ACADEMIA | Letters

Why do the white keys sound the way they do? Or, How did C come to be?

Brian Parks

In most writings about musics, authors assume that readers possess rudimentary knowledge regarding musical terms. Words like pitch, measure, key, scale, and tone are thrown about, even though those words may mean different things in different disciplines – baseball, carpentry, locksmithing, reptiles, and aerobics, for instance. And, since music and its constituent musics incorporate other disciplines to such a far-flung extent – mathematics, anthropology, human development, linguistics, religion, gender, and cultural studies – there is inevitable loss of precision when those assumptions are unmerited.

Rhythm – the placement in time of musical events – involves pulsed events or the status of events (tasks completed or not). Time is not the sole domain of music. But pitches and keys are products of endless backdoor negotiation and computation. We accept them like we do vending machine candies. How did they come to be? Why do we press the notes that we do on pianos? How did *those* keys come to be have *those* frequencies? This article briefly takes up, for lack of better words, the lower level (yes, the white) keys of the piano, which many folks might identify as "C Major."[1] These notes predominate in teaching music because of keyboardic hegemony, and when we sing or teach solfege with "fixed 'do"' (see below), 'do' itself refers to the pitch class "C", regardless of octave. This paper does *not* address how and why they became white on pianos, or why we spell them the way we do.

Humans have been singing for a long time, and the human voice has long been assumed to

[1](The lower level keys are *not* white on all keyboards. They are black on French harpsichords, for example).

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Citation: Parks, B. (2021). Why do the white keys sound the way they do? Or, How did C come to be? *Academia Letters*, Article 2339. https://doi.org/10.20935/AL2339.

be a "first" instrument (along with rocks).[2] [3] [4] [5] Musical development may have occurred for reasons of genetic impression, predation avoidance, emotional communication, and/or technical display. Nevertheless, we fast-forward to a situation where musicking exists unequivocally in and as culture, to the early 11th century and the time of Guido of Arezzo, the developer of *solfege*. Solfege, which the casual reader may have experienced as the syllables "do, re, mi, fa, sol…", provides a movable or fixed reference for scale degrees.[6] Guido was looking for a way to more easily teach his choir to sing things.[7] [8] (How far we have not come). At this point in history, we are *not* yet in the realm of "keys", which are, honestly, horrible for learning music because they fix musical events as belonging to particular frequency-spaces as if they actually and absolutely exist.

So here is Guido teaching a chant-line to cathedral singers. Undoubtedly, he uses a pitch ambit that they can *all* handle. This is the first part of C becoming C: disregarding octave separation for gender (broadly, women sing higher than men), *everyone* can sing the frequencies spanning 130 - 261 Hz (for men), and 261 - 522 Hz (for women). Basses sing comfortably some frequencies below 130 Hz, down to about 95 Hz (with Altos corresponding to frequencies down to about 190 Hz); sopranos sing frequencies above 520 Hz, up to about 790 Hz (and Tenors correspondingly up to 395 Hz).

But that octave range between 130-260 for men and 260-520 for women is *shared* by all members of each gender. Why that range of frequencies is separated into twelve ratiometrically-consistent "steps" is another story. And why those twelve steps are further divided into a set of seven unequal steps constituting the C-Major key is still another story. Yet, those seven steps became the lower level white keys of pianos. They are singable by people and, thanks to modern keyboard design, easily touchable by people who can press down on things.

And now for a second reason. If you've ever sat on the bench of a pipe organ, you've

[2]Cross, Ian. 2007. "Music and Cognitive Evolution." In The Oxford Handbook of Evolutionary Psychology, edited by R. I. M. Dunbar and Louise Barrett, 649–68. Oxford: Oxford University Press.

[3]Darwin, C. 1871. *The Descent of Man, and Selection in Relation to Sex*. London: John Murray.

[4]Bannan, Nicholas. 2012. "Harmony and Its Role in Human Evolution." *In Music, Language, and Human Evolution*, edited by Nicholas Bannan, 288–399. Oxford: Oxford University Press.

[5]Jonathan De Souza argues clearly for a more co-present model of vocal-instrumental formation: De Souza, J. 2014. "Voice and Instrument at the Origins of Music." *Current Musicology*, (97). Other excellent scholarship richly discusses musical origin: see Geoff Miller's, David Huron's, and Steven Mithen's monographs on the subject.

[6]With "moveable 'do'", the solfege system transposes – "moves" – to whichever frequency is desired as the tonal center. With "fixed 'do'", the solfege system remains "fixed" with "do" referring to "C"-frequencies, 130.5, 261, 522, 1024 Hz…)

[7]Palisca, C.V. and Pesce, D., 2001. Guido of Arezzo [Aretinus]. *The New Grove Dictionary of Music Online.*

[8]Reisenweaver, A.J., 2012. "Guido of Arezzo and his influence on music learning." *Musical Offerings*, *3*(1), pp.37-59.

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noticed either drawknobs or stoptabs with words and numbers on them:

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Let's zoom in on the "Pedal" division:

Look at all those binary-geometric relations to the number 8! Why is that?

So it turns out that wind blowing at a steady pressure through an 8-foot long tube produces a pitch at 64 oscillations per second (Hz). We know this as low C, or C2. When you cut that 8-foot tube in half to make it 4 feet in length and wind blows through it, a pitch at 128 Hz resonates. That's the C an octave higher. This could continue indefinitely, and in fact there are C pipes on organs of .75 inches (8,196 Hz) or even smaller/higher.[9]

The mixed fractions in the above picture (the Quint 10 2/3, etc.) are "mutations", meaning that the pitch heard does not literally correspond with the key played. What pitch comes into being if wind blows through a tube of length 10 2/3 feet? If we un-mix the fraction, we see that it is a length of 32/3 feet. If a pipe of 8' in length sounds at 64 Hz, then a pipe of 16' sounds

[9] I wish to thank John Bishop, Executive Director of Organ Clearing House, for discussing with me some aspects of tonal production and voicing in pipe organs. Specifically, he assured me that wind pressure has no bearing on pitch. That is, a rank of pipes under 2" of wind pressure will produce the same pitches (if not the same tone or volume) as pipes under 30".

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at 32 Hz (an even lower C). Those can both be made comparable to our unmixed fraction in the following way:

16 Hz (C_0-Phantom)	32 Hz (C_1)	**?** Hz	64 Hz (C_2)	128 Hz (C_3)	etc.
96/3'	48/3'	32/3'	24/3'	12/3'	etc.
32 ft	16 ft	10.6667 ft	8 ft	4 ft	etc.

Removing the denominator from the compared lengths, we find the ratio of 48:32:24 which we reduce to 6:4:3. We know that 6:3 is the same as 2:1, which makes sense that the pipe doubled in length would be an octave lower. Comparing 6:4 tells us that the larger pipe is 1.5 times the length of the middle- length pipe. The ratio of 3/2 produces an intervallic difference of a fifth. Hence the lower pipe is the interval called a "perfect fifth" below the middle-length pipe, which must be a "G". For non-musical readers, the G is consonant with the C in many contexts, as are all notes a "fifth" higher than their fundamental. When this 10 2/3' stop is pulled along with its 16' counterpart, the note a fifth higher will also sound. These two together will produce a well-supported sonority corresponding to the low bass note. In fact, the ear will often create a phantom tone an octave *below* the 16' stop because of the co-presence of the phantom's first two partials. This effect is called a "Resultant" in organ pipe design because the phantom tone is in fact the result of this acoustic "illusion." Now we can fill in our question mark:

16 Hz (C_0-Phantom)	32 Hz (C_1)	**48Hz (G_1)**	64 Hz (C_2)	128 Hz (C_3)
96/3'	48/3'	**32/3'**	24/3'	12/3'
32 ft	16 ft	**10 2/3 ft**	8 ft	4 ft

If we can roughly equate all of human cultural evolution to increased granularity in. . . everything (by which I mean the level of detail has increased in all forms of research), then it makes sense that during the Middle Ages it would be simpler to deal with integers than to deal with rational numbers of non-integer type. If I were a carpenter or organ pipe technician, then, I would rather cut a number such as "8" in half multiple times than, say, the number "6." I could cut the 8-foot pipe in half five times and still be measuring integers (8' –> 4' –> 2'–> 1'–> 6"–> 3"). If I was cutting a 6-foot pipe in half the same number of times, I would quickly be dealing with fractional lengths: (6'–> 3' –> 1'6" –> 9" –> 4.5" –> 2.25"). Incidentally, an organ built with 6' pipes as its basis would be an "F" organ (wind blown through a 6' pipe =

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85.33 Hz = F2). It is logical to me that 8' became the desired length for builders and therefore musicians came to accept that standard.

A last question to be asked combines these two phenomena: humans converge, regardless of voice type, to realize certain pitches; and the phenomenology of hollowed-out matter likewise allows us to produce pitch predictably. Is there a corresponding physiognomy in people that explain this common "pitch" ability?

The vocal folds of adult male humans are between 17-23 mm long, and 12.5-17 mm for adult females. Those lengths may be stretched 3-4 mm "by action of the muscles in the larynx".[10] [11] If we take the 17mm commonality to be significantly related to the shared frequency (high for male singers, low for female), it would correspond to the 261 Hz of so-called middle C or, C4. Pitch in the voice is a result of a combination of factors involving "…air pressure in the lungs and by the vocal folds' mechanical properties, which are regulated by a large number of laryngeal muscles".[12] Nevertheless, the length of the vocal tract must be indelibly related to pitch production, just as the wind-blown two- foot tubular column gives us a "middle" C.

Why these lower-level keyboard pitches are spelled "C" and not, say, "A" is not something addressed here. To be sure, the spelling of pitches is itself one of the great problems of functional harmony. Regardless, the lower level of keyboard pitches – the "white" keys of a piano – have become integral to modern music learning, and I hope this paper connects that reality with potential physical explanations. As for musical spelling and other related issues, I leave you with this very answerable riddle: notes on the piano can be spelled three ways – i.e., C can be spelled as "C", "B-sharp", and "D double-flat". In fact, *every* note can be spelled three ways, except one. Which?

[10]Nave, R. "Vocal Sound Production." Georgia State University, 2016, accessed April 15, 2021.

[11]Sundberg, J. (1977). The Acoustics of the Singing Voice. *Scientific American, 236*(3), 82-91. Retrieved April 26, 2021.

[12]ibid., 82.

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