# Listening, Imagining, Performing: Melody As A Life Cycle of Musical Thought

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**Melody has been defined as a distinct** perceptual unit that exhibits stability and coherence to listeners and performers. These psychological processes (distinctiveness, stability, coherence) contribute to the foundations of three theories of music cognition (Bregman, 1990; Krumhansl, 1990; Narmour, 1990), yet several mysteries still exist in the human experience of melody. From early exposure to lullabies and brief exposures in advertising jingles, to the full-length concert exposure of complex musical works, listeners' imagination and focus are captured in unique ways by the experience of melody. People with various amounts of musical training hum, tap, clap, and find other ways of interacting with a melody; they perform to it. Listeners report the experience of a recurring melody playing in their minds (earworms). I discuss neuroscience findings that aid in modeling the fine-level time course of melodic experiences, and address how the listener/performer identifies a melody as distinct in a complex auditory scene, how expectations unfold in implications and realizations that contribute to coherence, and how hierarchical tonal relationships of stability are detected. The life cycle of a melody in the ears, brain, and heart of a listener/performer sheds light on the human experience of music.

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The year **1990**, an auspicious year for knowledge, saw the publication of volumes by Albert Bregman (1990), Carol Krumhansl (1990), and Eugene Narmour (1990) that were to change the shape of scientific thought about musical experience. In the same year, we witnessed the beginning of the Human Genome Project, the launch of the Hubble telescope, and the first web server. Encyclopedia Britannica recorded the most sales it had experienced in any year (Evans & Wurster, 2000), and the largest numbers of US librarians were employed to date (Beveridge, Weber, & Beveridge, 2011). In the music world, American conductor, composer, and pianist Leonard Bernstein retired and subsequently died at age 72. In addition to conducting the New York Philharmonic for several decades, Bernstein's accomplishments included an influential series of lectures he delivered at Harvard, called the *Norton Lectures*, which explored musical syntax and its parallels with language. These lectures were subsequently published in another influential volume called *The Unanswered Question* (1976), named after Charles Ives' composition.

In his first lecture, Bernstein asked "whither music" and discussed an opening melodic gesture from Aaron Copland's *Piano Variations*, shown in Figure 1a. Bernstein was a devotee of the music of Copland, who once gave music composition lessons to Leonard Meyer, who was in turn Eugene Narmour's dissertation mentor. Bernstein (1982) wrote an article in honor of Copland's 70th birthday in which he discussed Copland's *Piano Variations*, the largely dissonant work that flirted with bitonality. In his first Norton lecture, Bernstein noted that the same four notes recurred in various orders within the *Piano Variations* (Figures 1a and 1b), as well as in the opening sections of Bach's *C-sharp minor Fugue* from Book 1 (Figure 1c) and Ravel's *Spanish Rhapsody* (Figure 1d), among other compositions. Bernstein used the examples in Figure 1 to pose the seeming paradox that what seems similar in a musical score can be heard or experienced as quite different.

The rich theories of melody perception represented in Bregman's, Krumhansl's, and Narmour's volumes (hereafter referred to as BKN theories) offer many insights into the perceptual paradox posed by Bernstein. Figures 1a and 1b, which differ by one tone presented in an altered octave, demonstrate a change in melodic implications, as described in Narmour's volume 1, *Basic Melodic Structures* (1990), and volume 2, *Melodic Complexity* (1992). The series of implications, based on the size and direction of each melodic interval among successive tones, give rise to expectations that are realized or denied; a series of implications, including the changing melodic intervals in the same direction in Figure 1a,

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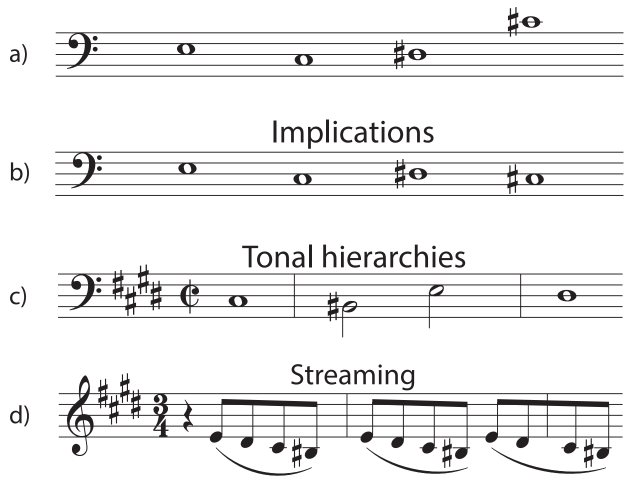


FIGURE 1. Four-tone opening themes adapted from L. Bernstein's Norton Lectures, lecture 1 (1976). 1a): opening four tones of Aaron Copland's Piano Variations. 1b): opening section of 2nd Piano Variation by Copland. 1c) opening section of J.S. Bach's Fugue in C-sharp minor (Book 1, Well-Tempered Clavier). 1d) opening section of Ravel's Spanish Rhapsody.

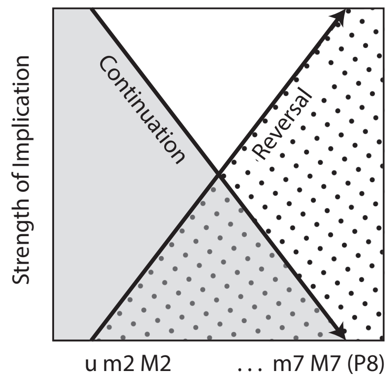


FIGURE 2. Continuation and reversal strength by melodic interval (adapted from Narmour, 1990).

yields a process that is open in terms of expectancy, and continues its implication. In contrast, the smaller melodic interval that is reversed in direction in Figure 1b, which appears later in the same voice, forms a continuation of the first three tones and thus provides closure or a sense of finality. The trade-off in strength of expectancy implications that arise from melodic interval and direction (reflected in continuation and reversal), shown in Figure 2 (adapted from Narmour, 1990), explains the different expectancies that listeners experience in the opening four tones of Figures 1a and b. These bottom-up principles, built on Gestalt laws of perceptual grouping, are proposed to apply to all melodies (not solely Western music styles), a claim supported by experimental studies (cf. Schellenberg, 1996). In addition to the bottom-up principles of continuation and reversal, Narmour specified melodic archetypes that form schematic hierarchies, based on prototypical patterns of implications. Thus, Narmour's theory contains both bottom-up and top-down principles of perceptual organization that can be applied to each of the examples in Figure 1, to explicate the expectations listeners have upon hearing the same pitch classes in Copland's work presented in different orders.

The opening tones of Bach's *Fugue in C-sharp minor* from Book 1 of the *Well-Tempered Clavier*, shown in Figure 1c, also contain the same four pitches. The notated key signature indicates the Western tonal scale from which the pitches in the fugue are drawn. Krumhansl's (1990) *Cognitive Foundations of Musical Pitch* builds on the premise that listeners are sensitive to the statistical regularities that define a key; these regularities, applied to Bach's Fugue, define a tonal hierarchy in which the C-sharp is the tonic or most central (and usually most prevalent) pitch, third and fifth scale degrees as the next most important pitches, remaining diatonic scale degrees as next most important, and nondiatonic tones as least important (and least prevalent). The tonal hierarchy shown in Figure 3, based on listener's ratings of how well each scale tone fit with the context of a harmonic minor scale (based on Krumhansl & Kessler, 1982), demonstrates graded levels of importance associated with the chromatic scale tones. Also shown in Figure 3 is the cumulative frequency of occurrence for all tone onsets in the Bach Fugue during the entrance of the first voice (labelled v1 Entrance: measures 1-3), plus the entrance of the second voice (v2 Entrance: measures 1-7), plus the entrance of the third voice (v3 Entrance: measures 1-12). The correspondence with the listeners' ratings demonstrates the role that each voice plays in reinforcing the tonal hierarchy; tone durations can also reinforce the tonal hierarchy (see Krumhansl and Schmuckler's algorithm, described in Krumhansl, 1990, Chapter 3). Through exposure to a musical culture and statistical learning principles, Krumhansl's (1990) theory further posits a four-dimensional representation of hierarchical relationships between tones, chords, and keys that is reflected in Bach's opening theme across the voices. This tonal hierarchy distinguishes the tones in the Bach theme from their use in the Copland work and explains the different percepts that can arise in the context of Bach's fugue.

The opening theme of Ravel's *Spanish Rhapsody* (Figure 1d), also composed for piano, contains a melodic sequence of isochronous eighth notes that repeat several

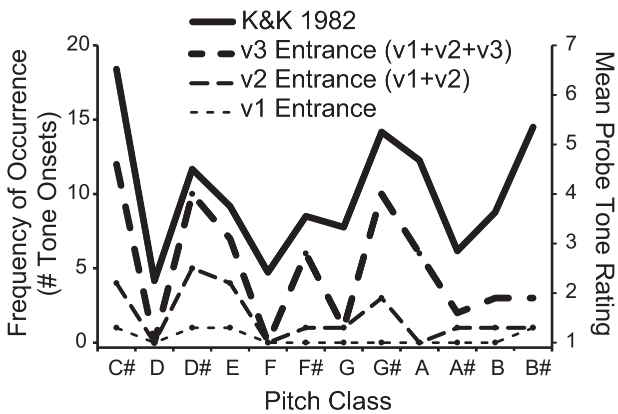


**FIGURE 3.** Cumulative frequency of occurrence (pitch class) for tone distributions in the Bach Fugue during the first three voice entrances, compared with listeners' probe tone ratings for pitches following a harmonic minor scale context (from Krumhansl & Kessler, 1982), for the tonic set to C-sharp minor. Voice 1 Entrance includes measures 1-3; voice 2 Entrance includes measures 1-7 (both voices); and voice 3 Entrance includes measures 1-12 (all voices).

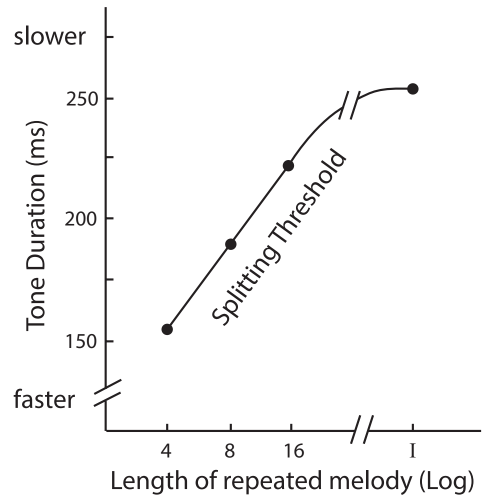


**FIGURE 4.** Listeners' splitting threshold for a single auditory stream by rate (tone duration) and length of repeated melodic gesture (adapted from Bregman, 1990).

times in two musical voices. The relationship of the small melodic intervals to their short tone durations is strikingly different in this example, compared with the other examples in Figure 1; Bregman's (1990) *Auditory Scene Analysis* proposes primitive or bottom-up principles that influence the perception of melody, including frequency proximity (successive melodic intervals) and temporal proximity (successive tone durations). The theory describes processes by which the auditory system separates incoming sound to the ears in terms of the sound's sources. Applied to music, one prediction is that listeners identify a pitch sequence as a coherent stream or unit, based on the relationship between its successive melodic intervals and successive tone durations. The smaller the ratio between change in pitches and change in tone durations, the more likely listeners will perceive the tones as arising from the same voice or stream. Several experiments demonstrate that perception of a sequence of pitch intervals is altered if the sequence is presented at faster or slower tempi; Figure 4 (adapted from Bregman, 1990) shows the relationship between the length of a repeated melody and the rate at which it is presented, and how the splitting threshold (threshold at which listeners no longer hear a single coherent melodic stream) changes depending on the presentation rate. Thus, this theory explicates the example in Figure 1d in terms of bottom-up perceptual tenets, based on Gestalt perceptual grouping principles, that underlie listeners' perception of the 4-tone melodic gesture in the context of Ravel's work as a single coherent stream.

Although the examples in Figure 1 are each taken from multi-part music, Bernstein focused on melody in the Norton lecture (1976) in order to demonstrate the perceptual similarities and differences that listeners experience. Melody, derived from the Greek word "melodia," refers to a chant or part that can be sung by humans. The *Harvard Dictionary of Music* (Randel, 2003) describes melody as a *coherent* succession of pitches, and the Oxford English Dictionary (2014) refers to melody as a series of single notes arranged in a *distinctive* sequence. Several definitions of melody refer to an experience of pleasure that results from *perceived stability*; unpleasant melodies are not expected to survive in an oral or written tradition. This raises the question of whether Bernstein intended melody as the whither of music, the most important part. As Kirnberger (1771), a contrapuntal composer once wrote, "The true goal of music—its proper enterprise—is melody. All the parts of harmony have as their ultimate purpose only beautiful melody. Therefore the question of which is the more significant, melody or harmony, is futile. Beyond doubt, the means is subordinate to the end." (as cited in Forte, 1979, p. 203).

Although Kirnberger's view represents an extreme, melody is often defined by its sources of *coherence, stability,* and *distinctiveness* - the same psychological principles used to define important voices or parts in the BKN theories. Melody perception can be conceptualized psychologically as a tug of war between sequential and simultaneous relationships that arise while experiencing multi-part music. Each of the BKN theories offers contrasting perceptual principles to explain listeners' reactions to melody: streaming versus fusion (Bregman), tension versus release (Krumhansl), and implications/realizations (Narmour). Several dimensions of Western tonal music, including rhythm, harmony, and meter, can give rise to perceptions of *coherence*, *stability*, and *distinctiveness*; there is no doubt, however, that melody is a primary source of these psychological principles in multi-voiced music. In the remainder of this paper, I will focus on melody to elaborate the perceptual principles outlined in the BKN volumes.

There is substantial psychological evidence to suggest that our percepts for melodic tones in multi-part music are privileged; listeners tend to perceive altered pitches more accurately when they are placed in the melodic voice (Palmer & Holleran, 1994; Trainor, Marie, Bruce, & Bidelman, 2014), performers tend to make fewer pitch errors in the voice intended as melody (Palmer & van de Sande, 1995), and composers build variations and elaborations on melody following perceptual principles of voice-leading (Huron, 2001). The bottom-up perceptual principles proposed by the BKN theories can account for perceptual advantages conferred on the melodic voice: These include sensitivity to ratio relationships between amount of change in frequency and amount of change in time, combined with masking across simultaneities (Bregman, 1990). Supporting evidence comes from compositional regularities in small pitch movements among successive tones within voices (Huron, 2006). Statistical regularities to which listeners are sensitive affect the perception of stability often observed for the melodic voice (Krumhansl, 1990). Although the specific regularities can differ across musical cultures, the statistical learning required is general-purpose; similar learning mechanisms have been proposed to account for language learning, pattern recognition, and other human behaviors (cf. Saffran, Aslin, & Newport, 1996). Finally, common melodic shapes or archetypes of implications-realizations that arise from perceptual principles of good continuation and common fate affect the perception of coherence in melody (Narmour, 1990). Cross-cultural applications of those melodic implications (Narmour, 1990) provide support for listeners' perception of closure, implication, and realization in Chinese folk songs built on a pentatonic scale and in atonal songs of Webern (Krumhansl, 1995; Russo & Cuddy, 1996).

What is the source of the bottom-up principles that drive melody perception? Tierney, Russo, and Patel (2011) propose a motor theory of vocal constraints that shape melodic structures in both human and bird song. Bee and Klump (2004) demonstrated electrophysiological evidence from European starlings' auditory forebrain neurons to support bottom-up (pre-attentive) grouping principles proposed for human listeners; differential responses of the starlings' neurons to the pitch sequences correlated with both starling and human listeners' perceptions of stream coherence as the streams diverged in frequency proximity. More recently, Trainor and colleagues (2014) suggested a peripheral auditory explanation for the high-frequency voice advantage, based on middle-ear filtering and cochlear nonlinearities. The melody in multi-voiced music often (but not always) occurs in the highest frequency range. As well, the high-frequency voice is often (but not always) the most salient, stable, or coherent voice in multi-voiced music. Interestingly, the four-note pattern in Figures 1b and c are first introduced in the musical works of Bach and Copland in the low-frequency range without other voices or parts, conditions under which no interference arises.

Perhaps the melody advantage is not specific to listening; to shed light on its origin, we consider when melody begins in the minds of its audience. Musical experience is often discussed in terms of components of creation (composition, improvisation), performance (interpreting, planning, movement), and perception (identifying events as melodic, recognizing melodies as familiar). An individuals' experience with a specific melody can begin at any one of these stages, and in fact, several types of musical experience demonstrate that the stages are not easily dissociated. Mark Schmuckler (1989), using Carlsen's (1981) method of good continuations, presented performers with short musical excerpts which they performed and then generated melodic continuations, thus combining performance and compositional aspects of melodic experience. Other common examples of creation-performance-perception combinations include humming, imagery, and even earworms (songs that persist in the mind), which are difficult to pinpoint as to their origins.

Stage models of musical communication, such as that depicted in Figure 5 (top), first proposed distinct compositional, performance, and perception stages of musical experience, similar to information-processing theories of communication in which the output of a previous stage served as input to the next stage (cf. Sternberg, 1969). Further experimental findings, such as Schmuckler's (1989), led to the addition of connections between stages; similar to a local connectionist network, an adapted model, shown in Figure 5 (middle), allowed output from one stage to be shared across stages simultaneously, while maintaining unique inputs at each stage. Both types of stage theories, however, fail to take into account the changes within a single composer/performer/listener's mind that come about with melodic experience in one

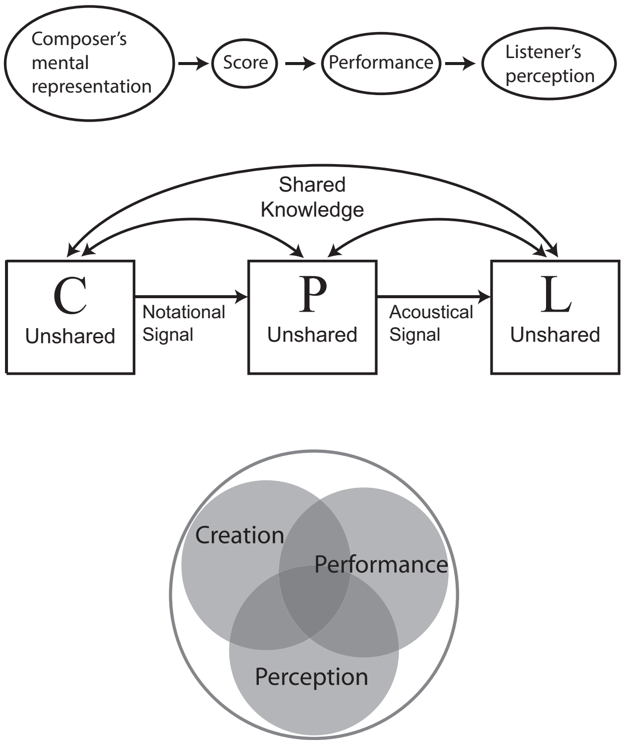


**FIGURE 5.** Schematic representation of musical communication of information between listeners, performers, and composers. Top: Stage theory (adapted from Friberg, 1995); Middle: stage theory with feedback (adapted from Kendall and Carterette, 1990); Bottom: proposed distributed theory.

or more of the component behaviors. Figure 5 (bottom), a completely distributed model of the same three states (in contrast to stages), allows the melodic context in which a performer encounters a melody to influence his/her subsequent perception of that melody; this shared representation holds similar predictions across other composition, perception, and performance interactions.

Evidence to support a distributed theory like that depicted in Figure 5 (bottom) comes from findings that individuals alter their behavioral and neural representations of music during perception, depending on prior performance experience with that melody. Similarly in speech, the "production effect" (MacLeod, Gopie, Hourihan, Neary, & Ozubko, 2010) refers to the fact that words read aloud are later recognized better than words first read silently, or words mouthed without sound. Similar work in music performance has shown that previously performed melodies are later recognized more accurately than melodies that were only heard, or melodies that were performed in the absence of sound (Brown & Palmer, 2012, 2013). These findings point to an auditory-motor connection that forms during the simultaneous experience of motion and sound to yield a different type of percept than that resulting from listening alone. Thus, joint auditory-motor learning may yield a qualitatively different memory representation than perceptual or motor learning alone.

We tested this prediction by measuring musicians' neural and behavioral responses to altered pitches placed in novel melodies that pianists first learned either by performing or simply by listening (Mathias, Palmer, Perrin, & Tillmann, 2014). We measured electrical activity on listeners' scalps using electroencephalography (EEG) methods, which are time sensitive (usually on a millisecond timescale). EEG signals typically yield an N2 event-related potential (ERP), a negative-going brain wave that occurs about 200 ms following the onset of an unexpected tone placed in a musical context (Miranda & UIlman, 2007). The N2 component is usually followed by the P3 component, a positive-going wave that peaks a few hundred milliseconds after the unexpected tone onset that has been associated with a denial of listeners' melodic expectancies (Janata, 1995). Bharucha (1987) distinguished between veridical expectancies (based on knowledge of events in a specific context such as a familiar melody) and schematic expectancies (based on event regularities abstracted across many melodies). An individual, therefore, who had not heard or performed a melody might possess schematic expectancies but lack veridical expectancies during the perception of a novel melody, and thus might not have the same pitch expectancy for the altered melody tones as an individual who had heard or performed it.

To test whether a musician familiar with performing a melody had a different memory representation than an individual with only listening experience, Mathias, Palmer, et al. (2014) presented skilled pianists with novel melodies, which they learned either by performing them several times, or by listening to them several times (without performing). Following learning, the pianists heard the entire set of melodies and were asked to identify whether an altered pitch occurred (by responding yes/no); half of the trials contained a single altered pitch, which was chosen to maintain the key, contour, and rhythm of the original melody. The authors expected that production learning should generate more accurate recognition of pitch changes and a larger N2 ERP component, if performance learning influenced memory more than perception learning. As predicted, pianists showed greater recognition accuracy for previously performed melodies than for perceived melodies; this accuracy was accompanied by a larger N2 response (about 200 ms after tone onsets) for melodies that had been learned by performance than for those learned by perception. Furthermore, the more accurate the pianists were at identifying the altered tone, the larger the N2 response.

To better understand how neural changes differentiated production learning from perception learning, we conducted standardized low-resolution brain electromagnetic tomography (sLORETA) analyses, which provide estimates of neural source electric current density from the EEG measures (Pascual-Marqui, 2002), during the melody recognition task. This analysis indicated greater activity in premotor and supplementary motor regions (Brodmann Areas 6, 8, and 4) at 200-300 ms after the altered tone onset for previously performed melodies than for previously perceived melodies. In contrast, greater activity in auditory regions (Brodmann Areas 30/31) was noted 200-300 ms after the altered tone onset in previously heard melodies than in previously performed melodies. These source localization measures suggest that performance experience changes memory representations for specific melodies by strengthening neural auditory-motor networks as pianists learn new melodies, and increases musicians' ability to recognize familiar melodies and generate expectancies. Thus, the production effect (MacLeod et al., 2010) may reflect memory benefits arising from performance experience that affect the encoding of future listening, consistent with motor prediction mechanisms (Mathias, Palmer, et al., 2014).

Does performance experience with a melody enhance musicians' veridical or schematic expectancies? The melodies used by Mathias, Palmer, et al. (2014) contained in-key (diatonic) pitch changes only, which violated veridical but perhaps not schematic expectancies. We repeated the experiment, this time with *nondiatonic* altered tones that maintained the melodic contour and rhythm but introduced an out-of-key pitch change in half of the recognition trials (Mathias, Tillmann, & Palmer, 2014). Pianists first learned the novel melodies by either perceiving or performing them, and then identified whether an altered pitch had occurred in a recognition task. Again, responses to the altered pitches yielded a larger-amplitude N2 ERP component for melodies that pianists had performed than for ones they had only perceived. Interestingly, the P3 response (about 300 ms after the tone onset) was enhanced in response to the altered non-diatonic pitches: the mean amplitude correlated negatively with Krumhansl and Kessler's (1982) tonal stability ratings of how well listeners rated the goodness of fit for that pitch with the tonal context immediately preceding it, indicating a larger neural response to pitches that did not fit well schematically. Furthermore, this correlation was reduced for melodies that pianists learned by performing. This finding suggests that responses to the unstable non-diatonic pitches may be based on schematic expectations alone and, with performance experience, may become differentiated as veridical expectancies for the specific pitches in a melodic context are formed (Mathias, Tillmann, & Palmer, 2014).

In summary, the EEG experiments described here document behavioral and neural changes that reflect the stability of melodies after musicians have performed them. Figure 5 (bottom) depicts the only model that is consistent with the notion that performing or creating experience systematically alters the musical experience of melody during perception. The pianists who participated in the studies described here (Mathias, Palmer, et al., 2014; Mathias, Tillman, & Palmer 2014) showed principled, systematic changes in behavioral and neural measures following performance experience with specific melodies; the correlation of ERP amplitudes with Krumhansl and Kessler's (1982) tonal stability ratings is one example. Individual differences in performance skill could not account for the outcomes, as all pianists participated in all conditions in the experiments (a within-subjects design). Instead, it seems that performance experience creates lasting changes that generalize from the task of learning to perform a novel melody to later recognizing altered pitches during perception. The systematic changes and generalizations in our responses to music are hallmarks of psychological principles guiding musical experience that the BKN theories attempt to explain.

Several psychological theories of musical experience have built upon the BKN theories (Chew, 2002; Huron, 2001; Snyder, Alain & Picton, 2006; Temperley, 2001; Tierney et al., 2011). What causes some theories to exhibit longevity in their impact beyond 25 years? I propose that three important factors play a role: first, the theory must be psychologically grounded. The BKN theories propose substantive bottom-up principles of stability, salience, and coherence, by drawing inferences from a context with as little top-down theorizing as possible. In that process, they define the self-organization that individuals impose on the sound heard. Most important, they aim to identify the necessary steps to create percepts as human listeners do: Not just any process that generates the same outcome will do. A second factor that contributes to longevity is a theory's computational or analytical formalisms. Each of the BKN theories yields testable predictions beyond the immediate goals of the theory. The computational specificity of a theory permits us to apply it, as elaborated here, to both previously published puzzles such as that raised by Bernstein (1976), as well as to neural (EEG) measurements of the type discussed here. The principle of computational specificity also contributes to the theories' breadth to apply across domains that employ different research methods (computer science, cognitive science, philosophy of art, music technology, musicology, music neuroscience, etc.).

Finally, a theory's longevity may be attributed to its ability to generalize beyond the materials to which it was originally applied. The BKN theories have been applied to speech signals, environmental sounds, and to listeners' cross-cultural musical experiences. As mentioned earlier, Narmour's theory has been tested extensively with atonal music, Chinese pentatonic music, Finnish folk hymns, and Bohemian folk songs (Krumhansl, 1995; Krumhansl et al, 1999; Thompson & Stainton, 1998). Krumhansl's theory has been extended to Indian ragas (Castellano et al., 1984), Balinese music (Kessler et al., 1984), and North Sami yoiks (Krumhansl et al., 2000). Bregman's principles of auditory scene analysis have been applied to starlings' song (Hulse, MacDougall-Shackleton, & Wisniewski, 1997) and to neural responses of macaque monkeys (Fishman, Arezzo, & Steinschneider, 2004). In addition, these theories have been implemented in machine learning and artificial intelligence applications whose goals often extend beyond the original scope of the theories (Ellis, 1999; Temperley, 2007).

Bernstein's unanswered question – whither music – can be interpreted specifically in terms of melody. Melody - the primary voice that grabs listeners' attention, sticks in performers' minds, and arguably is conceived first in multivoiced music - may be the reason why music exists. Humans are biased toward pleasant sound, a percept that is discussed in the BKN theories as arising from salience, stability, and coherence. Was Kirnberger (1771) correct to claim that melody is the reason for music's existence? Or do our Western ears reflect a cultural bias toward melody? The dominant perceptual principles of salience, stability, and coherence that sway in and out of music, as it shifts from moments of ambiguity to specificity, are what make music so compelling. It may be the perceptual principles themselves that are dominant across the minds of listeners, performers, and composers in different musical cultures.

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