Music Perception and Cognitive Function in Older Adults:

An Exploratory Analysis

A thesis submitted by

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Abstract

This study explored the relationships between several key cognitive (episodic memory, inhibition, processing speed, working memory, and cognitive flexibility) and music perception (MP) domains (melody, tempo, rhythm, rhythm-to-melody, and beat) in older adults. We explored the ways in which these well-studied aspects of age-related cognitive decline affect older adults' perception of music. As this is the first study to examine several MP and cognitive factors within one sample, the results also have the potential to inform other MP and music training studies. In a correlational analysis between each MP and cognitive measure, we found that melody perception was strongly related to inhibition and working memory performance, and rhythm perception was related to inhibition performance, while tempo perception was weakly related to all cognitive measures. Thus, it appears that melody and rhythm perception are the most cognitively demanding aspects of MP for older adults, and tempo perception is the most preserved. This finding also informs the music training literature, in that melody and rhythm perception likely drive the cognitive changes seen in musicians. We also investigated whether aspects of music experience, such as music training or current listening behaviors, could impact MP or cognition. Even though most participants only received a small amount of training many decades ago, the presence of training was the strongest predictor of MP performance. This finding suggests that distant training experiences can still affect cognition.

Music Perception and Cognitive Function in Older Adults: An Exploratory Analysis

Age-related cognitive decline is a well-known phenomenon, as it impacts domains such as working memory, inhibition, processing speed, and cognitive flexibility (Salthouse, Atkinson, & Berish, 2003; Dempster, 1992; Kail & Salthouse, 1994; Hedden & Gabrieli, 2004). Meanwhile, we have a limited understanding of how music perception changes with age. In order to begin to understand these age-related changes, this study explores the relationships between cognitive functioning and music perception in healthy, older adults.

The results of this study may also help begin to answer questions about music perception that are specific to the aging population. It is possible that cognitive decline actually changes the ways in which older adults perceive music (For example, do deficits in working memory functioning affect how music is processed?). Also, music engagement has been hypothesized to be a lifestyle factor that may relate to preserved functioning with age (Wan & Schlaug, 2010). Several studies have begun to investigate the ways in which musical training relate to preserved cognitive functioning in older adults (Bugos, et al., 2006; Moussard, et al., 2006). The present results may inform the aspects of musical processing that may drive these changes.

Examining the cognitive factors related to music perception may also further our understanding of music perception in a variety of populations, such as younger adults (Hallam, 2010) and those with extensive musical training (Gaser & Schlaug, 2003). Firstly, these comparisons may help us understand how music is processed in the general population. While many studies have examined various aspects music perceptions separately (Herholz, Halpern, & Zatorre, 2012; Tierney & Kraus, 2016; Krumhansl, 2000), this is the first study to examine several components of music perception within one sample, allowing us to draw comparisons between different types of musical factors. Many studies have also considered how musical training relates to differences in cognitive functioning (Zuk, Benjamin, Kenyon, & Gaab, 2014; Schellenberg, 2011; Moreno & Bidelman, 2014). The results of this study have the potential to inform the ways in which music training fuels these improvements in cognition.

The present study

The present study capitalized upon a rich cognitive testing data set in order to examine the relationships between cognitive function and music perception (MP) in 36 older adults (average age= 70). The cognitive tasks include domains which are known to be sensitive to cognitive decline: episodic memory, inhibition, processing speed, working memory, and cognitive flexibility. The MP battery examined several central aspects of music, including melody, tempo, rhythm, beat, and a test that required participants to attend to rhythmic changes, when the rhythm was presented as a melody. The breadth of these measures allowed the researchers to explore the ways in which MP is related normal age-related cognitive decline.

Musical behaviors in older adults

Firstly, we set out to characterize the musical experiences and abilities of the older adults in the sample. Participants were asked to answer a variety of questions about their music experiences, including extent of training, current musical activity, and current music listening behaviors, such as amount of music listened to and live performance attendance. Further, we examined the extent to which training and current musical behaviors related to MP and cognitive performance. Given that the sample received relatively small amounts of training (average= 3.25 years) many years ago, we predicted that measures of training would not relate strongly to either cognitive or MP performance. We predicted that current musical engagement, such as the hours spent listening to music per week, might relate more strongly to MP and cognitive measures, as these measures are better measurements of current musical behavior.

Studying the musical behaviors of older adults is of great interest, as many researchers have investigated which lifestyle factors are related to the maintenance of cognitive health in this age group. For example, Wan and Sclaug (2010) posit that musical training can create beneficial neuroplastic change in older adults, as it is a demanding, multi-sensory experience. Indeed, several large-scale studies have found that older adults who engage in music-making have preserved cognitive health, compared to those who engage in many other kinds of activities (Bygren, Konlaan, & Johansson, 1996; Verghese, et al., 2003). Some preliminary studies have found that older adults with several months of piano training show improvements in visuospatial processing speed and working memory (Bugos, et al., 2007), as well as in inhibitory functioning and subjective well-being (Seinfeld, Figueroa, Oritz-Gil, & Sanchez-Vives, 2013).

Relationships between cognitive and MP performance

Many studies have examined the cognitive functions supporting a specific aspect of MP, (e.g., musical beat processing, Patel & Iversen, 2014; or melody processing, Herholz, Halpern, & Zatorre, 2012) and many others have examined the differences in cognition in musicians versus non-musicians (Zuk, Benjamin, Kenyon, & Gaab, 2014; Schellenberg, 2011; Moreno & Bidelman, 2014). This study may further inform the music cognition literature in our examination of the relationships between several types of cognitive and MP funcitons within one sample. With a considerable variety of cognitive measures-- examining episodic memory, inhibition, processing speed, working memory, and cognitive flexibility—and a good distribution of MP assessments—exploring melody, rhythm, tempo, beat, and rhythm-melody perception—we were able to investigate many ways in which these cognitive factors relate to music perception. While this study is exploratory in nature, several hypotheses informed our analysis. Two general research questions guided these hypotheses: 1) Are there any cognitive measures that explain variance across a range of musical tasks? 2) Which cognitive measures are important for specific types of MP abilities (e.g., particular melodic or rhythmic skills)? Our predictions are summarized in Table 1.

General cognitive relationships: inhibition and processing speed

Out of the five cognitive domains examined, inhibition and processing speed were both predicted to relate to many aspects of music perception. Supporting the hypothesis regarding inhibition, some have argued that deficits in inhibition may explain many other deficits associated with cognitive aging (Dempster, 1992). Although inhibition abilities are predicted to relate to cognitive performance measures, such as in interference and selective attention, it is possible that inhibition processing is important for MP as well. Strong inhibition abilities on the present MP tests may allow participants to ignore information about past stimuli, and to maintain focus on the task at hand. Therefore, we predicted that deficits in this domain may negatively impact MP performance.

Others theorize that many aspects of age-related cognitive decline are related to changes in processing speed. In their 1994 review, Kail & Salthouse introduce a processing speed theory of aging, where they argue that slowed processing affects multiple levels of cognitive abilities, from simple computations to higher level operations. He cites evidence that changes processing speed explain more about the cognitive performance of older adults, compared to changes in working memory. In particular, decision-making was found to be affected by processing speed (both in accuracy and reaction time), as separate cognitive processes hypothesized to be integrated at a slower rate. Several studies have noted that musical processing requires the integration between neural systems (see Repp & Su, 2013 for review). As such, it was predicted that slowed processing speed may be detrimental to performance on a variety of MP factors.

Specific relationships between cognitive and MP performance

Melody perception—Three aspects of melody are known to contribute to its perception: melodic contour (the ups and downs of a phrase), the size of pitch intervals, and the presence and strength of tonality (ie., the key). These near-universal aspects of melodies have been found to contribute to the perception of melodies (Dowling & Fujitani), and can also relate to difficulties in musical performance (Jebb & Pfordresher, 2015). The same-different PROMS (Profile of Music Perception Skills) test, used in this study, manipulated each of these melodic factors (Law & Zentner, 2012). Many researchers have considered working memory to be a necessary aspect of musical processing. Berz (1995) argues for a working memory model in which music processing is supported by its own subcomponent of working memory. Some experimental evidence has suggested that, indeed, melodic and verbal stimuli are processed differently in auditory working memory (Williamson, Baddeley, & Hitch, 2010). We predicted that working memory would likely support melodic processing as participants stored, rehearsed, and compared information about the presented melodies. In other words, we hypothesized that auditory working memory, as measured by a digit span backwards test, would be positively correlated with melody performance.

Tempo and Beat Alignment Test (BAT) —The musical beat can be defined as the even pulse in music, perceived as the regular occurrence of musical events over time. The tempo, or speed of a tune, can be determined by the amount of time between beats. We hypothesized that both BAT (Iverson & Patel, 2008*)* and tempo performance would relate to similar cognitive measures, since both tests place demands on perception of musical time. However, given the measures at hand, we were not sure which cognitive measures would relate most strongly to tempo and BAT performance. Beat perception and synchronization is frequently attributed to the integration of auditory stimuli with motor processes. While few cognitive functions have been connected to this auditory-motor integration, it has been hypothesized that cognitive processes, such as mental timekeeping, may be important (Patel, Iversen, Chen, & Repp, 2005). Further, functional studies of auditory-motor integration have reported relationships between a wide range of neural systems, including timing processing and sensorimotor connectivity (see Repp & Su, 2013 for review). Given this reliance on widespread processing, we predicted that processing speed may be positively correlated with these measures of beat and tempo perception.

Rhythm perception—Rhythm can be defined as the patterns in durations of musical events. Rhythmic processing can be broken into three hierarchical subcomponents: tempo, meter, and pattern. A recent PET study found that processing rhythmic patterns activated different brain regions, compared to meter and tempo (Thaut, Trimarchi, & Parsons, 2014). The rhythm test used in the PROMS specifically targets the detection of changes to the rhythmic pattern, so the present analysis will focus on how cognitive functions relate to the perception of pattern in rhythm. We hypothesized that accurate perception of rhythmic patterns would be positively correlated with working memory performance, as participants would be required to hold patterns of note durations in mind.

Rhythm-to-Melody (RM)—MP studies frequently examine different aspects of music in isolation in order to determine the separate ways these aspects are perceived. The PROMS test includes an interesting subtest that may model some of the multidimensional aspects of musical processing. In the RM subtest, participants are initially presented with a rhythm, played by non-melodic drum beats. They are then presented with a melody and are asked to determine if the rhythm of this melody is the same or different from the "dry" rhythm they heard before (see figure 2c for stimuli examples). While this exact task is not common in most music performance settings, the task may resemble some of the multidimensional processing required in the perception and performance of music. For accurate performance on this measure, participants likely had to a) maintain the "dry" rhythm in working memory, b) flexibly attend to rhythmic and melodic stimuli, while c) successfully ignoring the melody of the comparison stimulus in judgment-making. In summary, we predicted that RM performance would positively correlate with working memory (DSB), inhibition, and cognitive flexibility (WCST).

MP Measure:	Predicted relationships:
General MP performance	• Inhibition • Processing speed
Melody	• Working memory
Tempo & BAT	• Processing speed
Rhythm	• Working memory
Rhythm-to-Melody	• Working memory • Cognitive flexibility • Inhibition

Table 1: Summary of predicted relationships between music perception tasks and cognitive function performance.

Method

Participants

The cognitive data in the present analysis is borrowed from a study testing the effects of habitual caffeine use on cognitive performance in older adults. As the study was measuring habitual use, participants were not provided with caffeine at the time of the study. Since the effects of caffeine are reported to affect women differently than men, only women were recruited for the study. While the lack of male participants limits the generalizability of the study, it is reasonable to assume that music processing is similar between men and women.

Participants were healthy, community-dwelling women, recruited between six and 18 months after participation in the earlier study. Only participants who participated in both studies were used in this analysis. The average participant was 70.2 (SD= 5.56), ranging from 56 to 84, and 88.9% identified as Caucasian. Potential participants were contacted over the phone, and were prescreened to verify that they were non-smoking, had normal or corrected vision, did not suffer from any learning or cognitive disorders, did not have a history of drug or alcohol abuse, and did not have a history of head trauma, stroke or seizure. All procedures were approved by the Social, Behavioral and Educational Research Institutional Review Board of Tufts University.

Cognitive Test Battery and Procedure

Participants completed fourteen cognitive tests, lasting approximately two hours, including two scheduled breaks. Tests were performed verbally, with pen and paper, or on the computer, depending on the nature of the task. For each test, the instructions were provided in a written format and were read aloud by the experimenter. The tests are described in the order in which they were performed. The first tasks, the Mini Mental State Exam (Folstein, Folstein, & McHugh, 1975) and Shipley's Institute of Living Scale (Zachary & Shipley, 1986), were used as measurements of general functioning.

Episodic Memory Battery

Verbal Paired Associates I (WMS—3) (Weschler, 1997a). Participants were instructed to remember a list of 8 unrelated word pairs, which were read aloud to the participant. After all the pairs were provided, the experimenter tested memory for the word pair by asking, "Which word goes with _____?" Participants were told whether their response was correct, and if it was not, they were provided with the correct answer. This study-test pattern was repeated a total of four times. The same list of words was used throughout, with a different order of presentation and testing for each trial. The outcome measure for this task was the number of correctly recalled word associates.

Logical memory I (WMS—3) (Weschler, 1997b). The experimenter read aloud a short story, and the participants were immediately asked to recall the story. Two stories were used, and the second story was repeated twice. Participants were scored based on the number of correctly recalled details across all three trials.

Inhibition Battery

Stroop (Mueller & Piper, 2014). In this task, participants are tested on their ability to respond to either the printed color of a word (i.e., the font color), or the word itself (colors included red, yellow, green and blue). Three stimulus-response combinations occur in this task: congruent (word and font color match), incongruent I (word and font color do not match; participant instructed to report word meaning) and incongruent II (word and font color do not match; participant instructed to report font color). In the practice round, all trials are congruent. In the six test blocks, participants were instructed to focus on either the word or font color, alternating between blocks. This task was performed on a laptop computer, and participants entered their response by selecting a button that corresponded with the color of their answer. The outcome measure for this task was the mean reaction time for correct responses on incongruent trials. To rule out any false start responses and to eliminate response times for other miscellaneous factors, only responses between 200 ms and 4000 ms were considered (Davidson, Zacks, & Williams, 2003).

Flanker Task (Mueller & Piper, 2014). This test measured participants' ability to inhibit their responses to opposing visual information. Participants were instructed to indicate the direction of an arrow in the center of the screen, with distractor arrows flanking the central arrow.

The test included three conditions: center arrow presented with no flanking arrows, flanking arrows presented in the same direction as the target arrow (congruent), flanker arrows presented in the opposite direction of the target arrow (incongruent). Participants responded by using the keyboard arrows to indicate the direction of the central arrow. The outcome measure for this task was mean response time for correct responses on incongruent trials.

Speed of Processing Battery

Letter Comparison (Salthouse, Hancock, Meinz & Hambrick, 1996). In this test, participants were asked to compare two sets of letters, indicating whether they were the same or different. On a sheet containing 32 sets of letters, participants were given 20 seconds to complete as many letter sets as possible. Half the letter sets were the same, and different sets differed by only one letter. There were three levels of this test, with 3, 6 or 9-letter sets presented. Each test only contained letter sets of one length. Letter sets consisted of capitalized consonants, with non-repeating and non-sequential letters. The outcome measure for this task was the number of correct responses across the three levels of the task.

Line Comparison (Salthouse et al., 1996). In a similar design to the aforementioned Letter Comparison test, participants were asked to compare sets of line patterns. Participants had 20 seconds to complete three test levels, each containing 32 line sets. The three test levels consisted of 3, 6 or 9 connected line segments. Half of the line segments were the same, and half differed by one misplaced line. The outcome measure for this task was the number of correct responses across the three levels of the task.

Frontal Function Battery

Digit Span Backward (DSB) (Wechsler, 1997a). In this test of auditory working memory, participants were read a series of numbers at a rate of one number per second. They were then asked to reproduce numbers in the reverse order. The task consisted of seven levels, ranging from two to seven-digit sequences. For each level, participants were given two trials. The experimenter would only continue to the next level if the participant provided a correct response to at least one of the two trials of a given level. The outcome measure for this task was the total number of correctly recalled number sequences.

Wisconsin Card Sorting Task (WCST) (Mueller & Piper, 2014). In this test of rule learning and switching, participants are instructed to sort a series of cards into the correct pile, based on a rule that is unknown to them. There were four piles to sort in: a pile with one green triangle, a pile with two red stars, a pile with three yellow plus signs and a pile with four blue circles. With the feedback provided, participants had to sort based on one of three rules (color, shape, or number). The program was set to switch the sorting rule after 10 consecutive correct responses. The outcome measure for this task was the total number of perseverative errors.

Four other tests were performed during this session, but were not used in the analysis as they did not factor well to their respective batteries. The tests were: Face Recognition (Wechsler, 1997b), Stop Signal (Verbruggen, Logan, & Stevens, 2008), Digit Symbol Substitution (Wechsler, 1997a), and Mental Control (Wechsler, 1997b). The frontal function battery (DSB and WCST) did not factor well together, so they were analyzed individually.

Music Perception Battery and Procedure

Music perception testing took place at a separate session, which occurred between six and 18 months after cognitive testing. Participants were informed that the data from the music perception tests would be analyzed in conjunction with their previous testing data. After providing signed, informed consent, participants completed two short paper questionnaires, followed by a series of music perception tests. The stimuli for the music perception tests were played on a laptop computer, using headphones. Before the testing began, participants were allowed to adjust the volume to a comfortable level. The experimenter read the instructions for each task aloud, and provided clarification for any questions. During the testing, participants verbalized their response, which was then recorded by the experimenter. The order of the music perception tests was counterbalanced across subjects.

Questionnaires

The two questionnaires were a music experience survey, and a survey about hearing ability. The music experience questionnaire was created for the purpose of the study, based on measures of music experience in previous studies (White-Schwoch, et al., 2013; Iversen & Patel, 2008). Participants were asked about their past and current music training experiences, as well as questions about their current listening behaviors (see Appendix A). In the short form of the Speech, Spatial and Qualities of Hearing Scale (SSQ), participants are asked a variety of questions about their everyday hearing experiences (see Appendix B). A reliable measure of hearing ability, the SSQ was chosen to verify that all participants had normal hearing ability for their age group (Noble et al, 2013). Further, we tested hearing ability to be sure that baseline perceptual differences did not affect MP performance (Wingfield, Tun, & McCoy, 2005).

Music perception tests

Profile of Music Perception Skills Test (PROMS) (Law & Zentner 2012). The PROMS is designed to distinguish between music perceptual ability in individuals with varying amounts of musical experience. Participants completed the brief version of the test, which consisted of four subtests: melody, rhythm, tempo, and rhythm-to-melody. All tests consisted of 18 trials, with equal numbers of same and different trials. For each trial, the reference stimulus was played twice, followed by a comparison stimulus. Participants had to decide whether the comparison stimulus was the same as the reference, or whether it was different. Participants were instructed to indicate their confidence by saying the comparison was definitely or probably the same/ different, and were allowed to avoid guessing by selecting an "I don't know" option. They were provided one practice question prior to the start of each subtest.

Melody— All melodies were played as constant eighth notes on a "harpsichord" timbre from Logic Pro 9. Difficulty was manipulated by increasing atonality and note density. All trials were played at the same tempo, but some trials had more notes than others. Research has shown that tonal melodies tend to be easier to encode than atonal melodies (Schluze, Dowling & Tillmann, 2012) (see Figure 1a for stimuli examples).

Rhythm— All rhythms were two measures long, played at the same tempo, with varying patterns of quarter, eighth and sixteenth notes. Rhythms were played with the "rim shot" timbre from Logic Pro 9. Difficulty was modulated by the location and duration of added or subtracted notes in the different trials. For easy trials, the notes were changed on the downbeat, or on the upbeat for moderately difficult trials. Complex trials used sixteenth notes, and different trials involved changes to the sixteenth note patterns (see Figure 1b for stimuli examples).

Tempo— Tempo stimuli were between 110 and 130 bpm. Three different types of timbres were used, all with a strong downbeat: a multilayer timbre playing a complex rhythmic pattern (drums, bass, harmony and melody), a two-layer timber playing a pattern of sixteenth notes (conga and shaker), and a single layer playing quarter notes ("rim shot" timbre). Difficulty was modulated by the difference in speed on different trials; tempo differences ranged from 7 bpm (easy) to 1 bpm (difficult) faster or slower than the reference.

Rhythm-to-Melody (RM)— This subtest examines the ability to attend to one aspect of a musical stimulus while ignoring another. Participants must compare the rhythm of a melody to a non-melodic rhythmic presentation. In other words, the rhythm is presented percussively without pitch ("rim shot" timbre) in the reference, but in the comparison, it is presented as a melody ("harpsichord" timbre). Participants must attend to the rhythm of the melody, while ignoring its pitch contour. In order to limit distraction, no atonal melodies are presented. Difficulty was modulated in the same way as the rhythm subtest (see Figure 1c for stimuli examples).

Beat Alignment Test (BAT) (Iverson & Patel, 2008). In a test designed to detect differences in beat perception, participants are asked to decide whether an even train of beeps match the beat of a musical excerpt (only the perceptual judgment part of this test was used). The test consists of 12 songs of a variety of styles (rock, jazz, and orchestral). The average excerpt duration is 15.9 seconds (SD= 3.1 s), and beeps begin 5 seconds after the onset of each excerpt. Each song is presented twice, once with the beeps on the beat, and once off, with 24 trials in total. For the off-beat trials, the beeps are 10 percent faster or slower than the beat, with half (6) being faster, and half being slower (the first beep was on the beat in all conditions). For each trial, participants were asked whether the beeps match the beat, and to rate their confidence on a scale of 1 to 5.

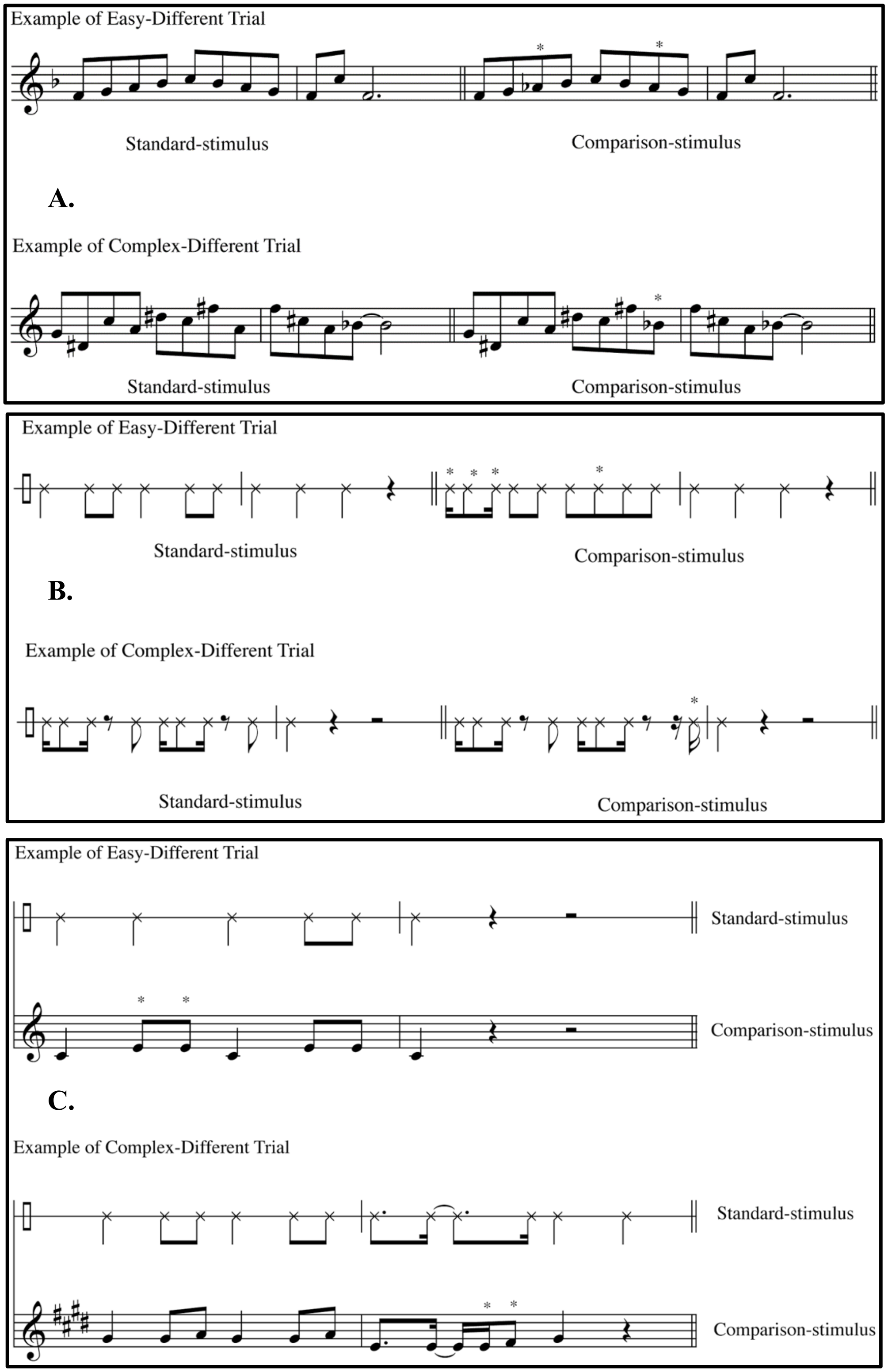

Figure 1. Examples of the A) melody, B) rhythm, and C) rhythm-to-melody PROMS stimuli. In all examples, the comparison stimulus is different (* designates the changed notes in the compassion trial). Examples of an easy and complex trial are provided for each.

Results

Description of sample

In total, 39 participants completed all cognitive and music perception tasks. Three participants were removed due to extreme outlier performance on the cognitive measures, leaving 36 participants in the present analysis. While a large number of participants showed outlier performance (no participants were outliers on more than one task), a Mahalinovis and Cook's analysis showed that these three participants had an extreme pull on the data set.

The sample was relatively well-educated; all participants completed high school, and 66% received a Bachelor's degree or higher. Participants were generally of good cognitive health: the average MMSE score was 28.0 (SD= 1.59), with the majority scoring above 25 (*n*= 34). The average score on the Shipley's Institute of Living Scale was 34.7 (SD= 3.52), ranging between 27 and 40.

Hearing ability

In order to ensure that music perception performance was not affected by age-related hearing difficulties, all participants were asked to complete the short version of the Speech Spatial and Qualities of Hearing (SSQ) questionnaire (Noble, et al., 2013), where participants rated their hearing ability in a variety of situations, on a scale from 1 (hearing difficulty) to 10 (easy to hear). Participants reported an average hearing ability of 7.18 (SD= 1.48), which is similar to other SSQ measurements in this age group (Singh & Pichora-Fuller, 2010). Three participants had SSQ scores approximately two standard deviations below the mean, which may have influenced their MP ability. However, in a correlation between hearing ability and MP performance, these three participants all performed above the MP mean, signifying that their hearing did not affect test performance. Three other participants reported that they currently use hearing aids. However, in a similar comparison, these participants all showed normal performance on the MP measures. For all participants, overall music perception performance was not significantly related to SSQ-reported hearing ability $R(35) = -0.149$, $p = 0.194$.

Music training and engagement

While 61.1% ($n = 22$) of the sample reported they had received musical training at some point in their lifetime, only 22.2% ($n = 8$) were musically active at the time of the study. For the 35% who received training but were musically inactive, the vast majority (86%) stopped their musical training before age 20, indicating that the average participant in this subgroup had not played an instrument in roughly fifty years. The average participant, currently active or inactive, received 3.25 years of training (SD= 2.30), and two outliers received greater than 30 years of training. The most common instruments were piano ($n = 11$) and voice ($n = 6$).

Although the sample in general received little training, most of the sample were relatively musically engaged. The average participant listened to 11.4 hours of music per week (SD= 14.3), with 64.1% listening to more than 5 hours per week. Participants went to an average of 4.67 live performances per year (SD= 4.96). In other accounts of listening behavior, 58.3% of participants ($n = 21$) reported that they sometimes or frequently sang along to their preferred music, and 55.6% reported that they sometimes or frequently danced to music.

Cognitive and MP test performance

Descriptive statistics for the cognitive function measures can be found in Table 2, and for the MP tests, in Table 3. It should be noted that outcome measures were kept consistent for the cognitive tests within each battery, also outlined in Table 2. As described earlier, three participants were removed due to their extreme outlier performance on the processing speed battery or the WCST. One participant was unable to complete the Flanker task due to physical disability, and was removed from the inhibition battery. All other tests were successfully completed by the entire sample.

The cognitive function batteries were created from a prior factor analysis using the same tests, on the same participants (Perry, et al., in review). A subset of the participants from the previous analysis were included in the present study. Given the fact that the tests were the same, and the participants were drawn from the same sample, the same factors are used here. Table 2 displays the tasks that factored to the episodic memory, inhibition, and processing speed batteries, and lists the outcome measure for each task. While the WCST, and DSB tasks have been shown to load to a single factor (e.g., Glisky & Kong, 2008), the two tasks did not load together in the factor analysis guiding the present study. Therefore, the two tasks will be considered independently.

Music perception scores reflect the number of correct trials on a given test or subtest. "I don't know" responses were marked as incorrect. The average participant used this response relatively infrequently (in 4.04% of trials, SD= 3.60%). While both the PROMS and BAT allow for confidence to be accounted for in the scoring (i.e., higher score for higher confidence rating), we chose not to include measures of confidence in this analysis.

An items analysis was performed for both the BAT and PROMS. It was found that one track on the BAT (the SMA on-beat trial) showed very low accuracy. As such, both the on- and off-beats of this BAT trial were removed, leaving 22 total trials. Several trials in the PROMS also showed similar low performance, but since these trials all happened to be "different" trials, they were not removed from the analysis. Accuracy rates were quite different for "same" and "different" trials on the PROMS. The Melody and Rhythm subtests showed similar accuracy rates on both types of trials, but the Tempo and Rhythm-Melody both showed dramatically higher accuracy on “same” trials than “different” (greater than 20% higher accuracy on “same” than “different” for both subtests).

Battery	Test	Mean	SD	Max. points	Outcome measure
Memory	VPA	18.58	7.67	32	Number of correctly recalled words
	Logical Memory	43.67	9.6	75	Number of correctly recalled story details
Inhibition	Stroop	1341.4	334.83	—	Reaction time for correct response on incongruent trials
	Flanker	583.15	126.11	—	Reaction time for correct response on incongruent trials
Processing Speed	Letter Comparison	19.86	3.96	92	Number of correctly judged letter sets
	Line Comparison	22.25	4.67	60	Number of correctly judged line patterns
Other	DSB	7.55	2.12	14	Number of correctly recalled number sequences
	WCST	15.81	9.14	—	Percent of perseverative responses

Table 2: Descriptive statistics of the cognitive tests. All tasks have N= 36, except Flanker, which was completed by 38. Batteries were created from a previous factor analysis. DSB and WCST are analyzed individually. VPA= Verbal Paired Associates; DSB= Digit Span Backwards; WCST= Wisconsin Card Sorting Test. Each battery was created by converting each test to z-scores, and then averaging the z-scores. To maintain consistency, DSB and WCST data were converted to z-scores as well.

Test	Mean (%)	SD (%)	Max. points
BAT	77.3	16.0	22
Melody	50.3	16.6	18
Tempo	59.5	17.0	17
Rhythm	63.7	19.3	18
Rhythm-Melody	63.7	12.7	18
PROMS (total)	59.3	10.0	71
Overall score	63.6	9.6	93

Table 3: Descriptive statistics of the music perception tests. Melody, Tempo, Rhythm and Rhythm-Melody are subtests of the PROMS. Overall score is the total number correct on all tests. BAT= Beat Alignment Test; PROMS= Profile of Music Perception Skills test.

Music experience: Relationships with cognitive and MP performance

The effects of music experience on cognitive and MP performance was considered based on past training experiences as well as current musical behavior. The effects of training (two levels: yes, *n*= 22 or no, *n*= 14) were examined in a series of one-way ANOVAs, separately comparing each cognitive (episodic memory, inhibition, processing speed, working memory, and cognitive flexibility) and MP test (melody, tempo, rhythm, RM, and BAT). In the comparisons with cognitive performance, it was found that the presence of training had a non-significant, but notable relationship with inhibition, $F(1, 34)= 2.082$, $p= .159$. The presence of training was also related to higher performance on melody ($F(1, 34)= 5.797$, $p=.022$), rhythm ($F(1, 34)= 4.043$, $p= .052$), rhythm-melody ($F(1, 34)= 6.269$, p= .017), and BAT ($F(1, 34)= 6.175$, $p= .018$). While training seemed to be important for each of these aspects of MP, training was not related to improved performance on the tempo test ($F(1, 34)= .028$, $p= .867$).

In order to further examine the effects of musical training on cognitive and MP performance, years of training and current musical activity were assessed in two separate analyses. In attempt to see if current music-making influenced cognitive or MP processing, a series of one-way ANOVAs (three levels: no training, n=14; past training, n= 14; and current training, n= 8) were generated, and group-specific effects were determined using Tukey HSD post-hoc test. No significant relationships were found for the cognitive tests, but participants with current training performed marginally or significantly better than those with no training on the melody (F(2, 33)= 3.856, p= .027), rhythm (F(2, 33)= 2.457, p= .096), rhythm-melody (F(2, 33)= 3.838, p= .032). These findings would have been interesting if there were significant differences between the current and past training groups, but these relationships were only significant for the current versus no training comparisons. The effect of years of training was analyzed in a similar one-way ANOVA, with three levels: no training (n=14), 1 to 3 years (n= 13), and more than 4 years (n= 9). This set of analyses did not further elucidate the relationships with MP; participants with training generally showed improved performance on the MP tests, but those with the most extensive amount of training (4+ years) did not show an advantage over those with some training (1-3 years). However, in examining the cognitive tests, those with the most extensive training (4+ years) did show a trend for higher performance on the DSB test, though this difference did not achieve statistical significance (F(2, 33)= 2.767, p= .097).

Given that training occurred many decades ago for most of the participants, we hypothesized that current musical behaviors may have an effect on cognitive and MP performance. Current musical behavior was considered in three ways, using one-way ANOVAs: the number of hours spent listening to music (per week), the number of live performances attended (per year), and how frequently the participant reported that they sing or hum along to music they enjoy. In general, theses analyses did not uncover any significant relationships with cognitive or MP performance.

It is also interesting to consider which relationships were least significant in these analyses. In the cognitive comparisons, processing speed seemed to be least related to any measure of music experience, with significance values $.946 < p < .997$. Similarly, music experience seemed to be least related to tempo performance, with significance values $.714 < p < .985$**.**

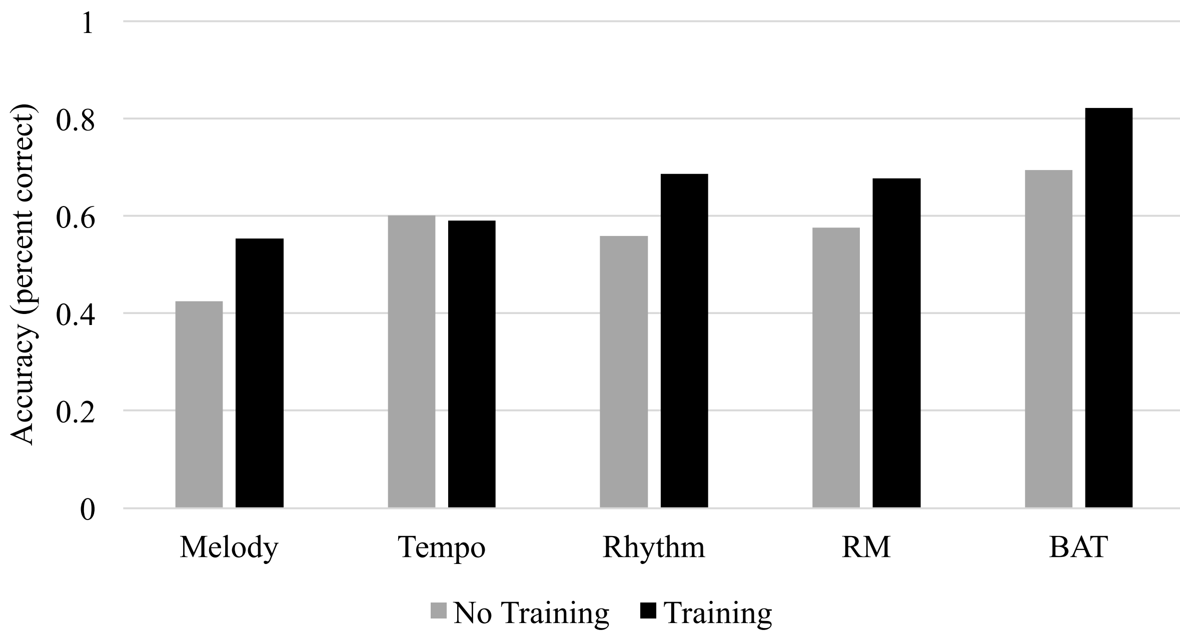

Figure 2: Performance on MP tests, as a function of training. It was found that in a series of one-way ANOVAS with two levels (training vs. no training), participants with musical training showed significantly higher performance on melody, rhythm, RM (rhythm-to-melody), and BAT (beat alignment test), but not on the tempo test.

Relationships between cognitive and MP performance

Correcting for multiple correlations

Since many comparisons were made between the cognitive and MP measures, we adjusted alpha in order to avoid making a type I error. These comparisons were divided by each MP comparison, with five cognitive relationships each. We separated the comparisons by each MP test because it was expected that each MP test would have independent relationships with the cognitive measures. In accordance with the false discovery rate method (Benjamini, 2010), the original alpha level, α= .05, was divided into five ascending sub-thresholds: α= {.01, .02, .03, .04, .05}. Then, the results from each MP component were ordered from most to least significant, and the progressive α sub-thresholds were applied to each individual relationship (i.e., the smallest threshold was applied to the most significant relationship, for a given MP component).

General relationships between cognitive and MP performance

In order to examine the overall effects of cognitive functioning on music perception abilities, each cognitive measure was correlated to the overall MP performance (total number of correct trials on MP tests). As summarized in the bottom row of Table 4, inhibition (*R*= -.421, *p*= .006) was the only cognitive factor that was related to overall MP performance, after corrections for multiple comparisons. It is important to note that inhibition scores reflect reaction time performance. Therefore, this negative relationship may be interpreted as those with faster, more efficient inhibition showed higher overall MP performance. Meanwhile, DSB (*R*= .292, *p*= .042, not significant after corrections), processing speed (*R*= .209, *p*=.110), WCST (*R*= .179, *p*= .148) and memory (*R*= .073, *p*= .336) were not significantly related to overall MP performance.

Specific relationships between cognitive and MP performance

It is important to consider how the cognitive measures at hand individually relate to MP abilities. After corrections for multiple comparisons, very few results remained significant. The results of these correlations are summarized in Table 4. Melody perception was significantly related to inhibition (*R*= - .505, *p*= .001) and DSB (*R*= .410, *p*= .007). Rhythm perception was also significantly related to inhibition (*R*= -.349, *p*= .020). BAT, tempo, and RM failed to show significant relationships with any cognitive factor.

Cognitive measure	**Episodic memory**		**Inhibition**		**Processing speed**		**DSB**		**WCST**	
MP test	*p*	*R*	*p*	*R*	*p*	*R*	*p*	*R*	*p*	*R*
BAT	.209	- .139	.121	- .203	.085	.234	.305	.088	.417	.036
Melody	.391	.048	**.001**	- .505	.151	.177	**.007**	.410	.046	.285
Tempo	.174	-.161	.261	- .112	.365	- .059	.286	.097	.144	.182
Rhythm	.076	.244	**.020**	- .349	.042	.404	.121	.200	.255	.114
RM	.056	.270	.475	- .011	.085	.234	.411	.039	.216	- .135
Overall MP	.336	.073	**.006**	- .421	.110	.209	.042	.292	.148	.179

Table 4: Relationship between cognitive and MP performance. Significance and Pearson's *R* displayed for each correlation. Significant relationships displayed in bold, after corrections for multiple correlations. Note that the inhibition battery is measured in reaction time, and that the WCST is scored as the number of perseverative errors, so negative relationships are to be expected. Overall MP= overall music perception performance (total correct trials). BAT= Beat Alignment Test; RM= Rhythm-Melody subtest; DSB= Digit Span Backwards; WCST= Wisconsin Card Sorting Test.

Discussion

The present study explored the relationship between cognitive functioning and music perception in older adults. While a number of studies have investigated the effects of musical training on cognitive processes, this may be the first study to examine relationships between several cognitive and MP domains within one sample. The results of this study have the potential to inform our understanding of the cognitive functions that support music perception in the general population, including in those who with more musical expertise than the present sample.

These results also inform our understanding of the ways in which music-making has the potential to promote cognitive health in the elderly. While there is a growing body of evidence showing support for a variety of cognitive benefits associated with music training in other populations, there is a limited amount of research investigating how training may preserve cognitive functions in older adults. A few preliminary aging studies have reported improvements in cognition as a result of music-making (Seinfeld, Figueroa, Oritz-Gil, & Sanchez-Vives, 2013;

Bugos, et al., 2007). The results of this study may help us understand which aspects of music drive these changes.

Cognitive functions supporting music perception

Based on the present results, it seems that melody perception may be the most cognitively demanding aspect of MP for older adults. Melody performance was strongly related to inhibition and working memory (DSB) performance. This finding is also supported by the fact that out of all the MP tests, melody performance was lowest. Rhythm performance may also be quite cognitively demanding, as it was significantly related to inhibition performance. Meanwhile, no other significant relationships were found for tempo, BAT, or rhythm-melody processing. Tempo processing showed the weakest relationships with the cognitive measures, which may indicate that tempo-related abilities are most preserved in older adults.

These relationships between music perception and cognitive functioning may provide support for findings regarding musical training and cognitive transfer. Patel (2014) hypothesized that musical training may promote cognitive transfer by placing higher demands on domains used in everyday functioning. The present results provide support for this hypothesis, in that higher performance on inhibition and working memory tests were related to better melodic and rhythmic perception. Several studies have found relationships between musical training and improvements in working memory and inhibition, in children, (Degé, Kubicek, & Schwarzer, 2011; Roden, Grube, Bongard, & Kreutz, 2014) and in adults (Zuk, et al., 2014; Hou, et al., 2014). Researchers are also beginning to investigate the ways in which musical training may preserve cognitive functioning in older adults. Some preliminary studies have found that musically-naïve older adults showed improvements in working memory (Bugos, et al., 2007) and in inhibitory functioning (Seinfeld, Figueroa, Oritz-Gil, & Sanchez-Vives, 2013) after several months of piano training.

Another recent study found that older adults with lifelong music training had improved inhibitory control, compared to those without training (Moussard, et al., 2016). It is possible that these cognitive benefits of musical training are driven by rhythmic and melodic processing.

Processing of musical sequence versus musical time

One of the most interesting trends that emerged from the exploratory analysis were the noticeable differences seen in the BAT and tempo relationships versus melody and rhythm relationships. Both the BAT and tempo tests failed to relate strongly to any cognitive measure. Meanwhile, melody and rhythm performance both related strongly to inhibition and working memory measures. This pattern seems to distinguish different cognitive processing styles supporting two general aspects of musical perception.

The melody and rhythm tests underscore the sequencing aspect of music. The same-different PROMS test required participants to make very specific judgments about the order and "identity" of notes (pitch or duration) in the melody and rhythm test. Inhibition and working memory processing likely supported these types of comparisons. Meanwhile, the BAT and tempo tests examine another aspect of musical processing: periodic time intervals. Both tests required participants to attend to and evaluate differences in the time between periodically-timed musical events. The fact that performance on these tests did not relate to any cognitive measure may actually reinforce what we already know about beat and tempo processing. Auditory-motor integration seems to be important for several types of musical processing, particularly for the perception of beat and tempo (see Zatorre, Chen, & Penhune, 2007 for review). Several studies have linked beat processing to activity in motor regions of the brain, including the basal ganglia, supplementary motor area, and cerebellum (Merchant, Grahn, Trainor, Rohrmeier, & Fitch, 2015), and there is some evidence that patients with Parkinson's disease have reduced beat perception abilities (Biswas, Jhunjhunwala, Pal, & Hegde, 2015). While no cognitive measures were found to be related to the BAT and tempo tests, it is possible that the processing of musical time is dependent on other non-musical cognitive factors.

It is important to note that while the present results do not provide evidence for any cognitive factors supporting the processing of musical timing information, other unmeasured domains may become evident in future studies. Patel and colleagues (2005) pointed out that while beat perception seems as if it is supported by primitive neural mechanisms, it is a process that is unique to only a small number of species, and may be more complex than it seems. They argue that beat perception and synchronization require a specific combination of sensory and motor abilities, and may depend on higher order processes such as coordination of distant brain systems and simulation of periodic movements (Patel & Iversen, 2014).

General relationships between cognitive and MP performance

It was hypothesized that both inhibition and processing speed may have general effects on MP, as deficits in these cognitive domains are theorized to have widespread effects on age-related cognitive decline (Kail & Salthouse, 1994; Dempster, 1992). While performance on the inhibition battery did relate strongly to overall MP accuracy, these effects were not uniform across the individual MP tests. In examining the data, it is possible that the strong relationships with melody and rhythm drove this finding, while the other MP measures showed weak or nonexistent relationships. Similarly, while processing speed was weakly related to several MP measures, it cannot be said that it has widespread relationships with MP abilities.

Cognitive functioning, MP and musical experience

We predicted that since most participants have received little to no musical training, current musical experiences, such as listening behaviors, would have stronger effects on cognitive and MP performance. However, this is not what we found. Although we considered several different types of listening behaviors, it seems that the presence of training was most strongly related to improved MP performance. It may be that even though training occurred many years ago, it can still influence the ways individuals process music. It would have also been interesting if the music experience measures were related to cognitive performance as well, as it would have provided support for music experience as a cognitive health-preserving lifestyle factor. This long-term effect of training has also been demonstrated in a study where older adults with some musical training showed faster neural responses to speech (White-Schwoch, et al., 2013), showing the potential for music experience to relate to other non-musical factors.

Lack of relationships

While this exploratory analysis uncovered very few significant relationships between cognitive and MP performance, some non-significant relationships are still quite informative. For example, the lack of significant relationships with BAT and tempo processing may indicate that older adults are able to process these components of MP despite cognitive deficits. It is also particularly interesting that none of the components of MP showed significant relationships with the episodic memory battery. This finding may connect to the intriguing phenomenon of preserved musical memory in patients with dementia (see Baird & Samson, 2009, for a review). While most studies of musical memory in dementia focus on long-term memory, these results may inform ways in which patients with dementia may be able to enjoy new music.

Limitations

The present study is limited in its generalizability in several ways. One issue that the sample consisted only of females. While one study found a gender difference the lateralization of ERP responses to musical syntax violations, (Koelsch, Maess, Grossmann, & Friederici, 2003), the study did not report whether there was a gender difference in MP accuracy. Without any existing evidence for gender differences in MP accuracy, we can say that these results generalize to both genders. It is possible that the present study only informs MP and cognitive relationships in older adults with a small amount of training, and that the results of this study may not generalize well to those with extensive training. However, the present results can at least begin to inform our understanding of these relationships in the general population. Finally, the exploratory nature of this analysis may have weakened the power of the results, as several relationships were lost after corrections were made.

Future directions

The present study has begun to increase our understanding of the cognitive factors supporting MP, as it is the first study, to our knowledge, to examine the relationships between several cognitive and MP domains within one sample. Future studies may expand on the present findings by examining relationships between similar tests in other populations, such as young adults, or those with more extensive musical training. Based on the results of the current work, it will be interesting to explore if musical training enhances cognition through the demands placed on inhibition and working memory by rhythmic and melodic processing. Future studies should examine these relationships further, possibly in a longitudinal study assessing cognitive changes throughout the course of musical training.

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Appendix A
Music Experience Questionnaire

1. **Past Musical Experiences:**
   a. Have you had musical training or experience in the past—instrumental or singing?
      YES/NO

   b. If YES, please describe what **type** of musical experience(s), and the **length of time** and **age** at which you had these experiences:

   c. Have you enjoyed participating in music making activities? YES/NO
   d. Did you participate in general music class in grade school? YES/NO
   e. Please rank your general music ability as you perceive it: (circle)

1---------2---------3---------4---------5---------6---------7---------8---------9
Beginner Professional

2. **Current Music Making:**
   a. Currently, do you sing or play an instrument on a regular basis? YES/NO
   b. If YES, please describe what **type** of music making and how many **hours** per week (on average):

   c. If YES, is your musical involvement solo or group? _____________

3. **Current Listening:**
   a. On average, how many hours do you listen to music per week? _______________
   b. What genre(s) of music do you typically listen to currently?

____

____

Appendix A
Music Experience Questionnaire, continued

c. How frequently do you attend live performances to hear music you enjoy?

____

d. How frequently do you sing, hum, or whistle along to music you enjoy?

☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Very Often

e. How frequently do you dance?

☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Very Often

a. If yes, what styles? ______________________________________

f. How would you rate your overall sense of rhythm, compared to the general population?

☐ Poor ☐ Below Average ☐ Average ☐ Good ☐ Excellent

Appendix B

Speech, Spatial, and Qualities of Hearing Questionnaire

Please check one of these options:	**If you have been using hearing aid/s, for how long?**
☐ I have **no** hearing aids ☐ I use one hearing aid **(left ear)** ☐ I use one hearing aid **(right ear)** ☐ I use **two** hearing aids **(both ears)**	*Left ear* _____years _____months or _____weeks *Right ear* _____years _____months or _____weeks

The following questions inquire about aspects of your ability and experience hearing and listening in different situations.

For each question, put a mark anywhere on the scale, which runs from 0 to 10. Putting a mark at **10** means that you are **perfectly** able to do or experience what is described in the question. Putting a mark at **0** means that you would be **unable** to do or experience what is described.

For example, question 1 asks about having a conversation with someone while the TV is on at the same time. If you are well able to do this, then put a mark up towards the right-hand end of the scale. If you could follow about half the conversation in this situation, put the mark around the mid-point, and so on.

We expect that all the questions are relevant to your everyday experience, but if a question describes a situation that does not apply to you, mark the "not applicable" box. Please also write a note next to that question explaining why it does not apply in your case.

All questions answered on a scale from 1 (with great difficulty) to 10 (perfectly). Participants also have the option of selecting "not applicable."

1. You are talking with one other person and there is a TV on in the same room. Without turning the TV down, can you follow what the person you're talking to says?

2. You are listening to someone talking to you, while at the same time trying to follow the news on TV. Can you follow what both people are saying?

3. You are in conversation with one person in a room where thre are many other people talking. Can you follow what the person you are talking to is saying?

4. You are in a group of about five people in a busy restaurant. You can see everyone else in the group. Can you follow the conversation?

5. You are with a group and the conversation switches from one person to another. Can you easily follow the conversation without missing the start of what each new speaker is saying?

Appendix B

Speech, Spatial, and Qualities of Hearing Questionnaire, continued

6. You are outside. A dog barks loudly. Can you tell immediately where it is, without having to look?

7. Can you tell how far away a bus or a truck is, from the sound?

8. Can you tell from the sounds whether a bus or truck is coming towards you or going away?

9. When you hear more than one sound at a time, do you have the impression that it seems like a single jumbled sound?

10. When you listen to music, can you make out which instruments are playing?

11. Do everyday sounds that you hear easily seem clear to you (not blurred)?

12. Do you have to concentrate very much when listening to someone or something?