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Did Non-vocal Instrument Characteristics Influence Modern Singing?

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Introduction

To what extent have musical instruments influenced singing? One could imagine three plausible scenarios: (1) Artificial instruments (fabricated, as distinct from vocal) were developed, over time, to mimic (or to extend) features of human singing; (2) After the early development of artificial instruments, such as bone flutes, those instruments influenced human vocalizations, especially singing; (3) The two evolved side by side, influencing one another. Over historical time, the third scenario can easily be defended. In prehistoric times the third could he imagined to incorporate different proportions of the ocher two. In this paper, we shall argue in favor of a large proportion of scenario 2, drawing on acoustic and cultural transmission perspectives to suggest the possibility that, from their earliest appearance, instruments may have had very profound effects on the nature of song.

We shall argue that the human voice is, in an acoustical sense, less well suited to perform music in which the pitch of notes is fixed, independent of their loudness-a feature associated with many modern singing styles, especially that found in Western music. Much modern music,' and especially much Western modern music, uses categorical pitch and varies the loudness independently of pitch during single notes. We shall argue that these features are nor natural for the voice, because of physiology and acoustics. These two unnatural features, however, are relatively easily produced on simple flute, reed, and string instruments. Examples of flutes are among the earliest pitched instruments known (Dauvois et al. 1998; Zhang et al. 1999). Other early instruments, such as the ancestors of reed and string instruments, were made of less durable materials and have left no similarly ancient examples. We argue that the ease with which such instruments were able to produce notes with discrete pitch, independent of loudness, may have strongly influenced musical style and that singing acquired these features from the music that such instruments produced.

Acoustics of Musical Instruments

Nearly all artificial pitched musical instruments have a component, such as vibrating string or a vibrating column of air in a wind instrument, whose resonant frequency determines the pitch (Fletcher and Rossing 1991). The modes of vibration or resonances of the string and air column have rather precisely determined frequencies. In terms of physics, we say that the string or air column is linear and that their resonances have a narrow bandwidth. Consequently, a string with a certain length, mass, and tension will play an A, but will not play A# unless one changes the parameters. Further, it will produce its note with a frequency *almost independent of amplitude:* over a large range of loudness, it will still play the same pitch. Instruments often have another linear component whose purpose is to radiate the sound: the body of a string instrument and the bell of wind instruments serve to transfer energy from the string or air column into sound more rapidly. For example, an acoustic guitar is louder than an unamplified electric guitar. The bodies of string instruments also have resonances, but those resonances have negligible effect on the pitch, with rare exceptions such as wolf notes on cellos.

Instruments that produce a sustained sound, such as bowed strings or wind instruments, also have a component that continuously inputs energy. In strings, this comes from the stick-slip cycle of the bow on the

string, in wind instruments from the regular vibration of a control mechanism, which may be a reed, an air jet, or, for bran, the player's lips.

In physical terms, the string and the air column behave linearly: doubling the amplitude of the vibration corresponds to doubling the amplitude of the varying component of the force. In contrast, the bowstring interaction, the reed, air jet, and lips are inherently nonlinear. For instance, in the case of wind instruments, turbulent losses introduce a quadratic relation between pressure and air flow, while the friction between bow and string introduces a function which is almost discontinuous. Both are strongly nonlinear.

In normal performance, one of the resonances of the linear resonator controls the frequency at which the nonlinear component operates. Thus the string vibration determines the frequency of the stick-slip motion of the how, while one of the bore resonances in a wind instrument determines the frequency of vibration of the reed, air pet, or player's lips. The amplitude may be varied (by bowing faster or blowing harder) over a large range with little effect on the pitch. To change the pitch, one usually changes the geometry of the string or air column. Fingers of the left hand stop a string at different length, valves or a slide change the air column length in most brass instruments, and opening tone holes shortens the effective length in woodwind. Thus an artificial instrument can easily play a range of amplitudes ("a range of dynamics," as a musician would say) at constant frequency, and so can play *crescendi, diminuendi,* and accents at constant pitch. Because such musical instruments are very familiar to us, this behavior may seem obvious. What is far from obvious is that the voice should readily behave in the same way. The voice can also vary loudness at constant pitch but, as we shall explain, it is more complicated to do so.

Comparing and Contrasting Musical Instruments and the Voice

Functionally, percussion and string instruments are the least like the human voice: their energy sources and excitation mechanisms are very different. Wind instruments, on the other hand, share with the voice the fact that they are powered by breath. The family whose sound production mechanism most closely resembles, that of the voice is the Lip-valve fam-ily, which includes the didjeridu, the modern brass family, and others.

Both lip-valve instruments and the voice derive their energy from air delivered from the longs at pressure above that of the atmosphere. For the lip-valve family. the nonlinear vibrating elements are the player's lips and the air let passing between them; for the voice it is the vocal lows and a similar air 'et. In both cases, the operation is rather similar: the vocal folds can close to seal the trachea from the vocal tract; the player's lips can close to seal the mouth from the bore of the instrument. From this closed position, high-pressure upstream can open the lips or folds. Once air starts flowing between them, this flow creates a suction that, together with the tension on the lips or folds, acts to close them. If the upstream pressure and the geometry are maintained, this cycle can repeat regularly, giving rise to a sound with a stable frequency. A consequence of the nonlinearity of this process is that, under steady conditions, the sound is usually periodic (it repeats in cycles with a definite period and frequency) and has a harmonic spectrum (its sound contains components with frequencies in the ratio 1:2:3:4 etc.).

Despite the similarities in excitation mechanism and pitch range, there are qualitative differences berween the lip-valve and the voice and these are critical to our argument. Downstream from the lips or folds lies an acoustical resonator: the bore of the instrument and the vocal tract, respectively. The resonances of these downstream ducts have qualitatively different effects and functions. Each of the resonances of the instrument has a rather precisely defined frequency, and several of them are able to determine the vibration of the lips. Thus, their frequencies span the playing range of the instrument and in fact largely determine it. The vocal tract (the downstream resonator for the voice) also has resonances, though each covers a relatively wide hand of frequencies. Importantly, all but one of these resonances lie at frequencies well above the normal range of vibration of the vocal folds. For most vowels and voice ranges, even the lowest frequency resonance of the tract lies above the vibration frequency of the vocal folds.

For the voice, the frequency of the vocal fold vibration depends on

the tension and geometry of the vocal folds, and also on the subglottal pressure (the pressure supplied from the lungs) Fant 1960; Sundberg 1987), Because of the relatively high frequency of the resonances (if the vocal tract, the vocal fold vibration usually is little affected by these resonances. Consequently, there is usually no simple relation between the frequencies of the resonances and those of the vocal fold vibration, although there are exceptions for high voice ranges (Joliveau et al. 2004; Gamier et al. 2010). So, for the voice, the downstream resonance does not determine the frequency of vibration. If the singer gradually changes either the subglottal pressure or the vocal fold tension, with a fixed vocal tract geometry, the pitch usually varies smoothly (exceptions involve sudden changes of vocal mechanism at the -break" in the voice). To a good approximation, the vocal fold parameters and the subglottal pressure together determine the pitch of the voice, independently of the resonances in the tract.

To illustrate the independence of vocal tract resonance and vocal fold vibration, the reader may try singing a steady note while moving the tongue, lips, and other articulators, Going smoothly from “ah” to “oo,” one reduces the frequency of the resonance of the duct by more than 30%, which is also what happens when the slide of a trombone is smoothly extended from its shortest position to arm's length. The difference is clear: with the possible exception of a high-voice singing in its high range, it is very easy for a singer to maintain a steady pitch while smoothly varying the resonator, whereas it is extremely difficult for a trombonist to do this without producing the characteristic trombone glissando.

To illustrate the dependence of the pitch on the subglottal pressure, the reader may try to sing a note at a constant pitch and then strike his/her chest with a fist. This briefly raises the suhglottal pressure and causes a brief rise in pitch, because the blow is too rapid to allow the compensatory change in vocal fold tension that one would normally use to maintain constant pitch.

For a lip-valve instrument player using lust a mouthpiece, without the rest of the instrument, the frequency of lip vibration also depends, as a Continuous function, on the tension and geometry of the lips and on the upstream pressure. Thus the player's lips behave much like the singer's vocal folds (Figure 1). When the instrument is added, however, the result is different: the vibration frequency is determined rather precisely by one or more of the resonances of the instrument. If the instrumentalist gradually changes the pressure supplied by the lungs while maintaining a fixed geometry of the instrument (no moving of valves or slides), the pitch does not vary smoothly: it stays almost constant over a considerable range, until it may "jump" from the pitch of one bore resonance to that of another. Here, the bore of the instrument (the linear resonator) "wins the battle" to control the pitch. Consequently, a *crescendo* or *diminuendo* over a large amplitude range may be performed easily with relatively little change in pitch, simply by not using valves or slides. Similar observations could he made about other artificial instruments including reed instruments, flutes, and bowed strings.

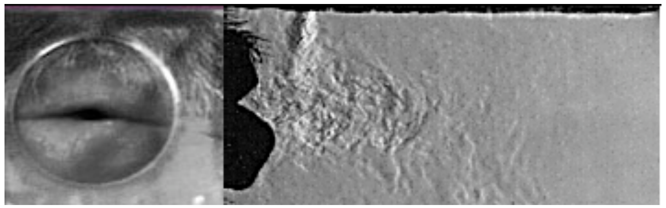

Figure 1
Example from a series of stroboscope photos showing she lip and the air jet that "drive" a lip-valve instrument- The vibrating lips emit an air jet, shown in Schlieren photography in the silhouette at right. Although direct observations are considerably more difficult, the vocal folds are believed to generate the voice in a similar

In contrast, the vocal tract does not control the vibration of the vocal folds and therefore does not determine the pitch. It does, of course, have an important function in speech and singing: its geometry is largely responsible for the production of different phonemes (Fant 1960). To

continue the comparison with music, we could say that the vocal tract

controls the timbre: a sustained "oo" is a different timbre from a sustained "-tab." Because the fundamental frequency of the voice usually lies below those of the tract resonances, these resonances selectively transmit some of the harmonics of the voice better than others, thereby creating formants or enhanced frequency hands in the (Output sound. The frequencies of the tract resonances, and therefore of the formants they produce, are determined by the geometry of the jaw, tongue, lips, etc. (e.g., Fant 1960; Clark et al. 2007). To make an analogy between different tract configurations and musical instruments, we could observe that the players of trumpets and trombones can change the timbre (much less rapidly) by placing in the hell one of several different mutes, which produce different formants in the output sound. The artificial instrument is good at stable pitch and controlling loudness at each pitch, but does not usually make large timbre changes rapidly. In contrast, the human voice is good at producing different timbres and thus different phonemes, but is not inherently suited to producing stable pitch independently of loudness. The *messa di voce,* a slow, controlled *crescendo* and *diminuendo* at a stable pitch, is not easy for a beginning singer, and remains a regular exercise for many expert singers, for example those trained in Western art music traditions.

The reason for the difficulty is the strong correlation between loudness and pitch over much of the vocal range. Increasing subglottal pressure increases loudness, but (all else equal) it also usually increases pitch. The phonetogram is a plot of the limits of vocal sound level over the range of pitch, and such plots are usually made for singers (e.g.. Gramming and Sundberg 1988). These plots vary among singers, but show a strong positive correlation in each vocal mechanism (vocal mechanisms M1 and M2 are associated with normal and falsetto for men, chest and head voice for women). An idealized phonetogram is shown in Figure 2. Most vocal gestures, in speech and in singing, correspond to trajectories within the limits and having generally positive slope: the highest note in a phrase is often sung most loudly, and the stress in a sentence is often conveyed by an increase in both loudness and pitch. A positive correlation between loudness and pitch is more than just a style of singing or speech: the positive correlation is also simply natural, in the sense of being easy to produce. In contrast, a *messa di voce*, if plotted on Figure 2, would be a vertical line that the singer first ascends and then descends as sound level rises and then falls at fixed frequency. A scale sung at constant sound level is a series of points on a horizontal line. Although these may seem natural and relatively easy to experienced singers, and natural to listeners having extensive exposure to these features in song, they require substantial amounts of practice.

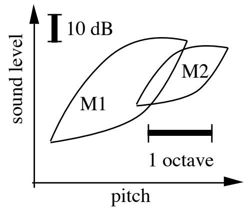

Figure 2

An idealized phonetogram for a man, showing the range of sound level that can be produced by a singer at any given pitch, for the two common vocal mechanisms M1 and M2. For a women, the region for M1 would typically be smaller and that for M2 larger.

The relative difficulty of a *messa di voce* poses no problem for speech. Languages have evolved to suit the human vocal system (and perhaps vice versa). Continuously varying pitch is common in many languages. Even in tonal languages, the distinction among a typically small set of different tones or pitch contours is relative, and varies among and within speakers (Clark et al. 2007) and the production of vowels does not require the pitch to be maintained precisely constant, independently of loudness. In many languages, louder, more passionate or angry utterances are accompanied by higher pitched and louder versions of vowel sounds (e.g. Thompson and Balkwill 2006, Juslin and Laukka 2003). Comparison with other species opens many new questions, be- -

because non-human animals use a range or mechanisms to produce sound (Fletcher 1992). Nevertheless, while varied pitch is common, crescendi and diminuendi on single, fixed pitch notes over a range of pitches is rare in non-human species.

While we do not have conclusive evidence that tells us whether learning to sing is harder than learning to speak, Patel suggests that the evidence at hand favours the argument that speech is indeed easier (Patel 2008, 373). Few deny that Western Art music singing, with steady pitch of individual notes over a large range of independently controlled loudness, takes a long time to learn and to master. So, why do many styles of singing in so many cultures require this independence?

Cultural Transmission

According to the above argument, the human voice might be doing something somewhat unnatural when singing in many common singing styles. Superficially, this might appear to place us in conflict with some current thinking of the origins of language. For example, Steven Brown (Brown et al. 2000, 271) refers to a common 'musilanguage' predecessor of modern languages and musics because "many structural features shared between music and language are the result of their emergence from a joint evolutionary precursor rather than from fortuitous parallelism or from one function begetting the other". Another important proponent of this view is Stephen Mithen, who suggests that

> there was a single precursor for both music and language: a communicative system that had the characteristics that are now shared by music and language, but that split into two systems at some date in our evolutionary history. (Mithen 2005, 26)

In other words, some scholars argue that music-like forms may have predated language. However, our view is not necessarily in conflict with these views because we are referring to modern, Western notions of music, rather than how it might have sounded before natural language evolved. We are certainly not in conflict with the arguments that propose that these protolanguages would have sounded as musical as they did speech-like, perhaps somewhat like the vocalizations found in music of sonic indigenous cultures, or in *Sprechstimme,* the speech-sung style associated with Arnold Schoenberg. Sachs (1965) proposed that the earliest music was vocal music, with instruments coming much later, and that this vocal music consisted of two basic forms. One of these resembled the "tumbling strains" (see Figure 3) found in some Aboriginal Australian music, which he describes as "a leap up to the highest available note in screaming fortissimo, [then] the voice rattles down by jumps or steps or glides to a pianissimo respite on a couple of the lowest, almost inaudible notes . . ." (51). This kind of singing may be regarded as having speech-like properties. What is important for our argument is that it demonstrates what the vocal apparatus is good at doing-when a leap is made to the high note, a correlated loud sound is made. The descending (tumbling) movements may he smooth, glissando-like, and the bottom of the range is less loud, as the correlation predicts. Traditional Western singing is just one example of the very many singing styles that do not explicitly do this, and it is a vocal style that evolved in the presence of artificial musical instruments.

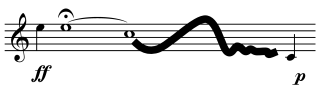

Figure 3
A transcription in Western music notation of a "tumbling strain"
(based on Example 3 in Sachs 1965. 52)

Of course, in many examples of singing, there is an overall correlation between pitch and loudness: in many music styles, singers sing the higher notes more loudly than the lower. Further, many musical instruments have a similar overall correlation: the high notes are often louder than the low. (To some extent, this is related to the greater sensitivity of

the ear to higher frequencies.) In both singing and instrumental music, making the higher notes louder is a common strategy for expressive performance (Friberg et al. 2006). So there is nothing surprising about this overall correlation, which is also exhibited in the "tumbling strain" of Figure 3. What is surprising in the voice is the variation of loudness at fixed pitch. The reduction of loudness during a single note is also a common expressive practice, particularly in accented notes or at the end of a phrase, and this is a practice that does not easily fit the positive pitch-loudness correlation of the voice (Figure 2)-the natural tendency of the voice to fall in pitch as the loudness is reduced.

So, the relevant central question in the present discussion is: how can we explain the wide occurrence of this fixed, stable pitched system with independently controlled dynamics? Part of the answer lies in the intrinsic capacity for humans to mimic and for human societies to transmit their culture. Young children naturally mimic things they hear and see, and it is possible that adults do not do so consciously merely because their mimicry instincts have been inhibited (Sato and Yoshikawa 2007). Several researchers have provided explanations of how ideas and behaviors are transmitted through culture. Shore's principle of *analogical schematization* (1996) recognizes how elements of culture become mental representations, and those representations can then reinforce or alter culture. Thus, without exposure to fixed-pitch artificial instruments, it may have been much more difficult or unlikely that humans develop fixed-pitch singing-the mental representations required for fixed-pitch singing would have required some other source in the culture. Similarly, according to Dawkins (2006), subconscious mimicry is central to the way cultural information is perpetuated. Dawkins conceptualized this kind of mimicry through units of information transmitted and replicated by the recipient-the units are referred to as menses, and they are more or less analogous to biological genes, but replicate themselves not just from generation to generation but across individuals of the same generation-from brain to brain, as Dawkins puts it (192). And the replication occurs simply through exposure to culture (including parents, friends, and societies). One example is when we pick up a physical habit of another person, even if it is a habit we deplore.

It is also argued that memes operate in music, and that they can explain how we have come to have the music of our culture (Jan 2007; Molino 2000; Walker 2004). However, what we are proposing here is that an important property of the sounds of artificial musical instruments, whether by accident or curious experimentation, has led to the development of scale systems found in songs in the modern sense (see, for example, some speculations on how this may have come about according to Blackmore [2007]). Tunes based on stable pitches have replicated and spread, perhaps in part because they were readily played on instruments, and in part because categorical pitch allows tunes to be reproduced from and remembered with relatively low information content (Wolfe 2003). *Crescendi, diminuendi,* and accents at stable pitch, readily performed on primitive instruments, have been imitated in song.

As mentioned, meme theory provides one example of how the mimicry of artificial musical instruments influenced and remained part of some vocal cultures. However, our proposal is not necessarily tied to a meme-based explanation. While transmission of ideas such as fixedpitch scales through mental self-replication provides a parsimonious explanation of the existence of such scales in many musical cultures, several other theories of cultural transmission, such as those discussed above, can also explain this outcome. What is essential to our argument is that cultural transmission of categorical pitched singing, in which loudness may be varied at constant pitch, did occur.

The argument of the order of these events (musical instruments chronologically leading stable pitch singing) is consistent with those who note that, in more recent times, instruments have influenced singing (e.g., Ellis 1965; Mithen 2005, 243, 260, and 270). The ethnomusicologist Catherine Ellis (1965, 128) argued that "it would seem possible that scale structure underwent considerable changes with the development of instruments, and in this case, pre-instrumental scales may be expected to have little or no relationship with those of a post-instrumental culture" (see also Will 1997). Our argument supports the stronger proposition that even the idea and regular use of a scale-a set of stable pitches-may be inherited from early instruments.

The evidence presented so far provides explanations of where stable

pitch may have come from-the imitation and cultural transmission of the features of performances on some artificial instruments. It could also he relevant to the emergence of tonal hierarchies (Parncutt 2011). However, the argument might be more convincing if there were some kind of cultural pressure, perhaps some advantage in retaining this less natural method of vocal production.

We propose that steady tone singing may serve another function and perhaps offer competitive advantages to individuals who use it or who are born to a culture that does (see also Trehub and Trainor 1998). Speech is a complicated acoustical signal, in which many very different parameters vary simultaneously. Most of the information about phonemes (individual speech sounds) is encoded in the spectral envelope and in transients (in musical terms, one might say encoded in the variations of timbre) and is largely independent of the pitch. The pitch can also carry small amount of phonemic information, especially in tonal languages, but can also carry complementary information. We have discussed some of the symmetries and complementarities of the coding used in music (Wolfe 2002). Many types of monophonic singing are relatively simple signals: during a note, the pitch is held constant and often the vowel is sustained for much longer than in speech. On the next note, a new pitch may he held constant. In many cases, humming or wordless songs are often produced for children, so that in this case the timbre is varied little. This could serve as a reductionist teaching strategy to enrich and to complement the largely exposure-only approach to language learning (Kamhi 1994). We have therefore suggested that some types of song may train aspects of auditory perception and attention that are later useful for the comprehension of speech (Wolfe 2002; 2007; see also Patel 2008).

Conclusion

In this paper we speculate that the extensive use of the independent control of pitch and loudness in singing, and even categorical pitch itself, may have appeared after, and as a result of, the development of artificial instruments with fixed resonances, such as the predecessors of modern string and wind instruments. We support this speculation with comparisons of the acoustical features of instruments and the voice, and the extent to which they are suited to aspects of what is now considered a conventional singing style in Western and many other cultures. We also argue that the functional advantage of singing as a tool for training the hearing of infants may have placed pressure on such a behavior to survive and permeate its was' through many cultures.

Researchers in biomusicology and the origins of music and language will continue to speculate on various aspects of the origins of singing. Our contribution has married principles in acoustics with the cultural transmission and serendipitous educational outcomes to argue that the ubiquitous fixed-tone singing style of Western and many other cultures does not hold a special, privileged, natural post in music making, but came about as a result of the discovery of stable, categorical pitch musical instruments. This was made possible through the human predisposition to mimic and to transmit information.

Note

1. By 'modern," we mean recent enough to have a notation of pitch. About styles earlier than this, there is little documented evidence.

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Abstract

This paper proposes that styles of singing in which pitch is fixed, categorical, and independent of loudness are a by-product of the development of artificial musical instruments capable of this loudness-pitch independence. The physical and consequent acoustic properties of the voice suit it to producing a range of timbres and vocalizations in which pitch and loudness are correlated and not controlled independently. To sing at fixed pitch while varying the loudness, singers must make compensations in the vocal mechanism. In contrast, fixed-pitch production is easy on artificial musical instruments, while large changes in timbre of sustained notes are usually difficult. We therefore propose that this "un-

natural," albeit ubiquitous, singing was influenced by musical instruments. One of the advantages conferred by pitch-loudness independence is in reaching infants to analyze vocalizations in a reductionist manner, because the songs sung to children are typically simpler signals than speech.

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