

## Qualia as Intervening Variables in the Understanding of Music Cognition

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One of the principal aims of cognitive psychologists in studying perception is to understand why we experience the world the way we do. In music perception in particular, I think one of the reasons we embraced Leonard Meyer's *Emotion and Meaning in Music* (1956) so eagerly was that he very clearly laid out a set of concrete proposals concerning how the stimulus properties of music lead to our experience of it, to our emotional responses, and to our understanding of its meaning. Similarly, Robert Francès's *La perception de la musique* ([1958] 1988) provided the foundations of a program of empirical research into our perception and memory of musical stimuli and our comprehension of musical patterns. In the 50 years since those seminal works, there has been a burgeoning of research on music cognition that has gone hand in hand with leaps and bounds of discovery in the cognitive sciences in general. (See the collections edited by Cuddy 2008, Gjerdingen 2009, and Guirard 2009, which link this research to the influences of Meyer and Francès.)

In our search for the links between mental experience and brain activity, we need to be cautious about falling into old habits of Cartesian dualism, viewing mind and brain as separate sets of occurrences to be causally related. However, even if we believe with Spinoza that mind and brain are two ways of observing the same underlying reality (cf. Damasio 2003), we still want to know why certain brain processes ap-

pear to be associated with certain experiences. We strive to sort out the ways in which observations of brain and of experience provide converging evidence for the ways in which we as organisms process information and come to understand the world. Mental experiences incorporate our understanding—our brain’s understanding—of objects in the world. It is often through looking at relationships between what we perceive and remember, and what is objectively out there in the world (the stimuli), that we come to understand how the brain operates.

### Qualia and Operational Definitions

Functioning as a basic component of the connections between the brain and experience are the properties of stimuli as experienced, which have been called “qualia.” I propose here that we should treat those qualia as intervening variables, that is, as inferred processes in the causal chain leading from stimulus to response. As intervening variables they are to be defined by operational definitions: operations in the external world by which we manipulate stimuli and observe responses. Because we are typically dealing with complex perceptual phenomena that are difficult to isolate unambiguously by means of operations, we use multiple “converging operations” (Garner, Hake, and Eriksen 1956) to triangulate on them. Furthermore, since our aim is to define operationally intervening variables that can be linked to conscious experience, at least one of the operations will involve some sort of introspective report. As an example, take Evans and Treisman’s study (2005) in which they presented viewers with rapid sequences of pictures, too rapid to see any one picture clearly. Sometimes a picture of an animal was included, and the viewers’ task was to report detecting animals, which they did with a fair amount of accuracy. Evans and Treisman were curious whether the viewers had clear and distinct percepts of the animals they reported, so they asked them, What quadrant (upper-left, upper-right, etc.) of the picture was it in? Responses were at chance. They asked, What animal did you see? Again, the viewers had no idea. From this, Evans and Treisman concluded that viewers were correctly detecting animal features

(ears, noses, etc.) when those occurred in the stimuli, but that with such rapid presentation their perceptual systems did not have time to put together a coherent image of the particular animal in its proper place in the picture. Their operational definitions relying on introspective reports allowed them to draw that conclusion. Using operational definitions linked to reports of experience puts into practice the program for a cognitive behaviorism outlined by Donald T. Campbell (1963) in the context of developing a social psychology that could draw on both the gestalt and the behaviorist traditions.

The relationships of qualia to the stimuli out in the world are sometimes relatively simple, as in the case of the loudness of sounds and the brightness of lights. As Stevens (1957; 1961) has shown, loudness and brightness vary in relation to stimulus intensity according to a power law: proportional increments in stimulation correspond to proportional increments in loudness or brightness. But even in this simple case we want converging evidence from a variety of methods; the same power function appears whether we ask observers to rate the stimuli, or adjust one stimulus to be twice or half as loud as another, or place one stimulus midway between two others, and even to match the intensity in another modality (such as roughness of sandpaper—Stevens 1969). And here we also see the usefulness of a theory in guiding the converging operations: the very same generalized rule governs the growth of perceptual intensity in relation to stimulus intensity across a number of sensory continua. (Note also the usefulness of using separate language for describing stimuli and sensations: loudness in “sones” in relation to intensity in decibels for sound, brightness in “brils” in relation to intensity in lumens for light.)

### Pitch in Music

Pitch, especially as used in music, presents a far more complicated pattern of relationships between stimuli and perceptions. At first glance, the psychophysical relationship between the pitch of a tone and its physical frequency would seem to be simple, but even the pitches of

pure tones, which physically have just one frequency, are complicated by their relations to other tones. These complications eventuate in some very interesting examples of the qualia of pitches in a tonal context, but to present those examples, first we need to elaborate the theory of psychological pitch relationships in music.

### *Pitch Height and Chroma*

The simple property of pitches, that higher pitches correspond to higher frequencies of tones, described above, is called “tone height.” In addition to tone height there is also the phenomenon of octave equivalence: in virtually all of the music of the world, pitches an octave apart (that is, in a 2/1 frequency ratio) are treated as functionally equivalent, and sound very similar. Both of these properties, tone height, and to which set of tones separated by octaves a pitch belongs (called “chroma”), determine the qualia of the perceived pitch. Middle C (“do”) sounds much more similar to the next C (“do’”) above it than it does to the B (“ti”) above it, even though it is closer to the B in terms of tone height. Shepard (1964) provided a convincing demonstration of the importance of this similarity by constructing a sequence in which the first chord consists of all the Cs on the piano, with the high and low frequencies tapered off and the middle frequencies more intense, following a bell-shaped curve (see Figure 1). He followed that with a combination of all the Ds, then all the Es, etc., with low notes entering softly at the bottom and getting stronger as the pitch rose, high notes fading out at the top, and notes in the middle remaining the strongest. He kept this progression up indefinitely. What you hear is a continually rising pattern in which the chroma changes but the pitch height remains about the same. The pitches rise but never seem to get anywhere: an auditory barber pole. Shepard (1982; 1999) captured this combination of pitch height and octave similarity with a psychophysical relationship represented as a helix (see Figure 2).

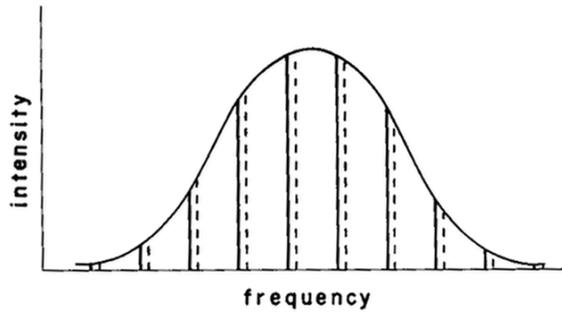


Figure 1

Diagram of auditory stimulus formed of Shepard tones, in which sine wave components at octave intervals (solid lines) are presented with their intensities shaped by a bell-shaped curve, with the strongest components in the midrange, fading out in the highest and lowest octaves. After 0.5s the solid lines (for example, C) are replaced with the dotted lines on musical step higher in pitch (for example, D), and so on, to produce a continually rising set of pitches. When the pitches reach the octave above where they started, the stimulus is identical to the initial stimulus (from Dowling and Harwood 1986, with permission).

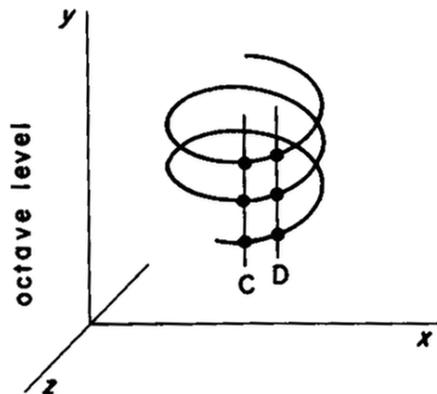


Figure 2

Shepard's helical model of pitch, in which pitches an octave apart—that is, all the pitches in a pitch class, such as C—fall in the same vertical column. Ascending a musical scale is represented by going around the helix. Pitch height is represented on the vertical axis (from Dowling and Harwood 1986, with permission).

The notes of the scale go around the curve of the helix and reach the octave as they arrive just above where they started. Shepard points out that the helix also captures the fact that melodies can be transposed to any pitch level as long as the relationships within the scale are preserved. That is, a melody can be translated along the helix and it will still remain the same melody, only at a different pitch height.

### *The Circle of Fifths*

There are other considerations that affect how we hear pitches in music. In Western European music, we divide the octave into twelve logarithmically equal steps called “semitones.” A semitone represents a pitch interval with a frequency ratio between the tones of 1.059, or the twelfth root of 2. Hence if we ascend in pitch by 12 semitones, we arrive at the next higher octave:  $1.059^{12} = 2.0$ . The major scales that we use most often for melodies make use of just 7 of those 12 pitch classes (“do–re–mi–fa–sol–la–ti”). The other 5 pitch classes are excluded from that scale, and from the key (the tonality) it represents. That contrast between the 7 pitches in a key and the 5 pitches outside the key is a very strong one, and one that would be desirable to capture in a psychophysical representation of pitch. An out-of-key wrong note sounds very jarring even in an unfamiliar tune—much more so than an in-key wrong note. You can also demonstrate the importance of these key relationships by playing a cluster of pitches (with the “sustain” pedal down) made of the 7 within-key pitches 2 octaves below middle C on the piano: B–C–D–E–F–G–A–B. Follow this with a cluster containing the 5 out-of-key pitches: B–C#–D#–E–F#–G#–A#–B. Even though the two patterns have about the same pitch height, and are muffled chords in which the individual pitches are indistinct, you can hear the difference between the two clusters. The qualia involved are very difficult to describe, but nevertheless could serve as a basis from distinguishing between the two patterns. In general, key membership—and a place in the tonal hierarchy of a key—is an important feature among the qualia of a musical pitch. (See Krumhansl 1990 for extensive explorations of the tonal hierarchy, making use of many converging operations.) A formal pattern in music

theory that captures this relationship of key membership is the “circle of fifths,” a circular arrangement of all 12 pitch classes set a musical fifth apart, so that moving clockwise you go up by fifths (C–G–D–A–E–B–F♯(=G♭)–D♭–A♭–E♭–B♭–F–C) around the circle, and counterclockwise you go down by fifths. Note that you can slice through the circle neatly dividing the seven pitches without sharps or flats on them from the five pitches with sharps or flats (that is, the pitches that belong to the key of C major from the ones that don’t). (Figure 3b shows a counterclockwise version of the circle of fifths.)

At this point we have three properties of musical pitch as found in Western music: tone height, chroma, and key membership in terms of the circle of fifths. Shepard (1982) was able to capture chroma and key membership in a theoretical model using a pair of helices going around a cylinder, so that the scale formed from the notes of a given key would follow a zig-zag path on one side of the cylinder, jumping from one helix to the other, leaving the out-of-key notes on the other side of the cylinder (see Figures 3a and 3c). In this model, chroma—the chromatic scale of semitones—would be represented along the length of the cylinder in equal steps, and the circle of fifths would be represented around its girth; that is, we could slice through the cylinder parallel to its length and divide the in-key notes from the out-of-key notes. Since chroma, the property of pitch classes in the scale, is cyclical, we can bend the cylinder around so that it recycles with every octave—in effect a torus (a donut shape).

Note that if we keep looping around the torus in this form, we are tracking key membership and chroma, but have lost track of pitch height. We can recapture pitch height by springing the torus out into its own helical pattern, so that the major axis of the torus (the center pole of the original cylinder) follows its own helix. Progressing along that helix, cycle after cycle, reinstates pitch height.

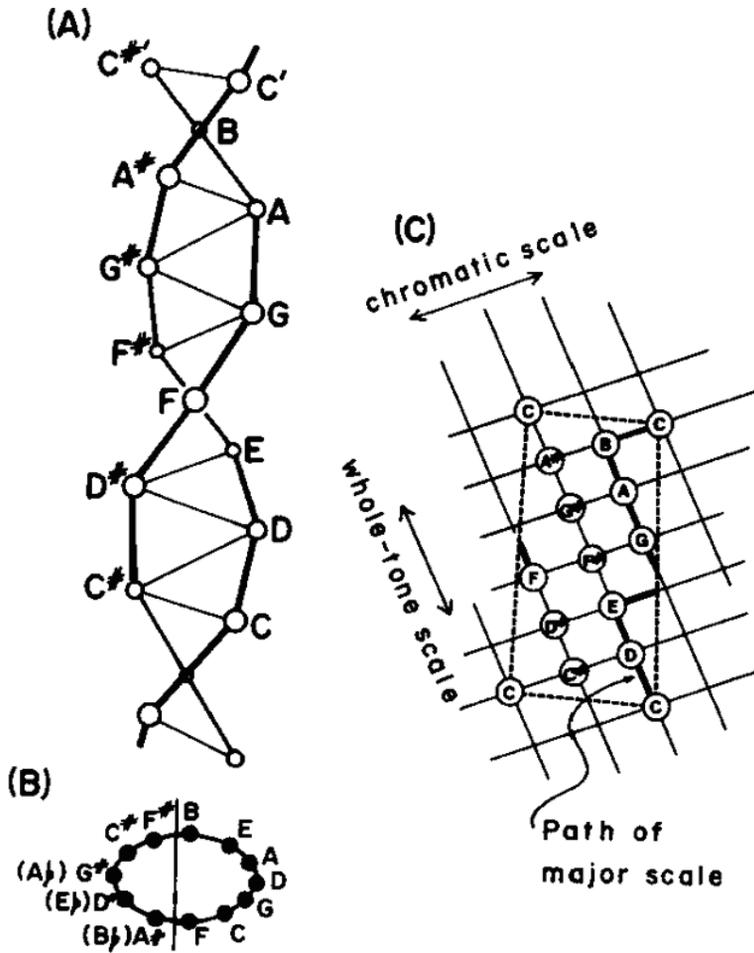


Figure 3

(a) Shepard's double-helix model of pitch perception, for which the circle of fifths is projected on the base of the diagram (b), here shown in counterclockwise form. Note that each helix contains pitches proceeding by 2-semitone intervals (whole steps) from node to node, and that to move by 1-semitone steps (half steps) you jump from one helix to the other, always moving along the vertical axis which represents tone height. In (c) the cylinder is unrolled onto a plane, and the C-major diatonic scale can be seen outlined in the zigzag pattern of thicker bars (from Dowling and Harwood 1986, with permission).

### *Equality of Diatonic Steps*

Finally, a fourth relationship among the pitches of a scale raises the most interesting issues involving qualia. Shepard had noticed that although the pitches of the diatonic scale, the major scale defining a key, are physically unevenly spaced, we generally hear them as equally spaced along the scale. When we hear the opening phrases of Beethoven's Fifth Symphony, we don't tend to think of the pitches as unevenly spaced. We hear four pitches in an interlocked pattern that goes down by 2 diatonic scale steps, then up by 1, and then again down by 2. We don't really register the fact that the first 2-step interval descends by 4 semitones, and the second 2-step interval descends by 3. The physical intervals in semitones of the major scale follow the pattern: 2–2–1–2–2–2–1. There are 1-semitone intervals between the third and fourth steps of the scale, and between the seventh and eighth, with 2-semitone intervals elsewhere. Shepard (2009) remarks that one of the attractions of the model we have just described involving the double-helix wound around a torus was that it could be made to represent the psychologically equality of diatonic intervals: "I originally arrived at this double helix on the torus . . . in an attempt to find a representation consonant with my intuition that the successive steps of the major diatonic scale—even though the major-second steps are twice the physical size of the minor-second steps—can be heard as musically equal steps in the diatonic context" (Shepard 2009, 138). The equality of diatonic steps is one component of how we hear pitches in music. Our perception in this case is not guided by the physical size of the intervals, but by the relationships among the notes in the tonal scale system.

The feeling that the notes of the diatonic scale are equally spaced is so strong that our perception of a scale that is actually equally spaced is distorted in the opposite direction. Shepard and Jordan (1984) found, for example, that when confronted with a scale of seven different pitches formed with logarithmically equal intervals, listeners tend to judge the intervals between the third and fourth steps and between the seventh and eighth steps abnormally large. That is, listeners, even nonmusicians, judge them with respect to the major scale with which they are familiar

from the music they hear every day. This brings us to the point about the qualia of pitches in a tonal context. Shepard points out that the pattern of unequal intervals in the major scale, with smaller intervals between the third and fourth, and seventh and eighth, steps, helps us keep our bearings. If all the intervals were equal (as in Debussy's use of the "whole-tone" scale of 2-semitone steps around 1900), the result would be ambiguity concerning the location of the tonal center, the "home base." Shepard goes on to cite the studies by Shepard and Jordan (1984) and Jordan and Shepard (1987) "as providing support for the possibility that information available in the physically unequal steps of the scale is perceptually manifested, not in hearing these intervals as unequal, but (instead) in experiencing each tone as playing its unique role in the tonal hierarchy." He goes on to suggest that "an equalization of the qualia of the intervals between successive diatonic tones gives rise to the emergence of the very different qualia of tonal functions of individual diatonic tones" (Shepard 2009, 139–40; see Figure 3c). Feelings of tonal tendencies, such as the attraction of the leading tone (the seventh scale step) toward the tonic, arise because the irregular structure of the scale allows us to maintain our bearings, that is, know where the tonic is. Then, for all practical purposes, such as "hanging" a melodic contour of ups and downs on a scale to generate a melody (Dowling 1978), the diatonic scale steps can be considered functionally equal (as when we sing the song "Do, Re, Mi," for example).

Note the linkage of the claim that the qualia of particular scale steps, which allow us to understand the music we hear, are a basic result of our experience with the music of our culture, to the claim that we have an internalized mental (brain) representation of the pattern of the scale. We can then ask, What are the properties of this brain representation? For example, is it rigid or flexible? If we stretch the intervals of the scale that listeners hear, will their internalized scale stretch to match? Shepard and Jordan (1984) played listeners stretched scales in which the intervals were all proportionally expanded so that the final note at the top of the scale was 1 semitone higher than normal. Then they tested the listeners to see if they could remember the beginning note of the scale. If the listeners had stretched their internal representations to match the

stretched scale they heard, they would have been able to answer that question correctly, identifying the actual starting point as the first note they heard. However, they had a strong tendency to identify as the starting point a pitch 1 semitone higher than the actual starting point, that is, exactly 1 octave below the ending point of the stretched scale. Hence we can conclude that they didn't stretch the internal scale representation, but rather moved it along in pitch so that its pitches matched the current pitch they were hearing. From this we learn two properties of the internalized scale: (1) its pattern of intervals is rigid, so that it moves as a whole when target pitches move, rather than stretching its intervals; and (2) it is flexible in that it can be shifted to a new tonic even in the midst of a distorted scale.

Converging evidence for this latter flexibility comes from Dowling, Lung, and Herrbold (1987) who taught listeners to discern target melodies that were temporally interleaved with distractor notes at rates of around 8 notes/sec. (The function of the distractor notes was similar to that of the rapidly presented pictures in Evans and Treisman's study [2005]. They hurried the processing of the target notes so that clear percepts of them could not be formed.) Listeners had to detect shifts of pitch within the target melodies, and Dowling et al. found that when the shifted targets landed on out-of-key pitches, listeners tended to report having heard neighboring in-key pitches; they assimilated the out-of-key pitches to more expected in-key pitches. Dowling et al. inferred that there was an internalized scale pattern that told them where the expected in-key pitches were, and that when processing was hurried, the auditory system gave hasty answers that gravitated in the direction of expected results. (This is similar to Evans and Treisman's observers reporting having seen animals when all they had actually detected was isolated animal features.) Since at that point all the melodies had been tuned to a standard frequency of A = 440 Hz, just as virtually all the music these Western listeners had ever heard, Dowling et al. asked whether if the whole experiment were moved half a semitone (a "quarter step") in pitch, chaos would ensue, or whether the listeners would simply shift their internal standards and produce the same results as before. In fact, the internal scale representation proved flexible in this case, too,

and the results were replicated when the experiment was repeated a quarter step out of tune. The internal scale simply slid a quarter step up in pitch to match the tonal context presented by the stimuli in the experiment.

The results of Shepard and Jordan (1984; Jordan and Shepard 1987) and others reviewed above can be taken as corroboration of Shepard's multidimensional model of perceived musical pitch. Converging evidence has even been found in studies of the brain. Janata, Birk, Van Horn, Leman, Tillmann, and Bharucha (2002) found something very much like an unrolled version of Shepard's toroidal model (see Figure 3c) in the lower frontal cortex of listeners tracking a musical pattern that continually modulated from key to key.

### *Summary*

Before proceeding to a discussion of a controversy surrounding the use of the term "qualia," I will summarize the broad points about qualia and mental representations that emerge from their use as discussed above in regard to musical pitch. Note that we need a good theory for several purposes in these investigations. First, a theory can guide multiple converging operations to focus on a purported intervening variable attached to qualia. Second, a theory can connect a number of disparate phenomena and different clusters of qualia; for example, in the case of qualitative differences in the perceived sizes of diatonic scale intervals' disappearing in favor of differences among the perceived tonal tendencies of pitches in a tonal context discussed above. Third, a theory can specify what the relevant stimulus information is, and how that information is combined and connected to mental (brain) representations that guide responses. This is a simpler version of the second principle just mentioned. A theory can also relate what the organism is trying to accomplish to the ways information is combined and responses produced. For example, we might ask listeners to characterize the emotional tone of a musical passage, or ask them whether it is in the major or minor mode.

In the various examples presented concerning the qualia of pitches in a tonal framework, we found that in those cases qualia were linked very closely to internal representations. Once the brain has identified the tonal context, the scale representation for that tonality, the tonal hierarchy, specifies the dynamic tendencies of the pitches it represents, and generates expectancies for the listener. The listener reacts differently as these expectancies are either violated or fulfilled, as Meyer (1956) suggested. When at the end of Mahler's *Das Lied von der Erde* or de Falla's *Noches en los jardines de España* the second scale degree ("re") keeps getting repeated without resolving to the tonic ("do"), the listener builds up an increasing sense of tension, continually expecting the resolution, and feeling a definite sense of relief when it finally occurs.

Since qualia in this sense are inferred from behavior, via operational definitions, we can never be sure that they are present in consciousness. We can be most sure in those cases where we ask the listener directly, Are you aware of the persistence of an unresolved 9–8 suspension at the end of this piece (as in the case of the Mahler and de Falla pieces just noted)? If the listener responds in the affirmative we suppose that at least *sometimes* in listening to the piece he or she is aware of the unresolved "re." We could imagine that other converging measures of tension might show the predicted effect of tension followed by release, even if the listener was not consciously aware of the structural device involved. It seems likely that the best we can say about conscious awareness and qualia in the sense defined here is that they refer to qualities that potentially enter into consciousness, and that they guide behavior even when they operate subconsciously. Note also that a person can be conscious of a stimulus, such as a particular note in a melody, and not necessarily be conscious of the qualia that are guiding behavior.

### The Traditional Concept of Qualia

The concept of qualia put forward departs from the traditional use of the term in the history of philosophy. Dennett (1988) criticizes the traditional concept of qualia. It may be that the concept I am proposing

would escape Dennett's criticisms. In any event, I differ with Dennett in thinking that the concept of qualia, appropriately defined and restricted, can be useful in psychology, especially if we seek a psychology that tries to understand the mechanisms by which we perceive and understand the world. Dennett's criticism focuses on apparent claims that qualia are ineffable, have intrinsic properties, are inherently private, and are supposedly directly apprehensible in consciousness. I offer some comments from the point of view of a cognitive psychologist who finds the term useful.

### *Ineffable*

By ineffable, Dennett means that "one *cannot say* to another, no matter how eloquent one is, . . . exactly what way one is seeing, tasting, smelling, and so forth" (1988, 228). Qualia, as I am proposing to use the term, are often extremely difficult to describe. This is one reason to rely on operational definitions that involve nonverbal responses, and when they involve introspective reports, they do not always require subtle descriptions but rather simple answers to questions like: What animal did you see? I tend to think that something truly ineffable would resist being manipulated as well as being described—would resist being given an operational definition. The qualia that operational definitions such as Shepard and Jordan's experiment (1984) point to are difficult to describe, probably impossible for nonmusicians to describe, but that does not prevent even the nonmusician's behavior from demonstrating that they are operating in perception. We also have operations that disclose when they are not operating. Using another set of operations, Dowling (1986) showed that nonmusicians, unlike moderately trained musicians, do not encode the pitches of a melody in terms of musical scale values. Thus it seems likely that those two groups of listeners hear the pitches of melodies in different ways at a very basic level; that is, encounter different sets of qualia when listening to the same music.

Dennett (1988, 233) acknowledges that with progressively subtle operations one can come as close as one likes to narrowing down a particular quale, and this is what we have in our examples. We do this

in science all the time. He says: “It seems easy enough, then, to dream up empirical tests that would tend to confirm [instances of individual differences in the experience of qualia], but if passing such tests could support their authority (that is, their reliability), failing such tests would have to undermine it. The price you pay for the possibility of empirically confirming your assertions is the outside chance of being discredited.” But of course, this is how science works. We have to be willing to pay that price.

We need to be ready to revise our characterization of qualia based on the empirical evidence. Dennett says “the friends of qualia want the existence of a particular quale in any particular case to be an empirical fact in good standing.” Well, there aren’t any incorrigible facts! The “friends of qualia” Dennett is talking about are apparently philosophers who are uncomfortable with chance and uncertainty and the noisiness of the world. Philosophers in the pragmatic tradition of C. S. Peirce ([1932] 1958) find fallibilism a comfortable stance vis-à-vis the world, and don’t expect to find any directly known incorrigible facts.

### *Intrinsic*

By “intrinsic” Dennett seems to mean that qualia are what they are by virtue of being connected to particular stimuli, and their properties are not context dependent. However, there is almost no area of human perception which is not context dependent. In our example drawn from Shepard and Jordan (1984), it is clear that the qualia of the pitches in a musical scale are not intrinsically properties of the pitches *per se*, but rather determined by the position of a pitch in relation to the whole context of the scale and its tonality.

### *Private*

Perceptual experience is inherently private. We as scientists can only infer what other people are experiencing. However, if (a) those inferences explain people’s behavior, and (b) the person when provided with the scientific explanation tends to agree that it makes sense, and does not do violence to the person’s own private experience of the world, then we

think we are on the right track. It is usually easier to decide what people are *not* experiencing (as in the case of Evans and Treisman’s animals) than what they *are* experiencing. We have to realize that ultimately there is a mystery to how we perceive things; there is even a mystery *that* we perceive things. This is akin to the mystery of: Why is there something, rather than nothing? We must accept this as just part of the way the world is, and try to figure out what we can. As Wittgenstein famously said, “What we cannot speak about we must pass over in silence” (1961, 151). But this does not prevent us from understanding quite a lot about the ways different people perceive the world, and the ways in which our own perception of the world changes over time.

### *Direct Perception*

We have the impression of perceiving things directly, and perhaps incorrigibly. This is a comforting illusion brought about by the way our brains (minds) are constructed. It is easy to demonstrate that our perceived view of the world is a clever construction that is actually a lot more like the actual world than is the image impinging on any of our sense organs (for example, the image on our retina—cf. Brunswik 2001). Perceptions are not *direct* apprehensions of anything—not of mental objects, nor of brain processes, and certainly not of objects in the world. And they are definitely not incorrigible. In cases where a confusing presentation of stimulus elements leads to “illusory conjunctions” (erroneous combinations of features belonging to different objects in an array—Treisman and Gelade 1980), the perceiver may be highly confident they have seen an object that was never presented. They “really” perceived it, and yet further inspection of the visual field would lead them to revise their judgment. Similarly, in the example described above, Evans and Treisman (2005) presented animals too rapidly to apprehend, yet viewers reported seeing animals, when all that their sensory systems had registered was animal parts.

## Conclusion

I have proposed that psychologists can find the concept of qualia useful if it can, in each case, be operationally defined in terms of stimuli and responses, if it can be connected to theory in a way that invokes converging operations, and if it can provide a potential perch from which to attack the problem of connecting behavior, brain processes, and experience. This use of the term clearly is not consonant with some of the ways it has been used in the history of philosophy, but nevertheless it is difficult to see what term could better be used to point to the functions described.

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## Abstract

In seeking to understand why we experience the world the way we do, I propose looking at qualia—the experienced properties of stimuli—as intervening variables, defined by stimulus-response relationships specified by converging operations, and linked (as closely as is possible) with perceptual experience. Examples from music cognition, particularly pitch perception, illustrate the usefulness and some of the intricacies of this approach. I offer some comments on Daniel Dennett’s critique of the concept of qualia (1988), agreeing with Dennett that in science we

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have severe limitations on the use of qualia that are ineffable, refer to intrinsic properties, are inherently private, and are apprehended directly and immediately.