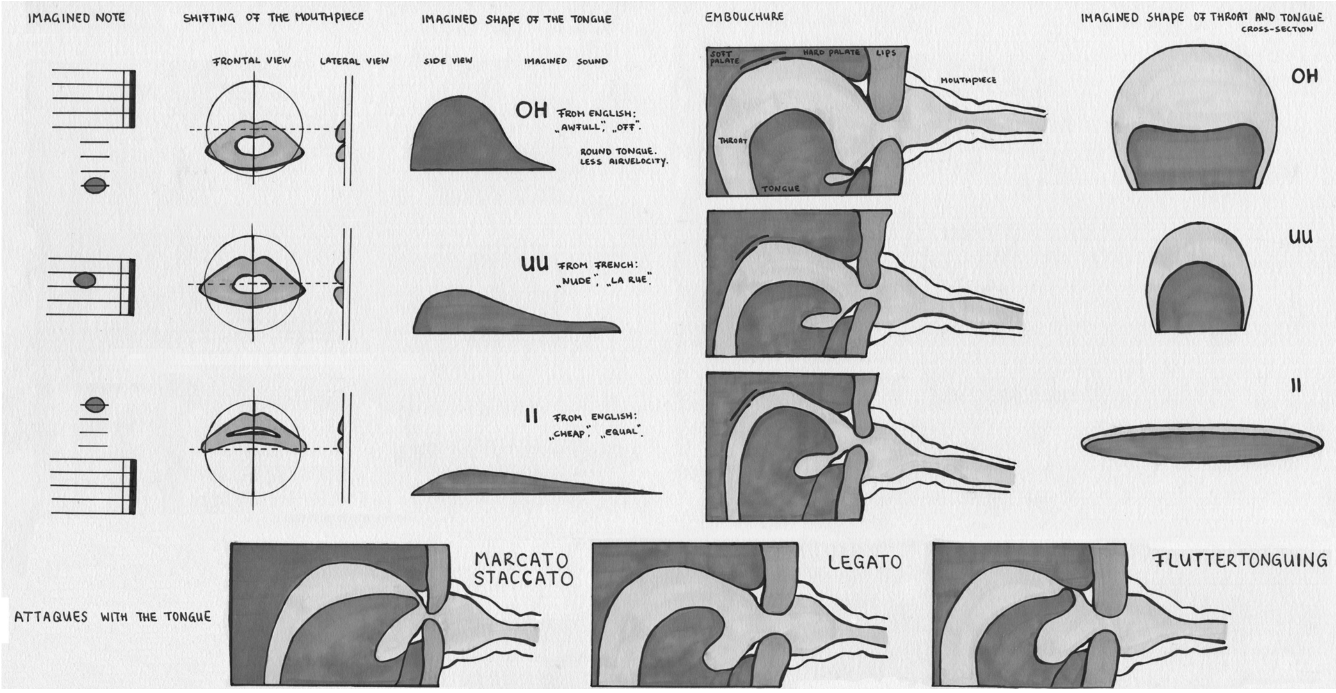

FIGURE 6. Main principles of form, position, and function of the tongue in brass playing. Variations are possible, but in a minority of the brass playing population.

breath support and for a fine control of the direction of the air stream.

Cheeks

The cheeks consist of different tissue layers (mucosa, submucosa, facial muscles, and skin) with different functions related to embouchure.[26,42] No literature could be found about this topic in relation to wind playing, except for the different facial muscles.[26] From our experience and based on the functional anatomy of the facial muscles in general,[51-53] the following can be said: just as in the second role of the teeth described above, the cheeks influence the direction of the expired air when the jaws are not closed. This role seems more important while playing low notes than while playing high notes.

The mucosa and submucosa are highly elastic and cause low friction. They minimize the friction in movements of the facial muscles relative to the teeth. This is important while playing consecutive notes with different lip apertures, during high speed performance. The function of the (outer) skin is important for the sensory feedback during playing, because the facial muscles have no muscle spindles, a unique characteristic of striated muscles.[51,53] It is assumable that, because the facial expression muscles are attached to the skin, the sensory perceptions in the facial skin can be regarded as an external replacement of these lacking muscle spindles. The facial muscles have a major influence on the process of embouchure. Although a detailed description is beyond the scope of this article, the main principle is that the mastication muscles are responsible for the movement and stability of the mandible, while the other facial muscles are responsible for the width of lip-opening, the configuration of the lips, and facial expressions. The orbicularis oris act as the core muscles in the whole spider web-like anatomic configuration.[51–53,71]

Some players play with puffed cheeks and/or puffed lips (with some air collection under the lips) to create soft jazzy notes, to use the circular breathing technique (without lung air circulation but directly via the nose), or to create more air pressure (with less tension in the embouchure-related muscles) in the instrument, as a compensatory mechanism in the case of perceived weakness.

Jaw

The (lower) jaw can be seen as the rudder of the embouchure. The large muscles of the lower face and mouth floor area open or close the mandible and determine the mouth opening in general.[13,51,53] The lips can adapt this mouth opening more precisely and at a much faster rate.

The incisors of the maxilla and mandible should meet in a vertical direction while playing.[26,44,45,62] This is only possible by protraction of the mandible. In this protracted position, the pressure of the mouthpiece on the lips and jaws can be divided equally over these structures. Playing very low tones, e.g., with the bass tuba, can be performed most easily with a protracted and backward overturned mandible position to enable sufficient air transit for a consistent low-pitched tone production.[42,38,40,61] Protraction of the mandible is also necessary to avoid the nicking of lips by the mouthpiece by improving the position of the teeth,

TABLE 1. Overview of Actions to Produce a High- or Low-Pitched Note in Brass Playing

	High-Pitched Tone	Low-Pitched Tone
Pronouncing vowel	Phonetic "I"	Phonetic "or"
Tongue configuration	Flat (low) tongue	Spherical (high) tongue
Lip configuration	Hard/thin	Soft/thick (extreme low: puffed cheeks and lips)
Lip opening	(Very) small	(Very) wide
Lip top (vertical string length)	Short	Long
Mandible position	Frontal (forward-protracted)	More backward/wider opened (extreme low: forward and tilled backwards)
Head position	Neutral/backward and upward	Forward and downward
Inclination edge incisors with reference to the instrument	More transverse (± 135°)	Less transverse
Position of mouthpiece (shifting)	Lower (less vertical length of upper lip)	Higher (increased vertical length of upper lip)
Pivoting of the instrument	Downward*	Upward*
Direction of air stream	Straight/ upstream	Straight/ downstream
Embouchure motion	Upper lip upward over the incisors	Upper lip downward over the incisors
Tension of embouchure-related muscles	Higher	Lower

* Pivoting with a big brass instrument is difficult to perform, and compensation is created by movements of the head and/or jaw.

with a decreased sagittal inclination angle of the incisors.[42,63] Most muscles in the facial area are relaxed during a low mandible position, which facilitates the relaxation of the lips necessary to play low notes.[12,26,51–53]

The production of high- and low-pitched notes is possible in various ways. Only a few brass players, even among elite players, are explicitly aware of the whole spectrum of actions (and combinations thereof) they perform to play the desired notes with different pitches. The possible range of actions used to meet the different demands in playing brass is described in Table 1. Several of these actions are intended to create a short and tensed upper lip with a sharp edge and narrow lip opening (in combination with strong breath support). The purpose of upstream and downstream playing is to reduce or to increase the pressure in the whole system and to create the correct lip flap length for the particular situation. Playing very low tones is somewhat different from playing low tones, as the mandible is positioned more frontally to open the mouth maximally, and breath support must be maximal as in playing very high (or loud) tones.

The clinical relevance of Table 1 is that in the assessment of embouchure, it is important (in both pedagogical and therapeutic situations) to measure across the whole range of tones, as different demands are made in the different embouchure situations. Some signs and causes of dysfunctional embouchure only occur in specific circumstances and can only then be detected by the observer.

The majority of brass players position the mouthpiece of their instrument at a ratio of two fifths and three fifths on the upper and lower lips, respectively, in small brass instruments, and at the opposite ratio in large brass instruments.[5,7,34,35,50,57–60] While playing the bass tuba, the mouthpiece is positioned nearly against the nose. Adaptations are possible, via the mechanism of "embouchure motion" and/or "shifting" of the instrument. In "embouchure motion," the lips and mouthpiece together move slightly in a vertical direction over the teeth; in "shifting," only the position of the mouthpiece moves in a vertical direction relative to the lips and teeth (Fig. 7). The reason for the different positions of the mouthpiece while playing different brass instruments is the adaptation of the lip function to the characteristics of the different instruments.

Existing Methods for Assessment of Embouchure

The most prevalent assessment of embouchure in daily practice is visual observation of musicians while they are playing a brass instrument. Some observation methods assess embouchure in a systematic way, for instance using the classifications of embouchure by Reinhardt,[4] Farkas,[47] Elliott,[6] and Wilken.[5] However, none of these describe embouchure in a way that is complete and systematic.

These four classifications are comparable in describing the direction of the air stream (upstream or downstream) and the position of the mouthpiece in relation to the position of

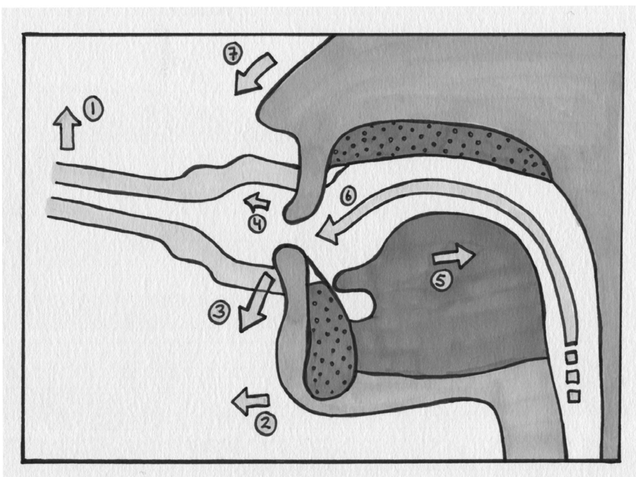

FIGURE 7. The basics of the mechanism of (upward) pivoting of the instrument (in low-pitch playing) ***1***, changing the direction of instrument (upward in this case); ***2***, chin forward; ***3***, puckering of lower lip; ***4***, length of lip flap of upper lip increased; ***5***, tongue backward; ***6***, air stream; ***7***, head bending forward.

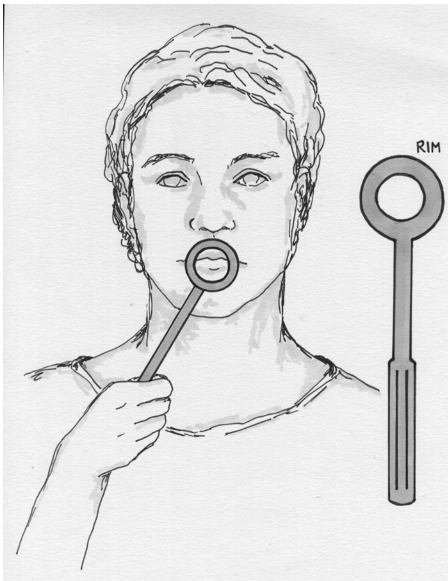

FIGURE 8. Rim visualizer, held in front of the mouth.

the lips (= shifting). In the classifications by Reinhardt[4] and Farkas,[47] this is combined with pivoting of the instrument. These two classifications (with four standard types and five subtypes) are not easy to understand.[5] In addition, the classifications fail to classify the "straightforward streaming" form of adjustment of the air flow. The abovementioned classifications assign a significant role to the direction of the air stream while playing. Others[4–7,35,39,42,44,45,57,71,72] find this less relevant and emphasize the individual player's anatomy as one of the most important factors determining which embouchure would work best for a particular musician. In line with our proposed definition of embouchure, the embouchure-related body structures should be regarded as the structural "preconditioning" factor for embouchure.

Since the mouthpiece is in front of the lips, a large part of the mouth area is hardly visible. For this reason, a ring-shaped open mouthpiece (the rim visualizer, Fig. 8) or a transparent mouthpiece can be used to observe what happens behind the mouthpiece. In line with a suggestion by Fritz and Wolfe,[67] we assume that the "muscle memory" should be reliable enough when doing a simulated task (like playing on a rim visualizer) instead of real playing. As far as we know, there have been no validity and reliability studies on these visual observations of the mouth. Observing embouchure via a transparent mouthpiece is difficult because it becomes steamed up by the warm and humid air in the mouthpiece. Observation using the rim visualizer differs from the normal embouchure in that there is no correction for the lack of counter-pressure and bouncing effects of the air (the part that does not directly flow into the leading pipe) from the mouthpiece cup back to the lips and vice versa. As a consequence, the brass player tends to play with pursed lips in an open mouthpiece, as in "buzzing with noise." This will cause the production of squeezed tones. A proper observation with a rim visualizer can be performed without expiration of air, while keeping the lip configuration the same as when playing a real tone of a certain pitch on the instrument. A novel approach to visualize embouchure in the mouth cavity while playing was introduced by Rietveld and Kersing,[74] using a flexible or rigid fiberoptic device inserted into the oral cavity via the nose or the corner of the mouth, respectively.

A technical support method in observing the dynamics of embouchure is stroboscopy. Stroboscopy is widely used in the observation of vibrating objects such as the vocal cords in ENT medicine.[75] When lit with a high-frequency flashing light, which has (nearly) the same frequency as the vibrating object, an object appears to move slowly or is stationary. This makes observation much easier. The reasoning behind observation with a stroboscopic tool may, however, not be valid. A valid observation is only possible if there is a (nearly) constant vibration frequency of the lips during observation, as otherwise no stationary image can be created with stroboscopy. As mentioned earlier, playing one tone is a dynamic phenomenon. In normal playing, the frequency at the onset of the tone is different from that during the rest of the tone, with a gradual decline in frequency towards the end. Stroboscopy is only suitable in the undesirable situation of playing with squeezed lips, because of the stable frequency patterns during the tones thus played.

DISCUSSION

Embouchure concerns the process in which a wind player produces a tone on a wind instrument. Many problems of embouchure can occur, in professional, pedagogical, and therapeutic situations. It is difficult to find systematic information, even in textbooks of music medicine[2,19,26] to confirm or refute any particular opinions in this situation. Because of the lack of an international open-access digital database of non-therapeutic music literature and very little information in (allied) medical databases, it was not feasible to perform a systematic literature review of embouchure. Nevertheless, to create an integrated view of the different fundamental aspects of embouchure, a synthesis was composed from information gathered using the unfortunately non-controllable and non-transparent approach described in the Methods section.

Up to now, there has been no agreed definition or operationalization of the construct of functional and dysfunctional embouchure. We conclude that the existing theories about embouchure are not soundly based in theory, or based on, or directly derived from, evidence. Moreover, the existing assessment methods for embouchure have not been studied for their psychometric properties.

The observation, classification, diagnosis, and evaluation of embouchure problems requires an accepted definition and a theory-based measurement instrument.[76] Such a measurement instrument must assess embouchure in its widest sense (Table 1) in order to provide insight into functional and dysfunctional embouchure for a particular wind player and, in case embouchure problems are found, to give an indication of the etiology and/or pathophysiology of this problem. Embouchure should be regarded as a multidimensional construct, which by definition cannot be assessed with a one-dimensional assessment instrument or strategy.

The construct of embouchure should be described and operationalized according to the international guidelines and terminology for the description and classification of human physical functions and functioning in general. The International Classification of Functioning, Disability, and Health (ICF)[76] should provide the appropriate semantics. However, the ICF lacks a description of embouchure (and breath support). Thus, as there is no definition of embouchure that complies with the criteria and that is also in line with the ICF nomenclature, the introduction of a new definition of embouchure can be justified.

Currently, there is no valid and reliable method to assess embouchure in clinical practice. The introduction of a valid and reliable measurement method, based on underlying related physical and acoustic laws, is crucial to the further development of both embouchure pedagogy and treatment in the case of dysfunctional embouchure. A structured approach should facilitate a more explicit assessment of the embouchure of an individual brass player, for both teachers and practitioners. A valid and reliable instrument would also allow the evaluation of treatment in individual musicians and a comparison of the effects of different therapeutic and/or pedagogical brass playing methods.

A limitation of the present study is that it probably did not include all relevant literature. Due to the difficulties of finding the relevant literature in a systematic search, we had to overcome this limitation and to minimize the risk of missing relevant literature via the process of critical feedback. We consider the risk of major bias in the final conclusions in this paper due to this approach to be small. The conclusions of this paper should be regarded as experience-based (level III, mechanism or expert-based reasoning),[77] which is the lowest level of evidence.

CONCLUSION

This article provides an overview—based on an extensive though non-systematic literature search, clinical experience, and elite brass-playing experience—of what is known about embouchure, its underlying physics, body structures and functioning, and assessment. A new definition is proposed. Embouchure should be regarded as a multi-dimensional construct. Future assessment of embouchure should include the measurement of all relevant dimensions. No clinical measurement tool is currently available to assess embouchure in a valid and reliable way.

Based on the content of this paper, an observation-based assessment, the **C**lassification, **O**bservation and **D**iagnosis of functional or dysfunctional embouchure and **E**valuation of treatment (**CODE** of embouchure) will be developed and subsequently tested for its construct and content validity and reliability.

In the process of our discussions, receiving feedback and separating myths from facts, it was of crucial help (level III: based on expert opinion)77 for the ecological validity of this study that author H.B., as an elite brass player, contributed his specific practical expertise.

A preliminary version of this paper was submitted to a panel of 28 worldwide experts in the field of embouchure (scientists, acousticians, music medicine practitioners, and internationally high-ranking wind instrument performers) to invite feedback about the definitions and argumentations. Due to lack of time, 4 panel members were unable to participate. The authors thank Line Atsma, Brandt Attema, Patrice Berque, Erik Bosgraaf, Prof. Matthias Bertsch, Prof. Matthias Echternach, Anncristine Fjellman-**Wiklund**, Rene Henket, Andre Heuvelman, Mariko Hattori, Wieke Karsten, Rob van der Laar, Jan de Laat, Gerdien Lindeboom, Johan van der Linden, Saskia Laroo, Jaume Rosset i Llobet, Herman Nijkamp, Michel Ricquier, Boni Rietveld, Sophia Schambeck, James Shepard, Denis Wick, and David Wilken for their critical review and comments on the content of this paper.

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