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Processing of Musical Pitch, Time, and Emotion in Older Adults

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MUSIC *and the* AGING BRAIN

   

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Chapter 2

Processing of musical pitch, time, and emotion in older adults

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The examination of musical processing in healthy older adults (OAs) is a comparatively recent endeavor, compared to a longer history of tracking musical development in infants and children. Although it is sometimes tempting to assume most perceptual and cognitive skills decline with age, the application of this pattern to musical processing is not straightforward. On the one hand, music exists in time, which requires moment-to-moment processing and other fluid abilities like a reasonable working memory span in order to appreciate musical structures. On the other hand, most people listen to styles of music that they have been familiar with since childhood, which should enable effective operation of top-down schematic knowledge even for unfamiliar pieces—of course favorite pieces will likely be represented accurately in semantic memory, thus providing more top-down processing support.

An additional factor is that music by its nature is an aesthetic and sometimes emotional stimulus (both in the sense of conveying and inducing emotion). This information may assist processing by the extra cues conveyed by the emotional message, but also possibly may trigger associated memories consistent with the emotion. Considering pieces inducing a positive mood, we know that all else being equal, positive affect enhances processing. A final interesting factor is that compared to many other kinds of information studied in cognitive aging, people vary in their specific musical training. This opens up the possibility that older experts might show less decline than nonexperts in age-related musically relevant cognitive skills (age × experience interaction), although that pattern is by no means guaranteed (Halpern & Bartlett, 2010).

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The following sections consider three domains of musical processing in their relationship to typical aging. I begin with two fundamental aspects of music: pitch and time. Pitch relationships are perhaps the most commonly thought-of hallmark of music compared to other types of auditory input, so are considered first. I then consider a musical dimension that is arguably at least as important as pitch, namely, the detection and production of temporal relationships. Finally, I consider a more multidimensional aspect of music: the emotional message (which no doubt depends on pitch and temporal elements), including detection of emotion, induction of a felt emotion, and the relationship of musical emotion to memory for music. Although I document some expected age-related declines, I also describe situations showing remarkable stability (and in some cases enhancement) of musical processing in senior adults.

Aging and pitch relationships

Music is constructed from a tonal system, which specifies the small set of notes that a melody draws from in a given musical culture, and with what probabilities. For instance, in the tune *Twinkle Twinkle Little Star*, the first two phrases end on stable notes of the scale (fifth and tonic respectively). But the next two phrases ("so *high*" and "in the *sky*") end on the second degree of the scale, which is unstable and conveys momentum to get to the final phrase, which ends comfortably on the tonic again. Exposure to examples of melodies leads to implicit learning of a tonal framework, which is a type of musical schema. The schema captures relationships among all the pitches of the scale. A listener must detect and process pitches before fitting them into these learned schemas, illustrating the bottom-up/top-down components operative in most cognitive processes. One does not need musical training to detect and respond to these relationships, just as passive exposure to language can engender implicit knowledge of schemas for syntax. On the other hand, we would not be surprised if musicians had superior skills in both the top-down and bottom-up components of pitch processing, whether due to predisposition, training, or both.

While substantial research has traced the development of tonal sensitivity in children (Lamont, 2016), the literature on tonal processing in healthy OAs is much sparser. But interesting questions do emerge from the fact that OAs have had decades more exposure to music in general than young adults, and particularly to culturally familiar music. It might therefore be the case that behavioral, as well as neural, sensitivity to different aspects of tonal processing might increase over the life span, or at least not decrease after some age. On the other hand, musical processing takes place in real time; this requires working memory resources, which on average are less available to older compared to younger adults (YAs). The studies reviewed in this section look at some basic tonal processing mechanisms (in most cases, after accounting for age differences in peripheral skills like hearing acuity), using behavioral and neural approaches, and in some cases, comparing musicians to nonmusician listeners.

Single notes

Some researchers, while not claiming to study actual musical patterns, have examined age-related differences in processing the building blocks of music. For instance, Zendel and Alain (2012) examined thresholds for pure tone-detection and detection of mistunings in harmonic complexes. In this latter task, the complexes comprised 12 pure tones with a fundamental frequency of 200 Hz. In the tuned complex, the upper harmonics were whole number multiples of the fundamental frequency; in the mistuned complex, the second harmonic was slightly above that value. Musicians and nonmusicians over a large age range (18−91) were asked, in a forced-choice procedure, to find the smallest detectable mistuning. Pure-tone detection thresholds rose with age, not surprisingly, and the loss profile did not vary by musical training. Detection of mistuning also was worse with age, but musicians had lower (i.e., better) detection thresholds than nonmusicians; this superiority was correlated with time per week practicing her or his instrument. Thus it appears that over and above some basic loss of frequency detection, older musicians (OMs) retain their advantage in recognizing when an instrument or ensemble is well or poorly tuned.

Using similar stimuli, O'Brien, Nikjeh, and Lister (2015) examined electroencephalographic (EEG) responses in a preattentive oddball paradigm. In this paradigm a frequent stimulus is sometimes replaced with a different (oddball) stimulus, and brain response is measured when the person is paying attention to another, primary task. In this case, OMs and older nonmusicians (ONs) passively listened to sequences of harmonic complexes while watching a movie. Mistunings of the fundamental frequency occurred 25% of the time (both a small 1% and larger 6% deviation were presented; the latter is about a semitone or musical half-step in the Western scale). Data were compared with a set of younger musicians (YMs) and younger nonmusicians (YNs) from a prior study, and both early (P1, N1, and P2) as well as later [mismatch negativity (MMN) and P3a] EEG responses were compared among the four groups. (The EEG picks up synchronized electrical activity from detectors on the scalp. The temporal precision is very fine in this technique; spatial (anatomical) origin of the signals is much less precise.) Pure-tone thresholds up to 3 kHz were normal in the older listeners.

A few early EEG responses (i.e., reflecting basic detection of the acoustic signal) were responsive to age (P1 latency was shorter for older listeners and P2 shorter for younger) and none reflected musicianship differences. However, later responses more linked to complex processing showed both the main effects of musicianship and an age × musicianship interaction: YM and

OM showed similarly short MMN latencies whereas the ONs had significantly longer latency than the other three groups. OM and ON had similar MMN amplitude, which meant that the OM's short latencies did not require larger neural responses; this was also largely true of the P3a signal. The authors concluded that age affects responsivity to the simple onset of an acoustic signal, but the later components, reflecting operation of sensory memory and "distraction" by the oddball stimulus, were more sensitive to musical background. Of course as the authors rightly point out, we cannot with this typical cross-sectional method separate out the influence of musical training from inborn neural differences. But, regardless of the influence of each, we see evidence that the OM maintains musical sensitivity to this important aspect of musical pitch, being in or out of tune. Untrained OAs had less sensitive responses compared to the other groups, having apparently the advantages neither of youth nor training/predisposition.

Turning now to somewhat more musical, but still basic stimuli of note intervals (the relationship of two notes to one another), Bones and Plack (2015) presented ON and YN with intervals comprising two simultaneously sounded notes that were either consonant in the Western scale system (such as a perfect fifth) or dissonant (such as a tritone). Listeners had to rate each stimulus for pleasantness, thus this was a conscious task in contrast to the paradigm presented earlier. EEG signal was recorded and the component of interest was the frequency following response (FFR), which originates in the precortical region of the brainstem and is responsive to the periodicity (regularity) in auditory stimuli (consonant intervals having a more periodic waveform than dissonant intervals). Given that consonance and dissonance are basic distinctions in most musical cultures, we might expect either similar response patterns to consonance and dissonance in the age groups, or perhaps more differentiation between consonance and dissonance among the older group given their longer experience with music listening. However, consistent with some of the patterns seen in emotional response to music (later in this chapter), OAs actually differentiated the intervals less on pleasantness than did the younger listeners, who rated the intervals as would be predicted in the Western tonal system. In particular, the older listeners rated dissonant chords as more pleasing than did the younger; that is, their "consonance preference" was less pronounced. In a verbal condition, younger listeners also rated happy voices as happier than did older people, but this was a smaller effect than for the musical stimuli. Considering the neural response, the FFR to consonant compared to dissonant chords was also less differentiated in the OA compared to YA.

Taken together, these few studies suggest that the average OA is not as responsive to some of the fundamental dimensions comprising tonality in music, compared to young adults. This is true despite the longer exposure to music accrued over the lifetime and is over and above peripheral hearing loss. This might suggest some age-related decline in sensitivity to psychophysical relationships associated with basic perceptual mechanisms. However, so far we have considered reaction to tonal "primitives" that do not have much if any musical context. Does this age pattern still obtain with somewhat richer musical material?

Pitches in a musical context

In real music pitches are heard in the context of a melody. A study from one of my research programs looked at ratings of how well different pitches fit into a tonal context (Halpern, Kwak, Bartlett, & Dowling, 1996). Using the probe-tone technique developed by Krumhansl (Krumhansl & Kessler, 1982), we presented on each trial a four-note context consisting of the major chord triad (do-mi-sol-do) to establish a strong tonal sense. Listeners (OM and ON and YM and YN) then heard a probe note, which sometimes did but sometimes did not belong to the scale established by the context. Listeners rated how well the probe tone fit the tonal context. Good implicit knowledge of the tonal hierarchy is reflected in a profile where the notes of the major triad are rated most highly, followed by other scale notes, followed by nonscale notes. We found that whereas musicians showed a somewhat more strongly hierarchical profile than nonmusicians, OAs had as differentiated (and in one analysis, a more differentiated) a profile as young adults. This pattern was shown when the tones were constructed so as to minimize pitch proximity effects (Shepard tones, which have a clear frequency class such as "C sharp" but ambiguous pitch height, or the actual frequency range). However, when sine waves were used, which have a definite pitch height, the OAs had a small tendency to be "captured" by pitch height (i.e., to rate tones closer in frequency to the tonic as being a better fit, rather than closer in the musical scale space), which could be considered an irrelevant dimension in this task. We did not find an interaction of musical training with age; both OMs and ONs had a good sense of the musical hierarchy.

Another study reflecting well-learned tonal relations used actual melodies, drawn from either the familiar Western tonal scale, a less often used Western scale (augmented: alternating semitones and minor thirds), or a Javanese scale that uses pitch relationships different than those in Western music (Lynch & Steffens, 1994). ON and YN judged two melodies as same or different on each trial. For the "different" trials, a randomly selected note was increased in pitch by 5%. The same procedure was done with single tones. The YA and OA performed equivalently with the single tones and the familiar Western melodies. However, the young adults were superior to the older in the two less familiar tonal contexts. The authors interpreted this pattern as reflecting the equivalent knowledge of the Western tonal schema in the two groups. But when processing what seems to be a sequence of notes rather than a melody, that is, without a schema to guide the processing, the task draws more heavily on working memory, which is typically less robust in senior adults. This dissociation reflects particularly well the top-down/bottom-up reciprocal interaction in music processing alluded to at the beginning of this section: the crystallized knowledge of the tonal hierarchy is an advantage for seniors; lacking access to that, working memory limitations, or a decline in fluid abilities, show up in musical tasks as they do in other tasks.

Melodic processing

The examples discussed so far have examined processing of single pitches or pitch complexes, even if embedded in a melodic context. I next turn to studies that queried melodic processing in a more holistic manner. One of the most basic aspects of melody is its contour, or pattern of ups and downs in the pitches. Since the foundational work of Dowling (1978), many researchers have shown that listeners can extract the contour of a melody relatively easily, and use it to identify a melody, at least over short temporal intervals (reviewed by Schmuckler, 2016). Jeong and Ryu (2016) used pairs of melodic five-note sequences, synthesized with instrument sounds, and asked ON and YN listeners to indicate the contours using diagrams of arrows. In successively harder conditions, simultaneous distraction was provided by environmental sounds or by another note pattern in a different instrument. In the latter case, listeners had to follow only one of the patterns (selective attention) or alternate between them. The young adults showed modest decline in accuracy and increase in reaction time as conditions became harder; the OAs were at a disadvantage in both tasks, and particularly declined between the easiest and intermediate difficulty levels. Findings from simultaneous functional near-infrared spectroscopy (a technique that can monitor blood oxygen levels) showed younger, but not OAs, had increased levels of oxygenated hemoglobin during the task in the right dorsolateral prefrontal cortex (DLPFC). DLPFC apparently plays an important role in extraction of contours, and other neuroimaging work also points to this area as being important in working memory tasks and as being vulnerable in aging (Keller et al., 2015). The question of whether this pattern would be obtained in OMs remains open.

Other examples of tonality processing come from studies that used fully melodic material. Lagrois, Peretz, and Zendel (2018) composed melodies consistent with the Western tonal system, on average about 10 notes long. The critical note was in the same position in all stimuli and was either a note consistent with the scale, or a semitone different from that note so was not in the key of the melody, or was a quartertone away from the note, and thus sounded out of tune (flat or sharp). Participants had none to a small amount of training in older and younger age ranges. Two different behavioral tasks were presented while EEG data were collected. In the click detection task, after hearing each melody, participants had to indicate if a soft click occurred just after the critical note, so was an indirect measure of whether the wrong note was processed and had distracted them. In the direct test, the task was to indicate if a wrong note had been played and is the task of more interest for the current point. The two age groups were equally adept at identifying out of tune notes, while at the same time, the late EEG components (ERAN and P600) were smaller in the OAs. The OAs were actually superior to the younger at identifying the out of key notes, and in this case the EEG amplitudes were similar in both groups. In both groups the P600 amplitude correlated with accuracy on this task. The authors interpreted this pattern as reflecting the robust representation of tonality in the context of a melody: the seniors were performing well in both tasks, while using *fewer* (but qualitatively similar) neural resources.

Another example of tonality processing in a fully melodic context comes from one of my projects (Halpern et al., 2017). We commissioned a composer to construct melodies that were well-formed up until the last note. The composer was asked to provide two possible final notes to each melody: one with a note highly expected according to the tonal system, and one unexpected. Importantly, the unexpected note was neither mistuned nor out of the key, but rather violated the composer's intuitions about appropriate phrasal endings. Those intuitions were confirmed both by judge ratings of the piano-synthesized melodies, and an analysis of information content using the IDyOM model (Pearce, 2005): unexpected final notes had a higher IC than expected notes.

The ON and YN listened to each melody and were asked to rate the goodness of fit of the last note, while undergoing EEG recording. Behavioral ratings were identical across the groups: the expected endings were judged as significantly better fits than the unexpected endings. The early EEG component (N1), tracking the onset response to the final note, was also identical in amplitude and latency. But beginning with the P2 and extending to P600, amplitude for both types of endings were larger for the OAs and also more widespread in locus (signal emanating from a wider span of electrodes or what is called a dedifferentiation pattern). All participants had to generate expectations as the melody unfolded, and then evaluate the degree of match to that prediction. As P200 enhancement for musicians compared to nonmusicians has been observed in other auditory tasks (Marie, Magne, & Besson, 2011) and as nonmusicians become more expert on an auditory task (Tremblay & Kraus, 2002), an interpretation of the higher amplitude found here is that the OAs were paying more conscious attention to structure than young adults in this complex task. The dedifferentiation pattern, compared to the more localized processing seen in YAs, is consistent with other aging studies (Park & Reuter-Lorenz, 2009) and suggests more marshaling of resources to accomplish tasks.

In summary, these studies on tonality and aging suggest that age-related declines are more apparent when tonal components are considered in isolation, either as single stimuli, or with sparse context. To the extent the task draws on more holistic implicit knowledge of the tonal system, we see either parity among the age groups, or sometimes better or more efficient performance in the older listeners. However, with a few exceptions, comparisons between musically trained and untrained groups are yet to be done; as we saw, different task components may be differentially sensitive to age versus musical background. It is also the case that studies even with the most musically rich stimuli considered here use simple melodies, so that the combined influence of melody, harmony, instrumentation, and style are yet to be investigated. Particularly useful would be cross-cultural studies, to see if people brought up with differing tonal systems nevertheless showed the same age-related patterns to culturally familiar music, as those reviewed here.

Aging and temporal processing

The average person, when asked to define "music" might give priority to the tonal aspects of music: the contour, height, timbre, and scale of a series of notes all make music different than speech and other auditory objects. However, a reasonable argument can be made that temporal aspects of music are even more essential to labeling a series of sounds as music rather than sounds. For instance, most people would agree that a solo on a nonpitched instrument like a drum set has timing but no pitches, and constitutes music, whereas it is hard to imagine music that only has notes but no temporal structure. Even a flowing musical style like Gregorian chant has a temporal contour deriving from the Latin words. Temporal structures of music have several dimensions. The overall speed, or *tempo*, is easily differentiated when comparing songs like the slower *Silent Night* with the faster *Jingle Bells*. Music also has a *meter*, or the periodicity of strong and weak beats; this is the pulse that people clap along or dance to. Waltzes have a three-beat pattern (strong-weak-weak) compared to marches that have a two- or four-beat pattern. Finally, music typically has *rhythm* or a coherent series of shorter and longer duration of notes (and silences), such as the timings of the long and short notes in *Happy Birthday*.

Timing is of course critical to many skilled behaviors, language, and social interactions. It is not completely obvious to what extent typical aging would be expected to modify these timing skills. On the one hand, many aspects of timing seem to have neural origins in lower brain structures (Tzounopoulos & Kraus, 2009) and may operate automatically, and thus be less vulnerable to the usual age-related diminutions in functions like reductions in working memory span. On the other hand, psychologists have posited that as a general rule, cognition slows with age at least partly due to decline in frontal lobe function and less efficient white matter conduction throughout the brain (Bucur et al., 2008; Bugg, Zook, DeLosh, Davalos, & Davis, 2006). So it is interesting to consider to what extent music, depending as it does on real-time temporal processing, sometimes on very short timescales, would reflect changes with age. One speculation has been that if the internal timekeeper is slowed with age, then OAs might report that a familiar recorded piece might sound "too fast" compared with listening to that piece earlier in life (Ragot, Ferrandez, & Pouthas, 2002).

The literature on timing and aging is large, but much of the research considers processing of temporal patterns outside of a musical context, such as psychophysical studies of gap detection between clicks or duration discrimination of pure tones. Other studies consider temporal aspects of production, usually in paradigms such as synchronizing tapping with a paced signal, or continuing the pattern after the pacing signal ends. In both perception and production studies, researchers typically try to separate out peripheral processes, such as hearing thresholds or motor speed, from more central aspects of temporal processing and coordination. I consider some psychophysical studies but emphasize studies that do have at least somewhat of a musical context, and make a case for needing more such studies.

Temporal perception

Considering temporal perception first, I begin with some very basic tasks of detection of a gap within one noise burst. Harris, Eckert, Ahlstrom, and Dubno (2010) related performance on this task to particular aspects of cognitive aging. They gave a battery of cognitive tests in addition to hearing tests and found that an age-related disadvantage in tests of processing speed and self-report of mental workload predicted gap detection threshold, but only in the more demanding condition where the location of the gap varied randomly within the noise burst. The age-related increase in threshold of gap detection within one noise burst age was confirmed in a recent study by Ozmeral, Eddins, Frisina, and Eddins (2016) with a particularly large sample (1071) and a particularly large age range (18−98 years).

The more important temporal gap important in music listening is the time between the offset of one note and the onset of the next, which may convey inaccuracy (if quite obvious for instance in an ensemble performance) or expressivity (if the variability is perceived as being deliberate). For discrimination of very short time intervals (a 50 ms standard, in this case), Rammsayer, Lima, and Vogel (1993) found no difference in duration thresholds in younger, middle-aged, and OAs. However, Gordon-Salant and Fitzgibbons (1999) found that OAs showed less sensitive thresholds for duration discrimination of longer (250 ms) durations as well as gaps, both when the durations were just presented in isolation or whether presented as part of a short tone sequence. This pattern obtained even among OAs without hearing loss. A review of 36 studies using nonspeech stimuli by Humes et al. (2012) showed a consistent OA disadvantage in temporal gap detection, temporal discrimination, and temporal order discrimination, with hearing loss seldom accounting for the effects. This same conclusion was reached in a more recent literature review that was part of a study on audiovisual temporal perception by Brooks, Chan, Anderson, and Mckendrick (2018). Given that perception of rhythm and perception and production of synchronized ensemble playing likely depends on sensitivity to time intervals in about this range, this suggests some basic age-related disadvantages for OAs in detection of small expressive timing deviations.

Fitzgibbons and Gordon-Salant (2010) created sequences that were a little more musical by virtue of having an accented note, created by lengthening the duration of one note (all pitches were identical otherwise). Discrimination threshold for intertone temporal interval was tested among younger listeners, and older listeners with and without significant hearing loss. Again, an age-related increase in threshold was noted [approximately 5% relative difference limen (DL) vs approximately 10%], with no difference between the older hearing status groups, and without much influence of the position of the target interval or whether the sequence had an accent (although the accent increased the DL for all groups, not surprisingly). The evidence is therefore quite robust that a basic musically related task, perception of time between temporal events, is less acute in older listeners. We cannot be certain that these threshold differences would result in lowered music appreciation, given that many styles of music (outside of electronic or techno styles) have a certain elasticity in timing patterns; thus less sensitivity to small timing deviations might not result in a perception of oddness or inaccuracy. However, as above, implications for detection (and production) of intentional temporal deviation in music production will be addressed later.

Another aspect of temporal processing considered by several researchers is arguably even closer to a truly musical task: that of discriminating the order of sounds in a sequence. Understanding a melody requires perception and memory not just of the sounded notes, but their ordering. Composers of course can deliberately alter the ordering of notes, for instance, when using an inversion or retrograde of a theme in a fugue, or a more free variation of a kernel idea. Several studies have examined ability to distinguish sequence ordering. In a foundational study, Trainor and Trehub (1989) asked listeners to distinguish two repeating patterns that differed in the ordering of a higher and lower note. Using different response modes (categorization of same/different tasks) and variants of the sequences over four experiments, the researchers found less adept performance among older than younger in sensitivity to tone order. This occurred even with more practice at the task or more distinctive sequences.

A similar age-related deficit in distinguishing temporal order in short sequences was found by Fitzgibbons, Gordon-Salant, and Friedman (2006), which did not depend on the speed of the sequence. This suggested to them an age-related process independent of generalized slowing, in agreement with Trainor and Trehub (1989). Finally, as part of a larger test battery, Murphy et al. (2018) included a “frequency pattern test” requiring actual naming of the order of three notes (using labels of low or high) in adults aged 50−70. Performance was not related to basic hearing thresholds, but was related to working memory span, more so than age. Together these studies suggest that temporal order processing declines with age, but due to declines in central cognitive processing like working memory rather than peripheral issues like pure-tone thresholds or an overall pattern of generalized slowing.

Temporal production

Producing a signal at the "correct" musical time can involve anything from a simple tap, to a dance move, to the complex fingering of a note on wind instrument. Numerous studies have investigated whether the typical age-related slowing of many motor and cognitive processes slows overall production behavior like spontaneous tempo or also has downstream consequences in diminished ability to monitor temporal performance or increasing different types of variability (error).

Just looking at the simple speed of spontaneous tempo, Turgeon and Wing (2012) showed age-related slowing in a sample ranging from 19 to 98 years of age, with a small increase in variability of tapping with age. They also found more overestimation in OAs when asked to tap at a specified interval (e.g., 1 or 2 taps tap per second) and increased variability with evidence for a "preferred period": people of all ages produced intervals more accurately that were closer to their spontaneous tempo. There was no age difference in relative performance: that is the ratio of the 1−2 taps per second did not differ according to age.

Ability to produce a regular beat is typically studied by asking people either to tap along with a pacing signal (synchronization) or requiring continuation of the tapping pattern after the pacing beat is no longer audible, to capture the internalization of the signal and coordinated motor response. Turgeon, Wing, and Taylor (2011) found that synchronization to a signal at interonset intervals (IOIs) of 300−900 ms did not vary by age even when the IOI was changed during the sequence (i.e., the time to compensate to the new period). Similar results were found by Drewing, Aschersleben, and Li (2006) in their large sample that also included children from age 6 (stability improved from childhood until young adulthood). However, when asked to continue tapping, accuracy at least for some IOIs was lower in the OAs, and variability generally increased with age (Turgeon & Wing, 2012). In other words, it was not the case that OAs tapped more slowly than YAs but rather they had less consistency in tapping pattern. In fact, OAs were the most consistent at the fastest IOI of 300 ms.

Other researchers have tried to identify conditions under which age differences would be most apparent. Krampe, Mayr, and Kliegl (2005) asked younger and older people to continue tapping to an isochronous sequence, a simple rhythm, and a complex rhythm. Age differences in variability of the tapping were only apparent for the complex rhythms or when participants were asked to switch tapping patterns at unpredictable times. The authors contend that low-level timing mechanisms are relatively stable with aging but aspects that require higher level executive control are more prone to age-related declines. In an even more challenging situation, Krampe, Doumas, Lavrysen, and Rapp (2010) asked people to perform continuation timing either as the sole task, or concurrently with working memory tasks of varying difficulty. In the easier continuation task (with a moderate rather than very long interstimulus interval), concurrent task increased tapping variability for everyone. In the harder, slower-paced tapping, although there were no age differences in single-task variability, the dual-task condition caused OAs to have a large disadvantage in variability compared to younger.

So far, then, it seems like OAs can maintain lower level timing performance in favorable conditions, such as without a concurrent task, with a simple rhythm or when tapping at a period close to their preferred tempo. What about studies that present a somewhat more musically realistic paradigm? Kim, Cho, and Yoo (2017) asked YAs, healthy OAs, and OAs with mild dementia to use drumsticks to beat along with a pacing signal on an electronic drum pad. They beat with both hands simultaneously and also in the arguably more natural rhythm of alternating the hands; tempos were the participant's own preferred tempo and then speeds faster and slower than that. Synchronization errors were equivalent in the two healthy groups in both tapping conditions (and larger in the dementia group) but variability was lowest in the young group for both conditions. Performance on cognitive measures of memory span and executive function (trail-making) predicted variability in the group as a whole, but only for tempos faster and slower than preferred tempo. These authors agreed with other researchers that the simpler aspects of time-keeping seem to be age-invariant in healthy people, with more risk of instability in more complex tasks; in this case the complexity of beating to nonpreferred tempos.

Musical training

The studies reviewed so far in this section comprised participants without specific musical training. Given likely predispositions in timing accuracy to enter the profession, plus years of training, we might not be surprised to see mitigation in OMs of the older-age-typical slower and more variable tapping. As one indirect indication this might be so, Wöllner and Halpern (2016) gave a suite of cognitive tasks to older (professional) and younger (conservatory student) pianists and conductors, both of whom need to maintain consistent timing in their performance situations. One of the overall findings was that the professionals showed *enhanced* performance compared to students in tests of working memory for notes and words, and selective and divided attention for melodies. This pattern is thus contrary to the usual age-related declines seen in such fluid abilities.

Two studies relevant to this question took different approaches to the training variable. Iannarilli, Pesce, Persichini, and Capranica (2013) recruited ON and YN, and a sample of trained musicians (details of training were not reported), aged 60−79. The participants were presented with three different rhythms of varying complexity, and the task was to reproduce the rhythms by tapping on an electronic pad. Reproduction errors and instability were higher for the older compared to younger general groups (except for the simplest rhythm, which was at ceiling). However, in a comparison of the 12 OMs and 12 age-matched ONs, the OMs were significantly more accurate and stable than their counterparts, and equivalent to the YAs.

Given that musical training in a natural situation is a correlational variable, and, as above, likely to encompass influences both of predisposition and training, it is useful to also examine short-term training studies. Although limited in scope, any training/no training differences must ipso facto be ascribed to the training. Fujioka and Ross (2017) compared a group of OAs who engaged in piano training for 4−6 weeks, to a no-training control group, in tests of tapping synchronization and continuation to isochronous sequences at three different tempos. Although the groups were not assigned randomly (participants knew there was a more intense commitment in the training group), their background musical training was modest and equivalent, and there was no difference in pretest tapping performance. Posttest, only the trained group showed improved tapping stability, although only in the continuation, not synchronization task, and primarily for a sequence quite a bit faster than the typical range of preferred tempo. The major focus of the study was reactivity to listening to a metronome beat, as indicated by magnetoencephalography; this measure showed more brain entrainment to the beat in the trained compared to untrained participants. It would be useful to repeat this approach with true random assignment, and also an active control condition.

In summary then, it seems that timing performance can be characterized as having lower level components that are manifest in synchronization to a steady beat, and reflect overall slowing in the production of spontaneous beats. Higher level components are required to maintain an internal tempo or react to temporal changes. Those latter components are sensitive to age-related changes in cognitive resources. However, even short-term training may benefit this more advanced temporal processing, consistent with the precise timing abilities shown by trained musicians in many domains.

Music and emotion

Much of the experimental literature in cognition explores perception and memory for items like words, pictures, and faces. And although some items simply are simply "things" in everyday life, and often the experimental literature asks people to remember items without any particular emotional context, we also encounter information that conveys affect. Basic to our evolutionary past, we may be scared by wild animals charging toward us, and feel happy when we see a smiling baby. We may also have similar reactions to *depictions* of objects and events, which we could consider a second-order representation. But humans are also capable of recognizing and feeling emotion to more abstract representations such as an abstract painting or a piece of music. We could therefore call this a third-order representation: a symbol of a depiction.

In music, a composer deliberately creates these third-order representations. To quote Bernstein (1976): "And it is thus that poetry and music, but especially music, through its specific and far reaching metaphorical powers, can and does name the unnameable. And communicate the unknowable" (p. 140). An important goal of music composition is certainly conveyance of emotion (for current purposes, we are considering music that does not contain words; songs would have a more direct pathway to meaning). This can perhaps be seen most obviously in "program music" such as the dissonant chords in the famous shower scene of *Psycho*. But many other kinds of music can convey emotion. Although we can also appreciate music for its aesthetic qualities, it is very likely that the voluntary self-exposure to music (e.g., the ubiquity of personal music listening devices in the 21st century) has much to do with people's engagement with the emotional tone of music. The question here is whether processing of music's emotional message is affected by normal aging processes.

I will consider three kinds of cognition/emotion links: the first is a consideration of how age may affect ability to *detect* (or decode) the emotion conveyed in a piece of music. A second question, dependent to some extent on the first, but different from it, is to what extent people of different ages actually *feel* an emotion from a piece of music, or what is called induced emotion. A third question is whether, with age, memory is better for more versus less emotional music, and if the former, whether the particular emotion matters.

Why might emotion/music relationships even vary with age? If we consider that emotion conveys extra information in any situation, then we might expect that typical age-related losses, such as sensory impairment, or loss of efficiency in creation of new long-term memories (Old & Naveh-Benjamin, 2008) might be mitigated with that richer kind of material. Processing emotion might be particularly robust to aging given reliance on limbic system structures and not just cortical pathways (Hsieh, Hornberger, Piguet, & Hodges, 2012). On the other hand, if emotional processing is somewhat impaired in older age, then we might find even larger age differences for that kind of material (because YAs would have an extra advantage). A final point of interest is that some researchers have proposed that OAs have a processing bias in perception, liking, and memory toward positively valenced materials (positivity effect; Reed, Chan, & Mikels, 2014) more so than YAs (who sometimes show a negativity effect). Is this equally true in music, where emotion is often intrinsic to the object?

Emotion decoding

We turn first to the question of whether age is related to ability to decode emotion in music. One challenge in all this research is to select or create materials that people within a musical culture would agree is conveying an emotion. This is typically done in one of two ways. Laukka and Juslin (2007) took one theme (from Mozart Piano Sonata in A Major, K. 331) and asked four musicians to play that one theme on an electric guitar to convey the emotions of fear, anger, happiness, and sadness (and neutral), respectively. The performances that best conveyed the emotion in a pretest were presented to OA and YA, along with speech stimuli, for categorization into emotions. YA were superior to OA only for categorizing fear and sadness; in fact OA were at chance in categorizing fear. This pattern is therefore somewhat consistent with the positivity effect (there was no difference for anger, although this emotion was also by far the most accurately categorized by both groups). The advantage of this approach was that the same tune was used, so rhythm, pitches, etc., were controlled. However, it is possible that this particular theme has unique aspects that would not generalize to other music.

Vieillard et al. (2008) published a set of short piano melodies especially composed (and validated) to convey four emotions of happiness, sadness, threat, and peacefulness, hereafter referred to as the Vieillard melodies. For instance, the happy melodies were in a major mode and at a high-pitch range, and the threatening pieces had irregular rhythms and minor, sometimes dissonant, chords. Many researchers have used those melodies in OA/YA comparisons. Lima and Castro (2011) included a middle-aged group, and asked everyone to rate the excerpts on each of the four emotions. Again consistent with a positivity pattern, accuracy for putative peaceful and happy melodies was the same across ages, whereas accuracy for threatening and sad music was lower in older compared to middle-aged, compared to younger listeners. In a later study using only OA and YA (Castro & Lima, 2014) they included musicians and nonmusicians. The prior effect was replicated in the nonmusicians. The musicians were on average more accurate, with years of training predicting accuracy; furthermore, musicians used structural cues such as temporal irregularities more consistently than nonmusicians to make judgments, which could account for that accuracy. Strikingly, among musicians, age was not correlated with accuracy. Whether due to training, propensity, or both, it seems that the musicians' more effective use of cues mitigated against the reduced capacity to decode, using perhaps more holistic strategies, seen in the nonmusicians with age (although we should note that Sutcliffe, Rendell, Henry, Bailey, and Ruffman (2017) did not find a correlation of years of training, here a continuous variable, with superiority on recognition of emotion in melodies selected from this same corpus).

Two other studies suggest potential mechanisms for the lesser decoding ability in OAs, particularly for negatively valenced music. Vieillard, Didierjean, and Maquestiaux (2012) again used the 2008 melodies and asked OA and YA participants to rate the melodies on what they called valence (pleasant to unpleasant), arousal (relaxing vs stimulating), liking (not at all to very much), and hedonic value (positive to negative). They also asked the listeners to do a free grouping of the melodies by dragging icons representing each melody into proximal areas of the screen. After covarying out educational level, and measures of fluid IQ (Raven's progressive matrices, and working memory span), the authors reported that the groups did not differ in liking or hedonic values, but the OA failed to discriminate peaceful from threatening emotional music on the arousal dimension (which the YA did), and the multidimensional scaling solution of the clustering data showed less differentiation of emotions in the OA compared to YA. Sutcliffe et al. (2017) added angry excerpts and also tested for emotion recognition from faces. The OA were worse at emotion detection in all melodies except the peaceful, after controlling for fluid IQ. The researchers also found that OAs were worse than YAs in detection of negative but not positive emotion in faces, but emotion detection in faces and music was unrelated on a per person basis.

Although there are some differences among these studies, overall it seems that emotion detection is never superior and sometimes worse in OAs, particularly nonmusicians. This might be due partly to their more global representation of emotions, rather than the valence/arousal dimensional model apparently used by YAs. This global approach seems to be particularly deleterious in classifying the negative emotions in music. The possibility that OAs have in addition a bias to classify melodies as pleasant should also be considered.

Emotion induction

If older listeners are on average less successful in classifying emotionality of melodies, we would not be surprised if they also felt the intended emotion less reliably or less intensely. Of course, asking people to feel emotions in a lab setting, and to respond to different melodies in rapid succession, is inevitably somewhat artificial, but we need to take at face value reports of felt emotions. Schubert (2007) used orchestral excerpts selected to convey/induce four "quadrants" of high/low arousal and positive/negative valence. He asked for judgments both of detected and felt emotions in OA and YA. The OA rated negative pieces as less negative and also detected lower arousal on average, similar to other studies. The felt emotions were also rated as less intense by the OAs. Vieillard and Bigand (2014) similarly showed that OA reported lower activation in felt emotion, but only to threatening excerpts; overall OA reported more positive emotions. Interestingly, OA took longer to detect a note target in threatening than happy excerpts, suggesting that vigilance may be particularly enhanced when older participants are hearing happy music/feeling the induced emotion (these are hard to separate in that paradigm). Pearce and Halpern (2015) presented 1-minute excerpts of film scores previously validated by Vuoskoski and Eerola (2011) as conveying different emotions. Using the nine-item GEMS scale (Zentner, Grandjean, & Scherer, 2008) to capture felt emotion, the results showed reduced reactivity among OA to all four kinds of music (happy, sad, peaceful, threatening) although the smallest age difference was in happy music, again somewhat consistent with a positivity effect.

The age difference in felt emotion was measured physiologically by Vieillard and Gilet (2013). Facial movements were recorded while OA and YA listened to the Vielliard melodies and rated their felt emotion. Again, OAs reported more intense reaction to happy compared to other music, and they showed larger facial movements in the muscles normally used for smiling (zygomatic muscles) than younger listeners, especially to threatening music. The authors speculated that the facial movements might serve to help diminish the negative affect of high-arousing, negatively valenced music. A different method used by Juslin, Liljeström, Laukka, Västfjäll, and Lundqvist (2011) employed retrospective reports from a sample of 762 adults who were asked to rate how often (never to always) they felt each of 44 emotions in music. OA reported more positive and fewer negative emotions in their memories of induced emotion. The YA reported that they more often use music to enhance negative emotions, such as sadness.

In summary, we do have evidence for overall reduction in emotional intensity felt in response to music, particularly for negative emotions. This seems to fit to a first approximation, the socioemotional selectivity theory suggested by Carstensen and colleagues (Carstensen, Fung, & Charles, 2003). They propose that over time, adults have an increasing tendency to derive emotional satisfaction from current life circumstances, and are less interested in "expanding their horizons." The idea is that OAs can use emotional regulation strategies effectively as a coping strategy to be more content with their life, by emphasizing and giving processing priority to triggers of positive emotion. However, without longitudinal investigations, we cannot exclude the possibility of cohort and generational effects: it is possible that having lived life in a different way and at a different time compared to YAs may also play a role in this approach.

Emotion and memory

The final issue we consider here is how emotional processing of music might affect memory of the music. Generally speaking, people better remember information that has emotional tone compared to neutral information. This could result from emotion being an additional attentional, encoding, and retrieval cue (Pool, Brosch, Delplanque, & Sander, 2016; Talmi, Schimmack, Paterson, & Moscovitch, 2007), and/or because emotional information conveys extra information that would have been useful for survival in our evolutionary past (Nairne, Pandeirada, & Thompson, 2008). Evidence is mixed on whether positively versus, negatively valenced material is typically more memorable; higher arousal material is typically better remembered than less arousing material (Lee, Greening, & Mather, 2015).

The prediction for age-related differences in the emotion–memory connection is intriguing: on the one hand, if the emotion–memory connection is a basic mechanism and linked to our evolutionary past, then we might predict no age-related changes. This first possibility was illustrated by Alonso, Dellacherie, and Samson (2015), who presented symphonic excerpts to OA and YA, and tested explicit recognition immediately and after 24 hours. Although there were some interesting patterns with retention interval (positive > negative for low-arousal pieces at immediate testing; high-arousal, negative pieces were the winners for longer retention) and the expected overall lower memory scores of the seniors, they found no age-related interactions. Consistent with prior work, the OA rated the emotions detected less specifically than did the YA.

A second possibility is that to the extent emotion serves as an extra cue, seniors would show a larger memory advantage for emotional versus neutral information, than do young adults. This was the pattern found by Deffler and Halpern (2011) who presented affectively neutral melodies for later recognition. They paired each melody with a category label (patriotic), a label plus a neutral fact ("this tune is played at military events"), or an emotional fact ("this tune is played at military funerals") in an attempt to imbue context (emotional or not) to the melody. Learning the neutral fact reduced tune recognition performance for OAs relative to no fact, but if the fact were emotional, that erased the disadvantage to bring memory back to baseline (but did not enhance memory above baseline). Young adults' tune memory was not affected by the type of fact. However, in this study, emotional facts were not separated by valence or arousal categories.

A third possibility is that to the extent that OA feel and recognize emotions in a less differentiated way than YA, they might show a smaller memory advantage for these materials than YA in tunes intended to convey emotion. Narme, Peretz, Strub, and Ergis (2016) used both an explicit and an implicit recognition task for the Vieillard excerpts the reader is now familiar with. Participants rated their liking for each excerpt on each of several presentations, and the researchers interpreted an increase in liking (some pieces were presented twice, and others six times) as a measure of implicit memory. The OAs were less proficient on both memory tasks, and the implicit task was not responsive to the emotional message for either group. However, in the explicit task, OA had enhanced recognition of positive and high-arousal pieces (which was not so for YA) so that age effects were minimized for the happy excerpts, which they also liked more strongly than did the YA (performance on implicit and explicit tasks was not correlated on a per person basis).

Thus we have some evidence that for emotions to which the OA are sensitive (high valence and arousal, typically), the emotion can serve as an encoding and retrieval cue to mitigate the usual age-related memory loss. In this context, it is interesting that fearful/threatening music, which one might consider to be quite salient from an evolutionary perspective, was not privileged by older listeners. It is also notable that, in a linkage of all three of the topics in this section, there appears to be a relationship between the lower overall precision of detection and induction of emotion in seniors. This can be interpreted as emotion overall conveying less information (in the sense of uncertainty reduction) to older compared to younger listeners, which in turn reduces the overall value of emotion as a memory cue. This pattern though is not as apparent when the emotion is positive, so that senior adults both decode positive emotions and can use them as a cue for memory encoding or retrieval.

Conclusion

This chapter began with consideration of the two main domains of music: pitch and time. In some ways, the pattern of age-related change in each domain was the inverse of the other. In the pitch domain, we saw age-related disadvantage in processing isolated pitches or in unfamiliar tonal systems. However, consistent with both the accrual of tonal knowledge over a lifetime, and the processing benefits conferred by relying on schema-driven top-down processes (when appropriate), OAs showed maintenance or even gains (considered as efficiency) in processing some aspects of tonal relationships. In the domain of time, production of timing patterns was relatively robust in OAs, perhaps because of the use of neural entrainment not dependent on cortical resources. Perception of fine temporal distinctions and production of complex patterns, particularly under divided attention conditions, showed declines consistent with overall less efficiency of neural transmission. Note that OAs are not necessarily "slower" in these tasks, but often show more instability from trial to trial, consistent with less effective management of executive resources.

In the area of emotion, the evidence suggests some reduction in both detection of emotion conveyed in music and the emotional and memory response to the music. These are both more apparent in negatively valenced music. These could be causally related: it would be logical that reduced reaction could result from reduced decoding. However, it is also possible that there are separable mechanisms in perceptual analysis and emotional response systems. It is notable that the relevant studies used materials both sparse (piano melodies) and rich (film scores) so that it is unlikely the reduced responsivity is due to declines in detection of basic musical cues, like mode or timbre. And given the lesser, and sometimes nonexistent, age differences in response to positive compared to negative valence in music (and in other domains), this response pattern is likely due to changes not particularly tied to musical response per se, but a more general processing bias. One thing to keep in mind in this area of research is that emotion is of course a self-reported entity. There may be some age-related biases in the reportage of emotion that would be interesting to pursue in future research.

Finally, we saw that in some (but not all) cases, musically trained older individuals showed less age-related disadvantage than their untrained age-mates. As noted several times, it would be imprudent, and inconsistent with increasingly well-documented evidence about genetic contributions to musical (and other) skills (Mosing & Ullén, 2018) to attribute this difference solely to an effect of training. As with many choices humans make, musicians choose to begin and continue training, which very likely reflects predisposition for fine pitch or temporal discrimination and well-controlled production. However, it is obvious that training is also an important variable, which can be demonstrated in experimental training studies, even when short-term in duration (Fujioka & Ross, 2017).

Taken together, we may conclude that OAs, even with somewhat less precise response/production patterns, are fully capable of understanding, performing, enjoying, and reacting to music, particularly from a familiar tone system. Future research would benefit from more cross-cultural comparisons, training studies (including longitudinal approaches), and, in studies involving OMs, more consideration of the type of training and performing genre. A study of temporal skills in older and younger percussionists, for instance, would be very illuminating for understanding of temporal skills, and the same goes for comparing older and younger singers (who serve as their own instruments!) in the area of pitch.

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I would like to dedicate this chapter to a long-time friend and colleague, James Bartlett, who was to have been my coauthor but who became ill during the planning stages, and passed away after its completion. His many contributions to psychology and his university will be appreciated for many years to come.

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