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Mental Control of Musical Imagery: Comparing Tonal and Song Stimuli

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Abstract

Mental control of musical imagery is a complex but understudied process that consists of two components: *initiation*—whether the musical imagery experience began voluntarily or involuntarily—and *management*—whether instances of control occur after the experience has begun (e.g., changing the song). The present research examined these two components using 11 lab tasks measuring both initiation and management abilities in a sample of 203 undergraduate students. The tasks varied in stimuli composition: 7 tasks used tones and tonal sequences frequently used as stimuli in auditory imagery research, and 4 tasks used stimuli resembling the contents of everyday musical imagery (i.e., song excerpts). Initiation and management abilities were closely related, and people with greater musical expertise showed a smaller difference between initiation and management ability. Similarly, performance on tasks using tones or tonal sequences and tasks using song stimuli were closely related, and people didn't differ in performance as a function of stimulus type. The present research demonstrates that people's ability to initiate and to manage musical imagery are strongly linked and that people are equally good at controlling relatively simple musical imagery and imagery of well-known songs.

Keywords: Musical Imagery; Auditory Imagery; Mental Control; Musical Expertise

Mental Control of Musical Imagery: Comparing Tonal and Song Stimuli

Hearing music in your mind is frequent in everyday life (Bailes, 2006; Cotter, Christensen, & Silvia, 2019; Liikkanen, 2011). Nearly everyone reports experiencing musical imagery—music that is not playing in the environment—at least occasionally, and experience sampling research shows that people report musical imagery roughly 25% of the time when randomly signaled during the day (Cotter et al., 2019). These imagery experiences are wide-ranging and diverse. People have both pleasant and unpleasant experiences (e.g., Beaman & Williams, 2010; Beaty et al., 2013; Williamson & Jilka, 2014) and show broad variation in the vividness (e.g., Bailes, 2015; Campbell & Margulis, 2015), length (e.g., Beaman & Williams, 2010; Lipson, 2006), and repetitiveness (e.g., Kvavilashvili & Anthony, 2012; Margulis, 2014) of their everyday musical imagery.

Studies of everyday musical imagery have tended to emphasize the *contents* of musical imagery—characterizing what music people tend to hear and what it is like—over the *process* of musical imagery, such as how it starts, unfolds, and stops. How people exercise mental control over inner musical experience appears complex and remains poorly understood. Traditionally, musical imagery has been labeled as voluntary or involuntary without consideration of the variety of ways in which people can exercise control over these internal experiences (see Cotter, 2019; Williams, 2015). A recent framework suggests that mental control of musical imagery can be thought of in two ways (see Cotter, 2019 for review)—initiation and management. *Initiation* refers to the start of the musical imagery episode—did it begin intentionally or unintentionally? *Management*, on the other hand, refers to control exerted over an episode after it has begun (e.g., sustaining the experience, altering the musical content, ending the episode). By distinguishing between these types of control, we can begin to see how treating mental control as a unitary construct could limit our understanding of musical imagery.

The present research uses this two-component conceptualization of mental control to address two open questions. First, we examine the relationship between initiation and

management abilities in the controlled lab environment—because these components have yet to be behaviorally measured within the same study, how these abilities relate remains unknown. Second, we examine how the contents of musical images relate to people’s ability to control these images. Can people more easily control images that differ from their everyday musical imagery but are relatively simple (e.g., single tones or tonal sequences), or can people more easily control images that resemble their everyday musical imagery (e.g., sections of songs)?

Cognitive Psychology of Auditory Imagery

The cognitive psychology of auditory imagery has traditionally used behavioral tasks to assess people’s imagery abilities¹. As a type of auditory imagery, musical imagery has often been studied using tonal stimuli to investigate principles of people’s auditory imagery experiences. These tonal auditory imagery studies assess a range of people’s auditory imagery capabilities, including information about people’s abilities to initiate and manage imagery.

Inherent in any auditory imagery task is the need to construct an auditory image. In some research, the tasks are relatively simple—imagining the pitch of a presented tone and completing a subsequent signal detection task (Farah & Smith, 1983) or hearing a single tone or chord, imagining the tone or chord, and determining if a second tone or chord is identical to the one imagined (Hubbard & Stoeckig, 1988). In these initiation tasks, people are probed on their ability to replicate the presented cue stimuli.

But people must also initiate imagery for other, more complex tasks (i.e., tasks requiring the manipulation or sustention of a tonal sequence), and people are generally able to initiate imagery to complete these tasks (e.g., Foster, Halpern, & Zatorre, 2013; Gelding, Thompson, & Johnson, 2015; Halpern & Zatorre, 1999; Herholz, Lappe, Knief, & Pantev, 2008; Janata &

¹ Here we emphasize the behavioral tasks used in auditory imagery research; however, we do recognize other methods have been used to examine control of auditory imagery experiences (e.g., the self-report Bucknell Auditory Imagery Scale subscale concerning control; Halpern, 2015).

Paroo, 2006; Weber & Brown, 1986). This provides further support that people can initiate simple musical images when asked to do so.

Several studies also assess people's ability to manage ongoing musical images. In many tasks, people must sustain their imagery to determine whether a probe tone matches the pitch (e.g., Herholz et al., 2008; Janata & Paroo, 2006) or timing (e.g., Janata & Paroo, 2006) of their imagined music, monitor the qualities of their image (e.g., pitch; Bailes, Bishop, Stevens, & Dean, 2012; Weber & Brown, 1986), or imagine whole musical segments to determine the temporal accuracy of their images (Halpern & Zatorre, 1999). But the far more intuitive sense of management is the ability to manipulate and alter aspects of an image. In many tasks, people are asked to alter the pitch of individual tones (Gelding et al., 2015; Hubbard & Stoeckig, 1988) or chords (Hubbard & Stoeckig, 1988), but in more complex tasks people will mentally transpose or reverse the temporal order of their musical imagery (Foster et al., 2013; Foster & Zatorre, 2010). In contrast to initiation tasks, management tasks probe people on their ability to "fill in the gap" by imagining the continuation of a presented cue (e.g., Janata & Paroo, 2006), manipulate their imagery in specified ways (e.g., Gelding et al., 2015), or monitor temporal qualities of their imagery (e.g., Bailes et al., 2012). These lab-based auditory imagery paradigms further illustrate people's abilities to control their musical imagery and show the diversity of management behaviors people can employ.

Ecological Musical Imagery

Researchers in the ecological musical imagery tradition tend to take a descriptive, exploratory approach: they seek to describe what people's everyday musical imagery experiences are like. Experience sampling methods, the most frequently used ecological assessment technique in this literature, require participants to report their musical imagery experiences as they are happening via completion of multiple surveys per day across several days. The small collection of studies that take this approach (e.g., Bailes, 2015; Beaty et al., 2013; Cotter et al., 2019; Cotter & Silvia, in press) captures involuntary, voluntary, and creative musical imagery

experiences and discusses musical imagery as a general phenomenon experienced by musicians and non-musicians alike. This approach also preserves any differences between episodes of musical imagery that can be obscured when using retrospective survey or interview measures of musical imagery that require respondents to pool or reconstruct their musical imagery experiences (see Cotter & Silvia, 2017, for additional details).

Mental control has not been a prominent focus of experience-sampling research. Some studies have asked questions that allude to people's ability to exert control over their musical imagery experiences. In their everyday lives, people don't often initiate musical imagery (Bailes, 2015; Beaty et al., 2013; Cotter et al., 2019). Cotter et al. (2019) asked a sample of undergraduate students, via experience sampling, whether they had initiated their musical imagery—people reported doing so approximately 25% of the time, suggesting that involuntarily-initiated imagery is the norm. In a follow-up, Cotter and Silvia (in press) asked music and non-music students to attempt to initiate imagery—not whether their imagery was purposefully initiated. Interestingly, when people are asked to initiate an episode of musical imagery in their everyday environments, both music and non-music students report being able to do so most of the time (61%). Overall, people do report intentionally initiating musical imagery occasionally in their everyday life and perceive the ability to initiate musical imagery when instructed to do so.

Researchers have also asked questions about people's management of their musical imagery. Many of these items involved wanting to get rid of (Bailes, 2007, 2015; Beaty et al., 2013) or alter the content of a particular musical image (Bailes, 2007, 2015). People generally did not strongly endorse these items, implying that management failure is not the norm. When asked whether they felt their imagery was under their control, Cotter et al. (2019) found that students generally perceive a moderate level of control over their imagery. Further, Cotter and Silvia (in press) reported that, when asked to change specific elements of their musical imagery in daily life (e.g., tempo, vocalist's gender) both music and non-music students report being able to do so most of the time and do not perceive managing their imagery to be difficult.

Collectively, these studies suggest that people perceive the ability to manage their musical imagery in the messy, complex environments encountered in daily life.

The Present Research

Since both initiation and management are present in both lab and ecological research, a natural step is to apply the lessons from one perspective to the other. The cognitive psychology of auditory imagery has many strengths. This approach emphasizes behavioral over self-report measurement of mental control. Given limitations in how people understand and report on their cognitive processes (Nisbett & Wilson, 1977), behavioral measurement of processes like mental control is invaluable. Additionally, the lab-based paradigms provide researchers with a fine level of control over the stimuli, tasks, and environment that isn't possible in experience sampling research. Collectively, this allows researchers to isolate specific mechanisms within people's mental control processes and examine people's control abilities under optimal conditions (e.g., reduced distractions, minimal environmental noises). On the other hand, the stimuli typically used in this research tradition are remarkably spare and simplistic (e.g., single tones, isolated musical passages), unlike the rich and complex imagery typically reported in everyday musical imagery (e.g., well-known or popular music; Bailes 2015).

The present research expands the current literature in two important ways. First, this is the first study to behaviorally assess both initiation and management ability in the same study. Even though there has been some work examining associations between self-reported initiation and management ability in daily experience (Cotter et al., 2019; Cotter & Silvia, in press), no prior research has examined how performance on initiation and management tasks are associated.

Second, to expand the lab-based auditory imagery approach, the present research uses both auditory imagery tasks with tonal and tone sequence stimuli and tasks in which stimuli consist of excerpts from songs that resemble the musical imagery contents reported in ecological musical imagery research. This allows for the examination of how stimulus qualities influence

control abilities. A few studies (Bishop, Bailes, & Dean, 2013; Godøy, Haga, & Jensenius, 2006; Jakubowski et al., 2015; Weir, Williamson, & Müllensiefen, 2015) have used songs as stimuli to assess control of musical imagery, but no studies have directly compared control abilities on tasks using tonal vs. song stimuli. It is possible that increased complexity impairs control performance, that similarity between the song stimuli and people's typical musical imagery contents bolsters control abilities, or that the complexity of stimuli is irrelevant to control abilities—the present research addresses this question.

We also examine how musical expertise relates to initiation and management abilities, and its relation to task performance as a function of stimulus complexity. Musical training (e.g., Foster et al., 2013; Gelding et al., 2015) has previously been positively associated with better performance on behavioral musical imagery tasks (e.g., pitch judgments, temporal judgments) and with self-reported general auditory imagery control abilities (e.g., Gelding et al., 2015). Therefore, we anticipated that musicians would have an advantage on these tasks.

Method

Participants and Procedure

Participants were 242 undergraduate students, and the sample was young (M age = 19.24, SD = 2.66, range = 18 - 41), mostly female (n = 179, 73.97%), and racially diverse (45.86% Black, 40.91% White). Thirty-nine participants were excluded from analyses due to elevated scores on items designed to capturing inattentive responding (see Maniaci & Rogge, 2014; McKibben & Silvia, 2016, 2017), resulting in a final sample of 203. Participants were compensated with research credits or \$20 in cash for their participation. The sample size goal for this study was to recruit at least 150 participants, and if this recruitment goal was achieved prior to the end of the academic semester, data collection would continue until the end of the semester. All procedures were approved by the University of North Carolina at Greensboro's Institutional Review Board.

Participants completed a 2-hour lab session and completed the auditory imagery tasks via DirectRT (Version 2012.4.0.166; Jarvis, 2012) and demographics and musical expertise measures via MediaLab (Version 2012.4.133; Jarvis, 2012) on desktop computers. Imagery tasks were completed in two blocks: all tonal stimuli tasks were in one block and all song stimuli tasks were in a separate block. Presentation of the two blocks was counterbalanced.

Apparatus

All imagery tasks were completed on Lenovo ThinkCentre computers with Sony MDR-ZX110NC headphones. Prior to completing any imagery tasks, participants adjusted the volume on the headphones to a comfortable level.

Auditory Imagery Tasks

People completed 11 auditory imagery tasks that varied in several ways (see Table 1). First, the tasks varied in stimulus complexity—in the tonal stimuli tasks, stimuli consisted of single tones, chords, tonal sequences, and major scales; in the song stimuli tasks, stimuli consisted of song excerpts (details of song selection are described below). Second, the tasks required people to make different kinds of judgments about their imagery—people made pitch (seven tasks), timing (two tasks), tempo (one task), and rhythm (one task) judgments. Finally, people completed tasks assessing both the initiation (two tasks) and management (nine tasks) of musical imagery. All task instructions and stimuli are available on the Open Science Framework (<https://osf.io/jgf84/>).

Tonal stimuli tasks. All stimuli were created using the MuseScore 2 (2019) composition software (Version 2.3.2). Notes were synthesized as piano tones, and WAV sound files were created for subsequent editing. All pitch and timing editing was completed manually using Audacity (Version 2.2.2; Audacity Team, 2019). Tasks were programmed using DirectRT, and both choice performance (correct/incorrect) and reaction times (in ms) were recorded. Participants were instructed to focus on the accuracy of their responses, not speed of responses,

and there was no time limit for responses. For all tasks, probe notes and patterns were randomly selected, and trial order was randomized within task.

Tone and chord initiation (Figure 1, Panel A). Both the tone and chord initiation tasks were adapted from Hubbard and Stoeckig (1988, Experiment 3). Stimuli were the 12 pitches of the chromatic scale and associated major chords. In each trial, people heard a cue tone or chord for 2.3 s, imagined the pitch(es) of the cue, and indicated when they formed the image. People then heard a 16-note tone mask (2.7 s) followed by a probe tone or chord (2.3 s; see Figure 1 panels A and B). A tone mask was included to reduce the likelihood of participants relying on echoic memory to complete the task—Hubbard and Stoeckig (1988) found that a tone mask slightly decreases accuracy but that task completion is still manageable. Probes were identical to the cue, sharpened by 30 cents, or flattened by 30 cents. (This degree of mistuning was determined by Janata and Paroo's (2006) findings suggesting this degree of mistuning is correctly identified approximately 50% of the time). Participants indicated whether the probe was higher than, the same as, or lower than the cue. Participants completed all 12 tone trials followed by 12 chord trials. People completed three practice trials before completing the test trials for each task.

Tonal pitch discrimination (Figure 1, Panel B). This task was adapted from Janata and Paroo (2006). Stimuli consisted of ascending and descending diatonic scales in all 12 major keys. In each trial participants heard the first four notes of a scale and were instructed to imagine the next four notes of the scale. The final note of the scale (i.e., the eighth note) was played in-tune, sharpened by 30 cents, or flattened by 30 cents (see Figure 1, panel C). Participants indicated whether the final note of the scale was higher than, the same as, or lower than their image of the final note. People completed 12 trials (one for each major scale; 4.2 s each). Prior to completing test trials, people heard complete ascending and descending scales and completed four practice trials (two ascending scales and two descending scales).

Tonal timing judgment (Figure 1, Panel C). This task was adapted from Janata and Paroo (2006). Stimuli consisted of ascending and descending diatonic scales in all 12 major keys. In each trial participants heard the first four notes of a scale and were instructed to imagine the next four notes of the scale. The final note of the scale (i.e., the eighth note) was played on time, 60 ms early, or 60 ms late (see Figure 1, panel D)—degree of timing deviance was determined by Janata and Paroo's (2006) findings that suggest this degree of timing deviance is correctly identified approximately 50% of the time. Participants indicated whether the final note of the scale was played earlier than, the same time as, or later than their image of the final note. People completed 12 trials (one for each major scale; 4.2 s each). Prior to completing test trials, people heard complete ascending and descending scales and completed four practice trials (two ascending scales and two descending scales).

Simple melody comparison (Figure 1, Panel D). This task was adapted from Foster and Zatorre (2010) and Foster et al. (2013). Stimuli consisted of novel, unfamiliar five-note melodies played in C major. In each trial, people heard a cue melody (4.1 s) followed by a 3 s silence and a probe melody (4.1 s). Participants indicated whether the probe melody was identical to the cue or if the probe melody contained one pitch that was different than in the cue (see Figure 1, panel F). Probe melodies different from cue melodies contained one note changed by one or two semitones, remained in the key of C major, and maintained the melodic contour (i.e., the pattern of notes moving up or down across the melody). The first note of the probe melody was never changed. Participants completed three practice trials and 20 test trials.

Transposed melody comparison (Figure 1, Panel E). This task was adapted from Foster and Zatorre (2010) and Foster et al. (2013). Stimuli consisted of novel, unfamiliar five-note melodies. In each trial, participants heard a cue melody played in C major (4.1 s) followed by a 3 s silence and a probe melody with all pitches transposed up (in E major) or down (in A^b major) by four semitones (4.1 s). Participants indicated whether the pattern of intervals between notes was identical in the cue and probe melodies or if this pattern was different in the probe

melody. Probe melodies different from cue melodies altered the pitch of one note by one semitone and maintained the overall melodic contour (i.e., whether the notes moved up or down in pitch). The first note of the transposed probe melody was never altered. Participants completed three practice trials and 20 test trials.

Rhythm judgment (Figure 1, Panel F). This task was adapted from Foster and Zatorre (2010). Stimuli consisted of five-beat rhythm patterns played on middle C/C4 consisting of both played notes and rests. In each trial, people heard a cue rhythmic pattern (4.3 s) followed by a 3 s silence and a probe rhythmic pattern (4.3 s). Participants indicated whether the probe pattern was the same as or different than the cue pattern. Probe patterns different from cue patterns contained one difference from the cues (e.g., length of a note or rest is altered). Participants completed three practice trials and 20 test trials.

Song stimuli tasks. Stimuli were selected through consulting multiple sources listing popular, iconic, or well-known songs (e.g., top songs on Spotify and rankings of iconic songs on prominent music websites, such as Billboard.com); generating songs frequently played in party or group settings (e.g., Y.M.C.A. by The Village People); generating frequently played seasonal songs (i.e., well-known Christmas songs); and consulting past research using similar tasks (e.g., Weir et al., 2015). From these sources, 54 frequently played songs were selected (see Appendix A) and were converted into WAV files for editing. An additional 54 infrequently played songs by the same artists were selected—selection of these songs was done by identifying the song from the same album or time period as the frequently-played song with the fewest plays listed on Spotify (see Appendix B). Spotify is a well-known music-streaming platform often used by young adults (e.g., Liikkanen & Åman, 2016). Play frequency was used as a proxy for familiarity during stimuli selection, but participant familiarity with each stimulus was recorded.

Excerpts for all songs were manually created using Audacity. Excerpts for frequently played songs were selected to include a highly memorable or familiar part of the song (e.g., chorus, beginning of the song) and were cut in musically meaningful places (i.e., not in the

middle of a word or phrase).² Excerpts for infrequently played songs were selected to feature a less memorable part of the song (e.g., the middle lines of a verse) and were cut in musically meaningful places. The end of all excerpts faded to silence. Frequently and infrequently played song clips did not differ in their beats per minute (BPM), $t(106) = -1.04$, $p = .30$, 95% CI: [-16.74, 5.19], Frequent: $M = 114.16$, $SD = 26.84$, Infrequent: $M = 119.94$, $SD = 30.51$.

All pitch and tempo changes were completed using Ableton Live version 10 (2019) using the “Complex Pro” algorithm to maintain sound quality for each excerpt. Song excerpts were randomly assigned to tasks. The tasks were programmed using DirectRT, and both choice performance (correct/incorrect) and reaction times (ms) were recorded. Participants were instructed to focus on the accuracy of their responses, not speed of responses, and there was no time limit for responses. For all tasks, probes were randomly selected, and trial order was randomized within task.

Song pitch discrimination. This task was adapted from Weir et al. (2015). Stimuli consisted of frequently played songs likely to be familiar to participants. In each trial, people heard a song excerpt featuring a highly memorable or familiar part of the song (M length = 28.74 s, $SD = 4.83$ s, range = 20.02 s – 37.30 s). People heard a portion of the excerpt (M length = 13.14 s, $SD = 4.02$ s, range = 5.47 s – 20.14 s) then the music disappeared for several seconds (M length = 9.69 s, $SD = 1.45$ s, range = 8.00 s – 12.70 s). During the silence, people were instructed to imagine the song continuing. The music then returned and played for several seconds (M length = 5.91 s, $SD = 1.90$ s, range = 2.83 s – 9.77 s). The returning music was sharpened by one semitone, unaltered, or flattened by one semitone—degree of pitch shift was identical to Weir et al. (2015). Participants indicated whether the pitch of the returning music was the same as the opening of the excerpt or if it was higher or lower in pitch. People also indicated their familiarity with the song excerpt on a four-point scale (*I have never heard this*

² Select songs were originally identified and tested by Weir et al. (2015)—these are indicated in Appendix A. For consistency, excerpts from these songs were also edited for the present study.

song before to I have heard this song many times and know it very well). Participants completed three practice trials and 24 test trials.

Song timing judgment. This task was adapted from Weir et al. (2015). Stimuli consisted of frequently played songs likely to be familiar to participants. In each trial, people heard a song excerpt featuring a highly memorable or familiar part of the song (M length = 30.77 s, SD = 6.57 s, range = 20.77 s – 44.20 s). People heard a portion of the excerpt (M length = 14.68 s, SD = 5.87 s, range = 5.93 s – 26.32 s) then the music disappeared for several seconds (M length = 9.62 s, SD = 1.11 s, range = 7.60 s – 11.73 s). During the silence, people were instructed to imagine the song continuing. The music then returned and played for several seconds (M length = 6.47 s, SD = 2.60 s, range = 2.97 s – 12.97 s), and the music returned two beats early, at the correct time, or two beats late—degree of timing difference was identical to Weir et al. (2015). Participants indicated whether the returning music was correct or if it was too early or late. People also indicated their familiarity with the song excerpt on a four-point scale (*I have never heard this song before to I have heard this song many times and know it very well*). Participants completed three practice trials and 24 test trials.

Key change. This task was designed to assess people's pitch discrimination ability, similar to the tonal stimuli melody comparison tasks. Stimuli consisted of infrequently played songs matched by artist to stimuli used in the song pitch discrimination and timing judgment tasks. In each trial, people heard a short excerpt featuring less memorable parts of the song (e.g., the middle lines of a verse; M length = 5.89 s, SD = .85 s, range = 4.72 s – 7.84 s). People heard a cue excerpt followed by a tone mask (3 s) and a probe excerpt with pitches sharpened by one semitone, identical to the cue, or flattened by one semitone. A tone mask was included to reduce the likelihood of participants relying on echoic memory to complete the task. Participants indicated whether the probe was the same as the cue or if the pitches were higher or lower than the cue. People also indicated their familiarity with the song excerpt on a four-point scale (*I*

have never heard this song before to I have heard this song many times and know it very well).

Participants completed three practice trials and 24 test trials.

Tempo change. This task was designed to assess people's ability to imagine temporal aspects of music, similar to the tonal rhythm judgment task. Stimuli consisted of infrequently played songs matched by artist to stimuli used in the song pitch discrimination and timing judgment tasks. In each trial, people heard a short excerpt featuring less memorable parts of the song (e.g., the middle lines of a verse; M length = 5.95 s, SD = 1.18 s, range = 4.60 s – 8.75 s). People heard a cue excerpt followed by a tone mask (3 s) and a probe excerpt with the tempo increased by 5% of listed beats per minute (BPM), the same as the cue, or decreased by 5% of listed BPM. A tone mask was included to reduce the likelihood of participants relying on echoic memory to complete the task. Participants indicated whether the probe tempo was the same as the cue or if the probe tempo was faster or slower than the cue. People also indicated their familiarity with the song excerpt on a four-point scale (*I have never heard this song before to I have heard this song many times and know it very well*). Participants completed three practice trials and 24 test trials.

Musical Expertise

Goldsmiths Musical Sophistication Index (Müllensiefen, Gingras, Musil, & Stewart, 2014). This 38-item measure assesses five facets of musical expertise: *active engagement* (amount of time and resources devoted to musical engagement), *perceptual abilities* (self-reported ability to evaluate musical performances), *singing abilities* (self-reported ability to sing accurately and from memory), *emotions* (emotional reactions to musical experiences), and *musical training* (the amount of formal musical training and identity as a musician). The scale also yields an overall *general musical sophistication* score, which contains items from all facets. All items are rated on a seven-point scale (*Completely disagree* to *Completely agree*). Past work has shown relations between the overall general musical sophistication score and mental control of musical imagery (Cotter & Silvia, in press) and that

people with greater musical training show better performance on musical imagery control tasks (Cotter & Silvia, in press; Foster et al., 2013; Gelding et al., 2015). Therefore, we were particularly interested in findings regarding the general score and the musical training subscale, but all subscales were analyzed.

Results

Trial and Task Exclusions

On all tasks, trials with reaction times faster than 200 ms were excluded. Because participants were told to prioritize accuracy, trials with longer reaction times were not excluded from analyses. Additionally, Song Pitch Discrimination and Song Timing Judgment trials in which participants were unfamiliar with the song (familiarity ratings of 1 or 2) were excluded, and Key Change and Tempo Change trials in which participants were familiar with the song (familiarity ratings of 3 or 4) were excluded. Participants who had fewer than 10 valid trials on a task were also excluded from analyses using that task.

Task Performance

Descriptive statistics for all tasks are in Table 2. Mean proportion of correct trials ranged from .38 (Song Timing Judgment) to .63 (Simple Melody Comparison). One-sample *t*-tests were used to determine whether performance differed from chance levels—performance on all tasks was above chance except the Transposed Melody Comparison, which did not differ from chance (see Table 2).

Additionally, the correlations (see Table 3) provide interesting information regarding the relations between the tasks. The initiation tasks were moderately correlated ($r = .49$) and were more closely related to one another than to the management tasks; however, these tasks did show notable correlations with pitch-related management tasks ($r_s > .29$). Management tasks demonstrated inconsistent associations with one another, but the pitch-related tasks demonstrated more widespread associations with other management tasks than timing-related management tasks. The song stimuli tasks were related to one another (except the Tempo

Change and Song Timing Judgment tasks), with the Song Pitch Discrimination tasks showing the strongest relations with the other song stimuli tasks ($r_s > .31$). The tonal stimuli tasks showed some associations with one another—the Tonal Timing Judgment, Transposed Melody Comparison, and Rhythm Comparison tasks had limited associations with the other tonal stimuli tasks. In general, tasks assessing time-related imagery aspects were not related to one another and showed few associations with pitch-related tasks; pitch-related tasks were generally related to one another, except the Transposed Melody Comparison task, which was unrelated to other pitch-related tasks.

This project also provides the opportunity to examine the performance in the present study and performance in the original studies (see Table 4 for a summary). It is important to note, however, that there are some differences in task specifications or sample characteristics that limit these comparisons. Performance on both initiation tasks were lower than the original study (49% for both tasks in the present research, 87% for tones and 78% for chords in original research; Hubbard & Stoeckig, 1988, Experiment 3). This sizable difference is likely attributable to the difference in probe construction—in the present research, probes different from cues were mistuned by 30 cents, whereas in the original research probes differed by a larger magnitude, likely making the task easier for participants. Likewise, performance on the management tasks were generally lower in the present study than in the original studies, but some within-study relative performance findings are consistent. People consistently perform better on the Tonal Pitch Discrimination task than the Tonal Timing Judgment task (Janata & Paroo, 2006, Experiment 1), better on the Simple Melody Comparison than the Transposed Melody Comparison and Rhythm Judgment tasks (Foster & Zatorre, 2010), and better on the Song Pitch Discrimination task than the Song Timing Judgment task (Weir et al., 2015). Collectively, this suggests that people tend to more accurately imagine pitch-related aspects than time-related aspects.

Initiation and Management

Our first aim was to examine the relation between initiation and management abilities and whether people show differences in these abilities. Confirmatory factor analysis in Mplus 8 was used to examine the association between performance on initiation and management tasks. Proportion of trials correct on the tone and chord initiation tasks were used as indicators for the initiation latent factor, and performance on all other tasks were used as indicators for the management latent factor. Factor variances were fixed to one and all factor loadings were free to vary. In this analysis, the proportion of trials correct was converted to T scores, which have a mean of 50 and standard deviation of 10, to put task performance on the same scale (i.e., because the tasks vary in the chance rate, a raw score of .45 indicates performance well above chance on some tasks but below chance performance on others). This model fit the data well ($\chi^2(55) = 369.41, p < .0001$; RMSEA = .05, 95% CI: [.03, .08], $p = .365$; CFI = .92; SRMR = .05). The two factors were correlated ($r = .81, p < .001$, 95% CI: [.66, .96]) indicating that initiation and management ability were closely related.

Latent growth curves (Duncan, Duncan, & Strycker, 2006; Preacher, Wichman, MacCallum, & Briggs, 2008) in Mplus 8 were also used to model people's imagery control abilities. This analytic approach was used to account for both overall task performance and how well people did on initiation tasks relative to management tasks (i.e., Are people better at initiation or management? Do people demonstrate equal abilities?). This analysis yields intercept and slope factors. To estimate the intercept, regression weights for all tasks were fixed to 1. To estimate the slope, regression weights for the 2 initiation tasks were fixed to -.5, and regression weights for the 9 management tasks were fixed to .5. With this scaling, the intercept represents the sample's estimated average performance (in the T-score metric) across all tasks, and the slope represents the difference in performance (in standard deviation units) in initiation versus management tasks. Positive slope values indicate better performance on management relative to initiation tasks (see Figure 2). Model fit was mediocre ($\chi^2(55) = 369.41, p < .0001$; RMSEA = .08, 95% CI: [.07, .10], $p = .002$; CFI = .74; SRMR = .16).

The intercept equaled 49.96 and its variance component (28.61) was significantly different from 0 ($p < .001$), suggesting that people differ in their average performance on the imagery tasks. The slope equaled $-.004$ and was not significantly different from 0 ($p = .994$), suggesting that, on average, people's performance on initiation and management tasks was equivalent. However, the slope's variance component (5.93) was significantly different from 0 ($p = .007$), suggesting that people vary in their relative performance on initiation versus management tasks. The intercept and slope factors were significantly correlated ($r = -.69, p < .001$, 95% CI: $[-.92, -.45]$) indicating that people who perform better on the tasks overall tend to have a smaller difference in performance on initiation versus management tasks.

Musical expertise was used to predict the latent intercept and slopes (see Table 5)—all reported regression coefficients are standardized. The global GMSI general sophistication score predicted both the intercept ($\beta = .44, SE = .08, p < .001$, 95% CI: $[.29, .59]$) and slope ($\beta = -.28, SE = .13, p = .028$, 95% CI: $[-.53, -.03]$). People with greater musical sophistication did better on the tasks overall and had a smaller difference in performance on initiation and management tasks. Stated differently, people with less musical sophistication did worse overall and did relatively better on management tasks versus initiation tasks (see Figure 3).

To examine if these findings are driven by particular aspects of musical sophistication, all five subscales were used to predict the intercept and slope. Musical training was the only significant predictor of the intercept ($\beta = .36, SE = .09, p < .001$, 95% CI: $[.19, .53]$), and both active engagement ($\beta = -.36, SE = .17, p = .031$, 95% CI: $[-.68, -.03]$) and musical training ($\beta = -.36, SE = .16, p = .021$, 95% CI: $[-.66, -.05]$) predicted the slope. This suggests that people with greater musical training show better performance on these tasks overall, and people with greater musical training and more active engagement with music have a smaller performance difference on initiation and management tasks. People with less musical training and lower active engagement with music tended to do better on management tasks relative to initiation tasks.

Tonal and Song Stimuli

Our second aim was to examine the relationship between people's ability to control musical images containing tonal versus song stimuli and if people differed in these abilities. A similar CFA in Mplus 8 was used to examine the association between performance on tasks using tonal and song stimuli. Proportion of trials correct on the Song Pitch Discrimination, Song Timing Judgment, Key Change, and Tempo Change tasks were used as indicators for the song factor; all other tasks were used as indicators for the tonal factor. Factor variances were fixed to one and all factor loadings were free to vary. As before, the proportion of trials correct were scaled as T scores for this analysis. This model fit the data well ($\chi^2(55) = 369.41, p < .0001$; RMSEA = .05, 95% CI: [.02, .08], $p = .462$; CFI = .93; SRMR = .05). The two factors were highly correlated ($r = .80, p < .001$, 95% CI: [.67, .93]), suggesting that performance on tasks with tonal and song stimuli are closely related.

Latent growth curves in Mplus 8 were used to model performance on tasks using tonal and song stimuli. The specification mirrored the prior analysis. To estimate the intercept, regression weights for all tasks were fixed to 1. To estimate the slope, regression weights for the 7 tonal stimuli tasks were fixed to -.5, and regression weights for the 4 song stimuli tasks were fixed to .5. Proportion of trials correct were converted to T scores. The intercept thus represents average performance (in the T metric) across all tasks, and the slope represents the average difference (in standard deviations) in performance on tasks using tonal and song stimuli. Positive slope values reflect relatively better performance on song stimuli tasks compared to tonal stimuli tasks (see Figure 4). Model fit was again mediocre ($\chi^2(55) = 369.41, p < .0001$; RMSEA = .09, 95% CI: [.07, .10], $p = .001$; CFI = .72; SRMR = .17).

The intercept equaled 49.94 and its variance component (23.22) was significantly different from 0 ($p < .001$), suggesting that people differ in their average performance on the imagery tasks. The slope equaled -.10 and was not significantly different from 0 ($p = .824$), suggesting that, on average, people's performance on tasks with tonal and song stimuli are equivalent. In addition, the slope's variance component (6.23) was not significantly different

from 0 ($p = .081$), suggesting that people do not vary in their relative performance on tasks with tonal versus song stimuli. The intercept and slope factors were significantly correlated ($r = .66$, $p = .003$, 95% CI: [.22, 1.10]) indicating that people who perform better on the tasks overall tend to have a greater difference in performance on tasks using tonal versus song stimuli.

Musical expertise was used to predict the latent intercept and slopes (see Table 5). The global GMSI general sophistication score predicted the intercept ($\beta = .44$, $SE = .07$, $p < .001$, 95% CI: [.30, .58]) but not the slope ($\beta = .36$, $SE = .20$, $p = .069$, 95% CI: [-.03, .74]), indicating that people with greater musical sophistication did better on the tasks overall but that performance on tasks using tonal versus song stimuli did not differ as a function of musical sophistication. Musical training was the only subscale associated with the intercept ($\beta = .31$, $SE = .09$, $p < .001$, 95% CI: [.15, .48]), and no subscales were significant predictors of the slope.

Discussion

Prior research on auditory imagery in the lab and in daily life suggests that people can both initiate musical images and manage ongoing musical imagery. But research has yet to explore the relation between these forms of mental control or how the contents of musical imagery influence control abilities. The present research had two main aims. The first was to examine initiation and management abilities in the same study and thus to see how they relate; the second was to see how control abilities differed as a function of stimulus properties.

How Well Did People Initiate versus Manage Musical Imagery?

There was no main effect for differences in performance on initiation versus management tasks—overall, people did equally well at these two kinds of mental control—but there was significant variability in overall performance and in the difference in performance on initiation and management tasks. Performance on initiation and management tasks was closely related ($r = .81$). We examined musical expertise—an important factor for mental control of musical imagery (Cotter & Silvia, in press; Foster et al., 2013; Gelding et al., 2015)—to explain this variability. As anticipated, people with greater expertise were more accurate overall and

showed a smaller difference between initiation and management task performance. These findings are consistent with past work showing people with greater musical expertise show better performance than musical novices on a variety of imagery tasks, such as altering pitches of individual notes (Gelding et al., 2015), detecting changes in novel melodies, and noticing changes in rhythmic patterns (Foster & Zatorre, 2010). Interestingly, it was engagement with music, not self-reported perceptual abilities, that also predicted performance differences in initiation and management. This suggests there may be a benefit to passive interactions with music in addition to formal musical training; however, this aspect of music engagement should be further explored with additional research.

Surprisingly, people with lower musical expertise showed relatively greater accuracy on management tasks compared to initiation tasks. This may suggest that working with pre-existing musical images is easier for musical novices than initiating entirely new images. It is possible, however, that task features may explain this difference—both initiation tasks contained tone masks following the initiation of the images prior to the presentation of the probes. These findings may instead suggest that musical novices struggle to initiate images when presented with additional musical interference. Although some differences in performance occur when including a tone mask as compared with no tone mask (Hubbard & Stoeckig, 1988), future research should explore this possible explanation of the present findings.

How Well Did People Control Imagery of Tonal versus Song Stimuli?

We found no main effect for differences in performance based on stimulus complexity, so the sample overall did equally well on the tonal and song stimuli tasks. In addition, there was not significant variability in the difference in performance between tonal and song stimuli tasks. There may be a few reasons for this null effect—it is possible that the complexity of the stimuli has no influence over control ability, that the simplicity of the tonal stimuli and familiarity of the song stimuli made these tasks easier and the novelty of the tonal stimuli and complexity of the song stimuli simultaneously make the tasks more difficult resulting in equivalent performance,

or there may be additional explanations for this null effect. One of the challenges in using more ecologically-valid stimuli is the reduced control over many musicological factors—future research should examine the influence of specific musical elements (e.g., lyrics) on people’s abilities to control their musical imagery. Performance on tasks using tonal and song stimuli was also closely related ($r = .80$).

There are a few potential reasons why we did not observe a difference in performance on tonal stimuli and song stimuli tasks. First, it is possible that the type of stimuli does not influence control abilities. Although the tonal stimuli are quite different than the contents typically reported in everyday musical imagery (i.e., familiar, popular music; Bailes, 2015), the underlying control processes may be insensitive to these differences. Alternatively, the tonal stimuli tasks were relatively simple but had novel, unfamiliar contents; the song stimuli tasks showed the opposite character—the contents were familiar, but the tasks were more complex. It is possible that these factors made tasks simultaneously easier and harder, resulting in equivalent observed performance. Further, the present findings provide preliminary evidence that what we know about mental control from auditory imagery research using tonal stimuli and lab paradigms (e.g., people are better at pitch discrimination than timing judgments, Janata & Paroo, 2006; people can change the pitch of their images in specified ways, Gelding et al., 2015, Hubbard & Stoeckig, 1988) may extend to people’s abilities to control their everyday musical imagery. Additional research is necessary to better understand the influence of imagery contents on control processes.

Future Directions

An interesting finding of the present research was the strong correlation between initiation and management task performance. The link between these two task types likely reflects several factors, such as the considerable similarity in the structure of the initiation and management tasks (e.g., examining control of pitch imagery, identifying deviations in probes)—future research on initiation and management processes should also examine performance on

tasks that reduces the amount of shared method variance to further understand the relation between these components. Although closely related in this study, it is important to treat initiation and management as conceptually distinct processes that fall under the global construct of mental control.

Additionally, it is important to acknowledge that people completed more management tasks than initiation tasks, which may have played a role in the present findings. There are a greater variety of management tasks, and the tasks assessing the ability to control song stimuli were best suited as management tasks, contributing to our decision to use many management tasks. The difference in number of tasks and trials people completed assessing initiation and management is a limitation of the present work and should be addressed through future work that uses similar numbers of tasks and trials.

The present research also suggests several directions for future research on the mental control of musical imagery. A strength of the current study is its consideration of both tonal and song stimuli types, but it is also important to consider the environments in which people typically experience musical imagery and may attempt to control it. People's everyday environments are rarely as calm and sterile as the lab environment, and people's initiation and management abilities and the relation between the two forms of mental control likely look different in people's daily life. Emphasizing lab-based approaches limits our understanding of these processes, so future work should examine similarities and differences in mental control in these two settings. Daily life assessment of musical imagery is common (e.g., Bailes, 2015; Beaty et al., 2013; Cotter & Silvia, in press), and it can be used to explore many research questions about mental control in everyday musical imagery.

But there are also additional questions for lab-based research to address. Management of musical imagery has different flavors—sustaining an image, actively manipulating and changing an image, or ending an episode of musical imagery—that can be examined and compared through behavioral tasks similar to those used in the present study and past research. Defining

and studying lower-order components of management is an important step towards growing our understanding of mental control of musical imagery and presents the opportunity to refine our conceptualizations of these processes.

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Table 1

Summary of auditory imagery tasks

	Tonal Stimuli Tasks	Song Stimuli Tasks
Initiation Tasks	Tone Initiation* Chord Initiation*	
Management Tasks	Tonal Pitch Discrimination Tonal Timing Judgment Simple Melody Comparison Transposed Melody Comparison Rhythm Judgment	Song Pitch Discrimination Song Timing Judgment Key Change* Tempo Change*

Note. * Indicates tasks using a tonal mask between cue and probe presentations.

Table 2

Descriptive statistics for imagery tasks and *t*-tests testing task performance against chance levels

Task	N	Chance	Median	Mean [95% CI]	SD	Range	<i>t</i>-test, Cohen's <i>d</i>, 95% CI
Tone	189	.33	.50	.49, [.46, .52]	.21	.08 – 1.00	$t(188) = 10.34^{***}$, $d = .77$, [.60, .93]
Chord	185	.33	.45	.49, [.46, .52]	.20	.08 – 1.00	$t(184) = 10.50^{***}$, $d = .79$, [.62, .95]
Tonal Pitch Discrimination	190	.33	.42	.46, [.43, .48]	.17	.00 - .92	$t(189) = 9.73^{***}$, $d = .72$, [.56, .88]
Tonal Timing Judgment	180	.33	.42	.39, [.37, .41]	.13	.08 - .75	$t(179) = 6.16^{***}$, $d = .48$, [.33, .64]
Simple Melody Comparison	191	.50	.63	.63, [.61, .65]	.15	.30 - .95	$t(190) = 12.34^{***}$, $d = .89$, [.72, 1.06]
Transposed Melody Comparison	193	.50	.50	.51, [.49, .53]	.13	.20 - .85	$t(192) = 1.07$, $d = .08$, [-.06, .22]
Rhythm Comparison	193	.50	.50	.53, [.51, .54]	.11	.25 - .80	$t(192) = 3.30^{**}$, $d = .24$, [.09, .38]
Song Pitch Discrimination	189	.33	.53	.53, [.50, .56]	.19	.11 – 1.00	$t(188) = 13.86^{***}$, $d = 1.02$, [.85, 1.22]
Song Timing Judgment	168	.33	.36	.38, [.36, .41]	.15	.06 - .91	$t(167) = 4.44^{***}$, $d = .36$, [.21, .52]
Key Change	193	.33	.48	.50, [.48, .53]	.19	.17 – 1.00	$t(192) = 12.72^{***}$, $d = .93$, [.76, 1.10]
Tempo Change	193	.33	.50	.49, [.47, .51]	.13	.21 - .85	$t(192) = 16.93^{***}$, $d = 1.24$, [1.05, 1.43]

Note. Descriptive statistic values represent the proportion of trials with correct responses. Chance probabilities indicate the proportion of trials participants would be expected to get correct if they were purely guessing. One-sample *t*-tests were used to assess whether mean task performance differed from chance levels. * $p < .05$, ** $p < .01$, *** $p < .001$. All *t*-tests indicated as significant remain significant when using a Bonferroni-corrected significance level ($p < .05/11$ or $p < .004$). Cohen's *d* values of 0.2, 0.5, and 0.8 indicate small, medium, and large effect sizes, respectively.

Table 3

Correlations among imagery tasks

Task	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Tone	1										
2. Chord	.49***	1									
3. Tonal Pitch Discrimination	.29**	.35***	1								
4. Tonal Timing Judgment	.11	.11	.07	1							
5. Simple Melody Comparison	.39***	.34***	.33***	-.01	1						
6. Transposed Melody Comparison	-.03	-.08	.11	-.13	.04	1					
7. Rhythm Comparison	.21**	.17*	-.01	.07	.08	-.04	1				
8. Song Pitch Discrimination	.40***	.30***	.30***	.18*	.38***	.09	-.00	1			
9. Song Timing Judgment	.30***	.24**	.27***	.03	.29***	.17*	.03	.31***	1		
10. Key Change	.36***	.39***	.22**	.11	.41***	-.01	.17*	.53***	.18*	1	
11. Tempo Change	.16*	.15*	.19**	.03	.11	-.00	.13	.31***	.14	.29***	1

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

Table 4

Summary of replication findings

Task	Present Findings	Original Study Findings
Tone Initiation	49% accuracy (12 trials)	Hubbard & Stoeckig (1988, Exp. 3) Sample: 21 undergraduate students 87% accuracy (48 trials)
Chord Initiation	49% accuracy (12 trials)	Hubbard & Stoeckig (1988, Exp. 3) Sample: 21 undergraduate students 78% accuracy (48 trials)
Tonal Pitch Discrimination	46% accuracy (12 trials)	Janata & Paroo (2006, Exp. 1) Sample: 24 undergraduate students 78% accuracy when probe in tune (120 trials) <i>Accuracy not provided for mistuned trials</i>
Tonal Timing Judgment	39% accuracy (12 trials)	Janata & Paroo (2006, Exp. 1) Sample: 24 undergraduate students Approx. 60% when probe in time (exact accuracy not provided; 120 trials) <i>Accuracy not provided for out of time trials</i>
Simple Melody Comparison	63% accuracy (20 trials)	Foster & Zatorre (2010) Sample: 68 adults (community sample) 76% accuracy (60 trials)
Transposed Melody Comparison	51% accuracy (20 trials)	Foster & Zatorre (2010) Sample: 68 adults (community sample) 69% accuracy (60 trials)
Rhythm Judgment	53% accuracy (20 trials)	Foster & Zatorre (2010) Sample: 68 adults (community sample) 69% accuracy (60 trials)
Song Pitch Discrimination	53% accuracy (24 trials)	Weir et al. (2015) Sample: 67 adults (online, community sample) 67% accuracy (9 trials)
Song Timing Judgment	38% accuracy (24 trials)	Weir et al. (2015) Sample: 67 adults (online, community sample) 43% accuracy (9 trials)

Table 5

GMSI predicting the intercepts and slopes of the latent growth models

	Internal Consistency (α)	Mean (SD)	Range	Initiation vs. Management		Tonal vs. Song	
				Intercept	Slope	Intercept	Slope
General Sophistication	.87	73.54 (16.62)	37 – 118	.44*** (.08) [.29, .59]	-.28* (.13) [-.53, -.03]	.44*** (.07) [.30, .58]	.36 (.20) [-.03, .74]
Active Engagement	.81	38.86 (8.97)	21 – 63	.17 (.10) [-.02, .35]	-.36* (.17) [-.68, -.03]	.09 (.10) [-.11, .28]	-.20 (.23) [-.66, .25]
Emotions	.74	23.78 (4.88)	20 – 42	-.01 (.11) [-.23, .21]	.35 (.18) [-.01, .70]	.10 (.11) [-.11, .32]	.45 (.26) [-.06, .96]
Musical Training	.88	20.94 (10.04)	7 – 47	.36*** (.09) [.19, .53]	-.36* (.16) [-.66, -.05]	.31*** (.09) [.15, .48]	.10 (.22) [-.34, .53]
Singing Abilities	.77	29.51 (7.25)	13 – 49	-.05 (.10) [-.24, .15]	.03 (.16) [-.28, .35]	-.05 (.10) [-.24, .15]	-.03 (.21) [-.44, .39]
Perceptual Abilities	.79	44.65 (7.32)	26 – 63	.10 (.13) [-.14, .35]	.06 (.19) [-.31, .43]	.14 (.13) [-.10, .39]	.27 (.27) [-.25, .79]

Note. Standardized regression coefficients (β) are reported with standard errors in parentheses and 95% confidence intervals around the regression coefficients presented in brackets. * $p < .05$, ** $p < .01$, *** $p < .001$.

Tone Initiation

A

Cue (2.3 s) Probe (2.3 s) Response

Tone Mask (2.7 s)

Higher, same, or lower?

Chord Initiation

Cue (2.3 s) Probe (2.3 s) Response

Tone Mask (2.7 s)

Higher, same, or lower?

Tonal Pitch Discrimination

B

Cue Notes Imagined Notes Probe Note Response

Higher, same, or lower?

Tonal Timing Judgment

C

Cue Notes Imagined Notes Probe Note Response

Early, on time, or late?

Simple Melody Comparison

D

Cue (4.1 s) Silence (3 s) Probe (4.1 s) Response

Same or different?

Transposed Melody Comparison

E

Cue (4.1 s) Silence (3 s) Probe (4.1 s) Response

Same or different?

F

Cue (4.1 s)

Silence (3 s)

Rhythm Judgment

Probe (4.1 s)

Response
Same or different?

Figure 1. Examples of tonal stimuli imagery tasks.

Figure 2. Latent growth curve model for initiation versus management tasks.

Note. Solid lines indicate loadings of 1, dotted lines indicate loadings of -.5, and dashed lines indicate loadings of .5.

Figure 3. General musical sophistication predicting difference in performance on initiation and management tasks

Figure 4. Latent growth curve model for tonal vs. song stimuli tasks.

Note. Solid lines indicate loadings of 1, dotted lines indicate loadings of -.5, and dashed lines indicate loadings of .5.

Appendix A

Details for frequently played song stimuli

Song Title	Artist	Start (s)	Cut Out (s)	Return (s)	End (s)	Clip Length (s)	BPM	Task
ABC	The Jackson 5	14.65	27.86	38.11	42.54	27.89	94	Pitch Discrimination
Africa	Toto	59.92	71.93	82.32	95.29	35.37	93	Timing Judgment
All Night Long (All Night)	Lionel Richie	61.42	75.70	84.57	90.32	28.90	109	Pitch Discrimination
All Star	Smash Mouth	28.54	39.87	50.59	55.95	27.41	104	Pitch Discrimination
Another One Bites the Dust	Queen	61.79	85.73	96.17	101.56	39.77	110	Timing Judgment
<i>Baby One More Time</i>	<i>Britney Spears</i>	<i>20.50</i>	<i>37.59</i>	<i>50.06</i>	<i>57.80</i>	<i>37.30</i>	93	<i>Pitch Discrimination</i>
<i>Beat it</i>	<i>Michael Jackson</i>	<i>14.40</i>	<i>31.70</i>	<i>41.20</i>	<i>48.40</i>	<i>34.00</i>	139	<i>Pitch Discrimination</i>
Billie Jean	Michael Jackson	78.18	92.76	104.14	111.35	33.17	117	Pitch Discrimination
Bye Bye Bye	NSYNC	54.24	67.24	76.17	81.40	27.16	173	Pitch Discrimination
Call Me Maybe	Carly Rae Jepsen	26.11	44.50	53.31	60.51	34.40	120	Pitch Discrimination
Carry On My Wayward Son	Kansas	138.99	153.13	161.71	167.55	28.56	127	Pitch Discrimination
Dancing Queen	ABBA	85.85	105.99	118.09	122.85	37.00	101	Pitch Discrimination
Don't Stop Believin'	Journey	77.01	89.07	101.77	105.74	28.73	119	Pitch Discrimination
Don't You Want Me	The Human League	61.29	77.60	85.74	93.48	32.19	118	Pitch Discrimination

Eye of the Tiger	Survivor	66.78	83.47	92.39	96.78	30.00	109	Pitch Discrimination
Hallelujah	Jeff Buckley	73.31	86.75	97.63	105.15	31.84	101	Pitch Discrimination
<i>Hey Ya</i>	<i>Outkast</i>	<i>18.01</i>	<i>26.20</i>	<i>34.40</i>	<i>38.88</i>	<i>20.87</i>	<i>80</i>	<i>Timing Judgment</i>
Hot Stuff	Donna Summer	47.32	55.47	67.20	73.55	26.23	120	Timing Judgment
Hotel California	Eagles	103.96	117.21	126.74	130.48	26.52	147	Timing Judgment
<i>Hound Dog</i>	<i>Elvis Presley</i>	<i>0.00</i>	<i>19.50</i>	<i>28.40</i>	<i>32.53</i>	<i>32.53</i>	<i>175</i>	<i>Timing Judgment</i>
I Don't Want to Miss a Thing	Aerosmith	71.53	83.97	92.71	102.48	30.95	121	Pitch Discrimination
<i>I Gotta Feeling</i>	<i>Black Eyed Peas</i>	<i>26.61</i>	<i>33.40</i>	<i>44.80</i>	<i>51.83</i>	<i>25.22</i>	<i>128</i>	<i>Pitch Discrimination</i>
I Will Always Love You	Whitney Houston	188.25	205.09	212.69	220.37	32.12	67	Timing Judgment
I Will Survive	Gloria Gaynor	47.71	58.93	67.65	72.88	25.17	117	Pitch Discrimination
<i>I'm a Believer</i>	<i>The Monkees</i>	<i>4.80</i>	<i>17.10</i>	<i>27.30</i>	<i>35.80</i>	<i>31.00</i>	<i>80</i>	<i>Timing Judgment</i>
Imagine	John Lennon	76.84	96.26	106.97	114.94	38.10	76	Timing Judgment
Jingle Bell Rock	Bobby Helms	7.78	27.17	35.77	38.60	30.82	120	Pitch Discrimination
Just Dance	Lady Gaga	32.75	47.83	58.63	66.61	33.86	119	Timing Judgment
Last Christmas	Wham!	17.54	36.06	44.85	53.81	36.27	108	Pitch Discrimination
Let it Be	The Beatles	25.69	37.79	47.85	51.51	25.82	143	Timing Judgment
Let it Snow, Let it Snow, Let it Snow	Dean Martin	20.92	34.23	42.23	46.35	25.43	134	Pitch Discrimination
Mambo No. 5	Lou Bega	49.67	55.14	66.22	72.11	22.44	174	Pitch Discrimination
Moves Like Jagger	Maroon 5 feat. Christina Aguilera	42.22	49.52	59.97	63.81	21.59	128	Pitch Discrimination

Over the Rainbow	Judy Garland	30.80	52.62	63.95	75.00	44.20	73	Timing Judgment
Poker Face	Lady Gaga	40.39	48.49	56.65	62.31	21.92	119	Pitch Discrimination
Respect	Aretha Franklin	88.12	109.20	117.39	121.52	33.40	115	Timing Judgment
Rolling in the Deep	Adele	22.96	32.08	41.66	47.07	24.11	105	Timing Judgment
School's Out	Alice Cooper	36.36	49.03	58.42	63.02	26.66	134	Timing Judgment
Silent Night	Bing Crosby	10.03	21.74	32.80	44.39	34.36	76	Timing Judgment
Single Ladies (Put a Ring on it)	Beyoncé	21.63	31.27	41.23	50.88	29.25	193	Pitch Discrimination
Smells Like Teen Spirit	Nirvana	42.06	54.45	62.59	65.75	23.69	117	Pitch Discrimination
Stand By Me	Ben E. King	30.12	51.69	61.41	64.38	34.26	118	Timing Judgment
Stayin' Alive	Bee Gees	23.07	37.39	46.51	51.44	28.37	104	Timing Judgment
Sweet Caroline	Neil Diamond	44.07	67.42	76.89	85.40	41.33	63	Timing Judgment
Take on Me	A-Ha	51.29	57.22	67.35	73.17	21.88	84	Timing Judgment
The Christmas Song	Nat King Cole	13.03	39.35	48.24	53.53	40.50	132	Timing Judgment
Thriller	Michael Jackson	81.60	89.53	97.83	102.37	20.77	118	Timing Judgment
Tik Tok	Ke\$ha	31.80	39.82	47.83	51.82	20.02	120	Pitch Discrimination
Uptown Funk	Mark Ronson and Bruno Mars	16.92	37.51	45.80	50.33	33.41	115	Timing Judgment
Wannabe	Spice Girls	31.62	40.59	49.31	58.24	26.62	110	Timing Judgment
<i>What a Wonderful World</i>	<i>Louis Armstrong</i>	<i>22.70</i>	<i>34.78</i>	<i>46.01</i>	<i>54.20</i>	<i>31.50</i>	<i>77</i>	<i>Timing Judgment</i>
White Christmas	Bing Crosby	10.03	20.26	29.71	34.70	24.67	96	Pitch Discrimination
Y.M.C.A.	Village People	51.65	59.99	68.53	75.20	23.55	127	Timing Judgment
Yeah!	Usher feat. Lil Jon and Ludacris	44.90	54.73	64.00	68.60	23.70	105	Timing Judgment

Note. BPM = Beats Per Minute. Songs in italics were originally used in Weir et al. (2015).

Appendix B

Details for infrequently played song stimuli

Song Title	Artist	Start (s)	End (s)	Clip Length (s)	BPM	Task
[I Prithee] Do Not Ask For Love	The Monkees	64.12	70.72	6.60	105	Tempo Change
A Marshmallow World	Dean Martin	42.94	47.92	4.98	111	Tempo Change
Another Christmas Without You	Bobby Helms	38.96	44.37	5.41	107	Key Change
Anymore	Whitney Houston	86.76	94.75	7.99	114	Tempo Change
Baby Be Mine	Michael Jackson	83.48	89.69	6.21	110	Tempo Change
Beautiful, Dirty, Rich	Lady Gaga	62.83	68.36	5.53	120	Tempo Change
Boots & Boys	Ke\$ha	53.38	59.61	6.23	126	Tempo Change
Breakout	Bee Gees	15.20	21.30	6.10	125	Key Change
Can't Slow Down	Lionel Richie	94.08	98.76	4.68	123	Tempo Change
Coming Soon	Queen	70.24	76.93	6.69	137	Tempo Change
Darkness	The Human League	72.89	78.10	5.21	122	Key Change
Dead or Alive	Journey	92.27	97.70	5.43	190	Tempo Change
Dear Mr. Gable: You Made Me Love You	Judy Garland	14.25	18.97	4.72	64	Key Change
Deep In The Morning	Neil Diamond	59.30	64.60	5.30	76	Tempo Change
Dig A Pony	The Beatles	75.65	83.49	7.84	59	Key Change
Don't Know Nothing	Maroon 5	14.81	21.93	7.12	130	Tempo Change
Don't Let Me lose This Dream	Aretha Franklin	42.63	49.23	6.60	126	Key Change
Drive	Carly Rae Jepsen	49.89	56.60	6.71	123	Tempo Change
E-Mail My Heart	Britney Spears	88.79	93.39	4.60	142	Tempo Change
Gutter Cat vs. The Jets	Alice Cooper	53.64	59.25	5.61	126	Tempo Change
Home	Smash Mouth	11.73	16.66	4.93	165	Tempo Change
I Dream Myself Alive	A-Ha	34.09	41.19	7.10	129	Key Change
I Guess I'll Get The Papers and Go Home	Louis Armstrong	78.68	84.01	5.33	80	Key Change
I Like It Rough	Lady Gaga	72.20	77.12	4.92	120	Key Change
Icecream	Lou Bega	55.81	60.90	5.09	109	Tempo Change
If You Were There	Wham!	43.97	49.74	5.77	131	Key Change

I'll Be Good For You	NSYNC	37.92	42.69	4.77	100	Tempo Change
I'll Bet You	The Jackson 5	57.48	62.78	5.30	82	Key Change
Is Christmas Only A Tree	Bing Crosby	58.44	64.51	6.07	83	Tempo Change
It's So Hard	John Lennon	51.61	57.54	5.93	83	Key Change
Love Me Real	Gloria Gaynor	31.63	38.90	7.27	126	Tempo Change
Lovers in the Night	Toto	60.80	65.64	4.84	130	Key Change
Money Make Her Smile	Bruno Mars	167.00	172.18	5.18	93	Key Change
My Baby Understands	Donna Summer	6.66	71.33	4.67	103	Tempo Change
Naked	Spice Girls	36.43	42.47	6.04	160	Key Change
Now Generation	Black Eyed Peas	89.66	95.02	5.36	145	Key Change
On a Plain	Nirvana	22.91	30.27	7.36	133	Tempo Change
On The Horizon	Ben E. King	30.07	37.28	7.21	104	Key Change
Pandora's Box	Aerosmith	68.08	72.86	4.78	115	Tempo Change
Parchman Farm Blues/Preachin' Blues (Up Jumped the Devil)	Jeff Buckley	33.58	40.80	7.22	135	Tempo Change
Pretty Maids All in a Row	Eagles	59.27	65.21	5.94	195	Key Change
Questions of My Childhood	Kansas	54.44	59.09	4.65	106	Tempo Change
Radio	Beyoncé	43.00	49.79	6.79	136	Tempo Change
She's Alive	Outkast	16.94	23.91	6.97	144	Key Change
Silver Girl	Survivor	41.28	46.78	5.50	179	Key Change
Tabloid Junkie	Michael Jackson	72.81	79.25	6.44	111	Key Change
Take Your Hand	Usher	27.84	33.42	5.58	96	Key Change
That Christmas Feeling	Bing Crosby	50.53	59.28	8.75	94	Tempo Change
That's When Your Heartaches Begin	Elvis Presley	87.07	93.42	6.35	82	Key Change
The Lady in My Life	Michael Jackson	20.08	27.22	7.14	146	Key Change
The Little Christmas Tree	Nat King Cole	50.01	56.56	6.55	74	Key Change
Tiger	ABBA	14.11	18.76	4.65	135	Tempo Change
Tired	Adele	19.61	24.57	4.96	194	Key Change
Ups and Downs	Village People	17.17	22.03	4.86	123	Key Change

Note. BPM = Beats Per Minute.