

Psychomusicology: Music, Mind, and Brain

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Guy Weir, Victoria J. Williamson, and Daniel Müllensiefen

Online First Publication, May 11, 2015. <http://dx.doi.org/10.1037/pmu0000076>

CITATION

Weir, G., Williamson, V. J., & Müllensiefen, D. (2015, May 11). Increased Involuntary Musical Mental Activity Is Not Associated With More Accurate Voluntary Musical Imagery. *Psychomusicology: Music, Mind, and Brain*. Advance online publication. <http://dx.doi.org/10.1037/pmu0000076>

Increased Involuntary Musical Mental Activity Is Not Associated With More Accurate Voluntary Musical Imagery

Guy Weir

Goldsmiths, University of London

Victoria J. Williamson

University of Sheffield, Lucerne University of Applied Sciences and Arts, and University of London

Daniel Müllensiefen

Goldsmiths, University of London

This study investigates whether there is an association between accurate performance on a musical imagery test and the extent to which people typically experience involuntary musical imagery (INMI, also known as “earworms”). This hypothesis was tested alongside a second hypothesis regarding the established association between musical practice (musical training and activity) and musical imagery ability. Sixty-seven participants were recruited from a general adult population to represent groups with high/low everyday INMI experiences and high/low levels of musical practice. The experimental musical imagery task required participants to listen to excerpts of familiar songs that contained a muted section of about 10 s and to judge whether the reentry of the music after the muted section was shifted in pitch (up/down by 1 semitone) or in timing (early/late by 2 beats). Results confirmed the second hypothesis: musical practice was positively associated with the accuracy of pitch judgments on the imagery task but not timing judgments. By contrast, none of the INMI measures were associated with imagery accuracy. Results are interpreted with reference to the literature on expertise effects and musical imagery.

Keywords: musical imagery, involuntary musical imagery, earworms, musical training, mental imagery

The soul never thinks without a mental image.

—Aristotle [ca. 330 B.C.]

Mental imagery is a prevalent psychological ability, and yet, it remains poorly understood compared with other forms of cognition. This situation is a consequence of the intractable nature of mental imagery, the historical unpopularity of introspective methods (Baddeley & Andrade, 2000), and the dominance of research on verbal processes for theory development (Kosslyn, 1994; Pylyshyn, 2002). The drive to understand mental imagery has, however, encouraged the development of creative experimental paradigms that measure aspects of mental imagery experience such as vividness, speed, and accuracy (Baddeley & Andrade, 2000; Funt, 1980; Janata & Paroo, 2006; Lucas, Schubert, & Halpern, 2010; Shepard & Metzler, 1971).

A typical voluntary mental imagery paradigm might require people to close their eyes and to imagine the sight of a kitten, the sound of a friend’s voice, or the smell of freshly baked bread. The

subsequent internal mental experience can be described as voluntary, as initiation and cessation of the imagery is under conscious control. The experience can also be compared with the corresponding perceptual occurrence, in the absence of any environmental stimulus.

Voluntary musical imagery (VMI) has been explored using similar paradigms. An example VMI trial might require a participant to state whether the fifth note of the song “Happy Birthday” was higher, lower, or the same as the sixth note. A participant would have to use his/her “mind’s ear” to solve the VMI query, making no overt musical sound (Halpern, 1989, 1992; Smith, Reisberg, & Wilson, 1992). Simple VMI judgments such as these are favored over complex phenomenological reports of musical mental imagery experiences; they are more replicable, adaptable to neuroimaging, and theoretically informative (Bailes, 2007; Halpern, 1988a, 1988b, 1989; Janata & Paroo, 2006; Reisberg, 1992; Weber & Brown, 1986; Zatorre & Halpern, 2005; Zatorre, Halpern, & Bouffard, 2010).

Trained musicians are known to employ VMI as part of their practice and performance habits, a process akin to notational audiation (Bailes, Bishop, Stevens, & Dean, 2012; Brodsky, Kessler, Rubinstein, Ginsborg, & Henik, 2008). Aleman, Nieuwenstein, Böcker, and de Haan (2000) established a link between an individual’s level of musical expertise and their VMI ability, finding that musicians outperformed a matched group of musically naïve participants on a VMI pitch test (comparing pitches, as in the earlier example of “Happy Birthday”) but not a similar visual imagery task. This result is in line with more recent findings reported by Bishop, Bailes and Dean (2013) using a similar ex-

Guy Weir, Department of Psychology, Goldsmiths, University of London; Victoria J. Williamson, Department of Music, University of Sheffield, Hochschule Luzern – Musik, Lucerne University of Applied Sciences and Arts, and School of Advanced Study, University of London; Daniel Müllensiefen, Department of Psychology, Goldsmiths, University of London.

Correspondence concerning this article should be addressed to Daniel Müllensiefen, Department of Psychology, Goldsmiths, University of London, New Cross Road, New Cross, London SE14 6NW, United Kingdom. E-mail: d.mullensiefen@gold.ac.uk

perimental paradigm and demonstrating a clear association between the accuracy of loudness imagery for musical stimuli and musical expertise.

The experience of VMI in both musicians and nonmusicians stands in stark contrast to the experience of Involuntary Musical Imagery (“earworms”: INMI hereafter). This is a term given to spontaneous, unbidden, and repeating excerpts of music in “the mind’s ear,” a common mental phenomenon that occurs in the absence of direct volitional control (Beaman & Williams, 2010; Halpern & Bartlett, 2011; Liikkanen, 2008, 2012; Williamson & Jilka, 2014; Williamson et al., 2012).

The premise of the present study was to test whether the regularity of INMI experienced in daily life is associated with improved accuracy in VMI judgments. Motivation for this prediction is drawn from literature on auditory memory. Repetition, such as that experienced with musical imagery in extreme INMI frequency, is one mechanism by which information may be successfully stored in memory (Atkinson & Shiffrin, 1968; Baddeley & Hitch, 1974). Voluntary repetition of musical imagery within memory is one reason why musicians may develop more accurate VMI pitch ability, though other explanations include greater attention focus at the point of encoding and more robust storage thanks to advanced knowledge of musical structure and notation (Bailes et al., 2013). To date, the question of whether involuntary repetition of musical material in the form of INMI also has a positive effect on VMI accuracy remains largely unexplored. Such a positive effect could suggest a link between the INMI phenomenon and involuntary repetition mechanisms, and could therefore contribute an answer to questions regarding the function and purpose of INMI.

Thus, the first aim of the present study was to replicate the established association between musical practice and VMI pitch ability. We decided to use a different imagery test than the one used by Aleman et al. (2000), one that makes use of realistic music stimuli. We also extended the scope of the experimental paradigm used by Aleman et al. (2000) to include a test of VMI timing as well as pitch ability. The second aim was to assess VMI pitch and timing abilities in individuals who report INMI that is frequent in occurrence and persistent in time (“extreme” INMI hereafter; Hyman et al., 2013; Liikkanen, 2012; Müllensiefen, Fry, et al., 2014; Williamson & Jilka, 2014). The research question was, is extreme INMI, like musical practice, associated with more accurate VMI ability?

The VMI Paradigm

The present study tested VMI ability in a paradigm whereby recordings of familiar pop songs were muted for a short period and participants asked to imagine the music continuing in their “mind’s ear.” Our paradigm has its origins in an fMRI study by Kraemer, Macrae, Green, and Kelley (2005) who intersected familiar music with short periods of silence (see also Bailes and Bigand (2004), for a behavioral version of this paradigm). They found that silence within familiar music elicited greater activity in the auditory association areas of the brain than did silence in unfamiliar music. Self-reports from the participants suggested that they were continuing to experience imagery of the familiar tunes during the silences.

Our paradigm aimed to extend and validate the findings from the existing musical imagery research (Aleman et al., 2000) by using recordings of familiar pop songs as in the above studies. This extension increases the ecological validity of the VMI approach as a whole and makes the task more engaging for participants, thereby achieving better data quality.

Stimuli in the paradigm were designed to ensure that short-term memory (STM) for harmony or pitch would not enable participants to respond correctly (see Method section). Thus, similar to the paradigms used by Aleman et al. (2000) and Halpern (1989, 1992), the only strategy available other than guessing was for participants to rely on their VMI of the songs, as the musical stimulus was entirely absent during the muted period. After the muted period a continuation of the music was presented either at the correct (unaltered) or incorrect (altered) pitch level and/or point in time. The participants’ task was to identify any pitch and timing manipulations.

Method

This study tested the VMI abilities of people who experience extreme INMI compared against those who do not. In addition, we tested the contribution of musicianship to VMI ability. A quasi-experimental design was used to assign between-subjects factors; participants were sampled to represent the four groups arising from the combination factor levels of high/low INMI experience and high/low musicianship.

Participants

Participants were selected according to their data on the earwormery survey database (Williamson et al., 2012). They were divided into one of four groups according to whether or not they experienced extreme INMI (both frequent and persistent), and whether or not they were practicing musicians.

The “extreme” INMI group comprised participants who reported experiencing INMI more than once a day for more than 3 hr a day, or constantly. People in the low INMI group fulfilled neither of these criteria. Practicing musicians were defined as individuals who classified themselves at least as “amateur musician” on a 6-point self-classification scheme (see Materials section), indicating that they had gone through a period of intense music making at some point during their lives. In addition, individuals in this group reported that they were currently playing their instrument or singing for at least 1 hr a month. Nonmusicians were defined as individuals who fulfilled neither of these criteria. Invitations to take part in the study were sent to 400 people randomly selected from the earwormery database who fulfilled the criteria for one of the four groups. Eighty-three individuals responded to the invitation (21% response rate) and 67 participants completed the full test. Table 1 gives the demographic information for the groups.

Materials

Individual differences. In addition to the group assignment, participants completed questionnaires that allowed us to apply a more refined assignment of their experiences at the analysis stage. As a measure of musical activity, we took four items from the Musical Behavior Questionnaire representing the factors Musical

Table 1
Size of Participant Groups, Distribution of Age, and Gender

Sample attribute	Musician and extreme INMI	Nonmusician and extreme INMI	Musician and low INMI	Nonmusician and low INMI
<i>N</i> (valid responses)	16	18	18	14
Female	10	7	15	7
Mean age (<i>SD</i>)	39.1 (12.7)	44.6 (13.4)	41.1 (14.9)	39.1 (12.8)

Note. INMI = involuntary musical imagery.

Practice, Music Professionalism, Listening Engagement, and Singing (Müllensiefen, Fry, et al., 2014, p. 328). More specifically, these four items measured (a) amount of musical practice done during a period of sustained musical activity (6-point scale with categories 0 = *Never practiced an instrument*, 1 = *About an hour per month*, 2 = *About an hour per week*, 3 = *About 15 minutes per day*, 4 = *About an hour per day*, 5 = *More than two hours per day*), (b) self-assessed musicianship (6-point scale with categories 1 = *Nonmusician*, 2 = *Music-loving nonmusician*, 3 = *Amateur musician*, 4 = *Serious amateur musician*, 5 = *Semiprofessional musician*, 6 = *Professional musician*), (c) current amount of attentive listening (6-point scale with categories 1 = *Never*, 2 = *Once a week*, 3 = *A few times per week*, 4 = *Nearly every day*, 5 = *Once or twice a day*, 6 = *Several times per day*), and (d) self-rated ability to carry a tune (4-point scale with categories 1 = *Not at all*, 2 = *Not very well*, 3 = *Fairly well*, 4 = *Very well*).

In order to assess the nature of INMI experiences, we used two items from the Involuntary Musical Imagery Questionnaire (Müllensiefen, Fry, et al., 2014) that relate to the frequency of INMI experiences (5-point scale with categories 1 = *More than once a day*, 2 = *Once a day*, 3 = *At least once per week*, 4 = *At least once per month*, 5 = *Less than once per month*) and the length of INMI episodes (5-point rating scale with categories 1 = *Less than 10 minutes*, 2 = *Between 10 minutes and half an hour*, 3 = *Between half an hour and 2 hours*, 4 = *Between 1 hour and 3 hours*, 5 = *More than 3 hours*).

Musical stimuli. The new VMI ability test was programmed into the online survey system “Qualtrics.” This system can play mp3 format sound files automatically when a Web page loads. It also allows the programmer to hide the media player from the participant so they are unable to manually stop, pause, or fast forward playback. All pages were set so there was no “back” function and after the music stimulus finished playing the pages automatically forwarded to the next one. The main advantages of using an online testing interface are that it enables the recruitment of a larger sample size and better response rate, and the access to a more diverse population (i.e., participants could be based all round the country and not be required to visit the lab). The main disadvantage is surrendering control of standardized lab conditions.

Excerpts from nine pop songs were selected as stimulus items. These songs were chosen from the bestselling downloads by decade, as recorded by the Official Charts Company (<http://www.officialcharts.com/>). They covered each decade from the 1950s through to the 2010s. We chose these highly popular songs in order to maximize the likelihood that each participant, regardless of their age, would have a good chance of being highly familiar with the songs. Details of the songs are listed in Table A1: All were

up-tempo apart from “Wonderful World” and were presented in the exact version that charted.

The order of the song presentation was randomized across participants. In order to reduce the overall length of the experiment, we extracted an excerpt from each song that included what we presumed to be the most memorable parts. Excerpts were cut in musically meaningful places and the average length of the song excerpts was 56.28 s (range 30.8–89.6 s).

Song manipulations were carried out in Cubase (V.4 for Mac). All pitch shifting used the MPEX3 algorithm set to “poly complex” quality. The pitch shift algorithm altered the entire content of the sound file, essentially resulting in a shift in key. Timing shifts were done by hand, erasing sections of the song for approximately 10 s depending on how the bars and beats of the songs presented themselves for cut points.

A 10-s silence was chosen to reduce the influence of sensory memory, which has an upper limit of about 5 s (Darwin, Turvey, & Crowder, 1972). Cuts were always made in musically meaningful places, that is, at phrase boundaries and were only done at beat locations in the song. The music dropped out suddenly, and did not fade out. Care was taken to ensure that the last chord heard when the music muted was different from the chord presented to the participant when the music returned, so that pitch judgments could not rely on STM for absolute pitch height or harmony. The returning music, altered or unaltered, maintained pitch and tempo properties until it faded out at the end of each trial.

Experimental conditions. For each song excerpt, nine versions were prepared that represented nine different experimental conditions. There were three pitch modifications (“-1” = pitch shifted flat by one semitone/“0” = pitch unchanged; “1” = pitch shifted sharp by 1 semitone) and three timing modifications (“-1” = timing shifted to come in 2 beats early/“0” = timing unchanged; “1” = timing shifted to come in 2 beats late). The combination of these 3 × 3 modifications gave rise to nine experimental conditions, which were selected at random for the nine trials of each participant. Each excerpt contained a section of around 10 s where the music was muted (for exact details, see Table A1). After this silent passage, the music that returned was subject to one of these nine modifications of pitch and/or timing.

Procedure

The protocol was conducted over the Internet, and participants were asked to find 20 min clear from distraction in a quiet space, and to wear headphones.

The experiment involved nine trials, one for each experimental condition. In each trial, a participant listened to around a minute of a well-known pop song to refresh their memory of it and mitigate

effects of recent exposure. They then listened again to the same section of the song, only this time the music was muted after around 10 to 40 s, for around 10 s (see details in Materials and Table A1). During this silent time, participants were asked to continue to follow the music as if it were still playing in their “mind’s ear.”

After the 10 s of silence, the music returned in one of the nine experimental conditions (see Materials). As soon as the music finished, the participant had to rate how early or late the music entry was in comparison with their imagination by moving a virtual slider on the screen. They used a similar slider to indicate whether the pitch was lower, the same, or higher than they imagined. We collected categorical data, with any slider movement one way or the other coded as early or late, flat or sharp. When the slider remained neutral the response was coded as unaltered. Finally, participants were asked how familiar they were with the song in general (1 = *extremely familiar*, 2 = *quite familiar*, 3 = *not very familiar*, 4 = *heard now for the first time*). No time constraints were placed on any of the judgments.

The nine songs were each presented in random order across participants. Experimental conditions were also paired with songs at random for each participant using the Qualtrics Randomizer function. After the test was concluded, participants were shown a debrief screen which thanked them, summarized the aims of the study, and gave them a contact email address in order to find out their results.

Results

Pitch and timing responses were scored as correct/incorrect for each trial. The VMI paradigm works on the assumption that participants make use of their memory of the song when performing the imagery task during the silent gap. We tested this assumption by comparing task performances for the lowest versus the higher levels of song familiarity. We used a binomial mixed-effects model (similar to a within-participants logistic regression model) with participant as the random effect variable, correct responses to both pitch and timing as dependent variable, and familiarity recoded as a binary variable (“never heard the song before” vs. all other levels of familiarity) as independent variable. Familiarity was a significant predictor in the regression model ($\beta = -0.9971$, $z = -2.265$, $p = .024$), indicating a lower probability for giving a correct response when the song was completely unfamiliar. This result supports the assumption that the VMI ability task measures musical imagery ability that relies on song memory: participants who are not familiar with a given song should not be able to form a mental image, leading to a significantly poorer performance on the task.

Following this analysis, participants’ responses were only scored if they stated that they were either fairly or extremely familiar with the song. Respondents with fewer than 5 of the 9 trials completed were excluded. As a result, three participants were removed from the analysis of the aggregated test scores.

An Initial Analysis of Aggregate Scores Using Multiple Regression

Three dependent variables were derived from the data by computing the proportions of correct responses across trials for each

participant with respect to their timing as well as their pitch responses: VMI *pitch score* (correct answers of pitch responses only), VMI *timing score* (correct answers of timing responses only), and VMI overall score (i.e., correct answers for both pitch and timing in the same trial). Scores on these three variables have a theoretical range from 0 to 1.

Participants were more accurate in their pitch responses ($M = 0.673$, $SD = 0.264$) than in their timing responses ($M = 0.434$, $SD = 0.186$). Because the overall score represented observations where both responses were correct, this variable yielded the lowest average score ($M = 0.306$, $SD = 0.220$). Taken together, all three accuracy scores were significantly different from chance level according to a binomial test ($p < .001$). Chance levels were 0.333 for the VMI pitch and the timing scores and 0.111 for VMI overall score.

In the main part of the analysis, we used six predictor variables, four relating to musical activity (current amount of attentive listening, self-rated musicianship, self-rated singing ability, and self-rated practice time) and two relating to INMI extent (INMI frequency and INMI length). These six predictor variables were entered in three multiple regression models, one for each dependent variable. Only the model for VMI *pitch score* was significant. The effect size of this model was reasonable, as indicated by the amount of the variance explained (adjusted $R^2 = .158$). Table 2 shows self-rated practice time was the only significant predictor for VMI *pitch score*. The models for VMI *timing score* and the VMI overall score were not significant and explained little variance in the dependent variables (adjusted $R^2 < .08$). Neither the predictor variables in the timing model nor the overall model reached significance.

In summary, the results indicate that being a practicing musician was the only significant predictor for accuracy in VMI ability, and this association only applied to the pitch task. Musicianship had no association with performance on the VMI timing task or the overall score. Finally, the extent of INMI experienced in daily life had no influence on any of the VMI ability scores, neither in terms of INMI frequency nor length.

Modeling Individual Trial Responses With Classification Trees

In a second analysis stage, we assessed the effects of the experimental conditions (i.e., whether the music came back in early/on time/late and flat/same pitch/sharp) and possible interactions with levels of musical practice and INMI activity levels. This analysis, conducted at the level of individual trials, allowed us to take into account the familiarity ratings for each song.

In total, there were 587 responses from the 67 participants (16 responses were removed due to individual cases of low song familiarity). Table 3 gives the distribution of responses given by all participants and across all conditions. All experimental conditions were presented equally often across participants; therefore, the distribution of responses indicates a clear bias to respond “same pitch” (unaltered) combined with a lesser bias to respond “late timing.”

We ran two separate analysis models on the participants’ responses, one with pitch and one with timing judgments as the dependent variable. The six predictor variables were used to assess the impact of musical practice and INMI activity levels on both

Table 2
Parameter Estimates and p Values for the Six Predictor Variables Entered Into the Three Multiple Regression Models With VMI Pitch Score, VMI Timing Score, and VMI Overall Score as Dependent Variables

Model predictor	Parameter estimate	95% Confidence intervals		<i>t</i> Value	<i>p</i> Value
		Lower	Upper		
Pitch score					
Intercept	0.201	-0.306	0.708	0.797	.429
Singing ability	0.067	-0.014	0.148	1.671	.101
Musicianship	-0.0002	-0.064	0.064	-0.008	.994
Attentive listening	0.019	-0.027	0.066	0.863	.393
Time practiced past	0.066	0.005	0.128	2.167	.035
INMI frequency	0.006	-0.065	0.078	0.190	.850
INMI length	-0.014	-0.084	0.055	-0.422	.675
Model fit:	Adj. $R^2 = .158$, $F_{(6,47)} = 2.653$, $p = .027$				
Timing score					
Intercept	0.397	0.005	0.788	2.038	.047
Singing ability	0.012	-0.051	0.074	0.375	.709
Musicianship	0.042	-0.007	0.092	1.719	.092
Attentive listening	-0.017	-0.053	0.019	-0.946	.349
Time practiced past	0.004	-0.044	0.051	0.160	.874
INMI frequency	-0.014	-0.069	0.041	-0.507	.615
INMI length	-0.020	-0.074	0.033	-0.765	.448
Model fit:	Adj. $R^2 = -.007$, $F_{(6,47)} = 1.065$, $p = .397$				
Overall score					
Intercept	0.067	-0.375	0.509	0.305	.761
Singing ability	0.046	-0.024	0.117	1.328	.190
Musicianship	0.038	-0.018	0.094	1.377	.175
Attentive listening	-0.001	-0.042	0.039	-0.074	.941
Time practiced past	0.017	-0.036	0.071	0.655	.515
INMI frequency	-0.019	-0.081	0.043	-0.611	.544
INMI length	-0.018	-0.078	0.042	-0.594	.555
Model fit:	Adj. $R^2 = .074$, $F_{(6,47)} = 1.705$, $p = .141$				

Note. VMI = voluntary musical imagery; INMI = involuntary musical imagery.

outcomes. In addition, participants' subjective song familiarity ratings and the experimental conditions (pitch and timing) for each trial were added as predictors into the model.

We expected to find high order interactions between variables; therefore, we did not use linear regression models. Such models are not well-suited to the task of detecting higher order interactions between predictor variables. Instead we opted for classification tree models, which are an established tool for the identification of significant interactions (Breiman, Friedman, Olshen, & Stone, 1984; Müllensiefen, 2009; Strobl, Malley, & Tutz, 2009). Tree

models also lend themselves to a graphical interpretation and understanding of the data. We used a family of tree models called conditional inference trees, which combine the rigorous theory of permutation statistics (Hothorn, Hornik, & Zeileis, 2006) with the principle of recursive partitioning (Hothorn, Hornik, & Zeileis, 2008). We used the software package "party," implemented in the free software environment R. The tree model for the pitch data is given in Figure 1.

The model in Figure 1 has a classification accuracy of 72.2%, which is significantly higher ($p < .001$ on a binomial test) than the accuracy expected from a random model (33.3%) and also higher than the accuracy of a model that classifies all observations to the largest response class ("unaltered pitch" responses; 55.9%; $p < .001$ on a binomial test).

The pitch tree model only made use of the experimental conditions, self-rated practice time, and self-rated singing ability as predictor variables. For each node of the tree, the p values indicating the significance of the split are given, as well as a description of the two "children" (i.e., subgroups) of the split on the independent variable. For the terminal nodes (i.e., nodes that are not split any further), the distribution of responses is shown in a bar graph with the categories "flat," "unaltered pitch," and "sharp" responses indicated on the x -axis.

Table 3
Percentages of VMI Pitch and Timing Responses by Response Category (N = 587 Observations)

	Pitch responses	
-1 (flat pitch) 21.1	0 (unaltered pitch) 55.9	1 (sharp pitch) 23.0
	Timing responses	
-1 (early timing) 29.0	0 (unaltered timing) 31.3	1 (late timing) 39.7

Note. VMI = voluntary musical imagery.

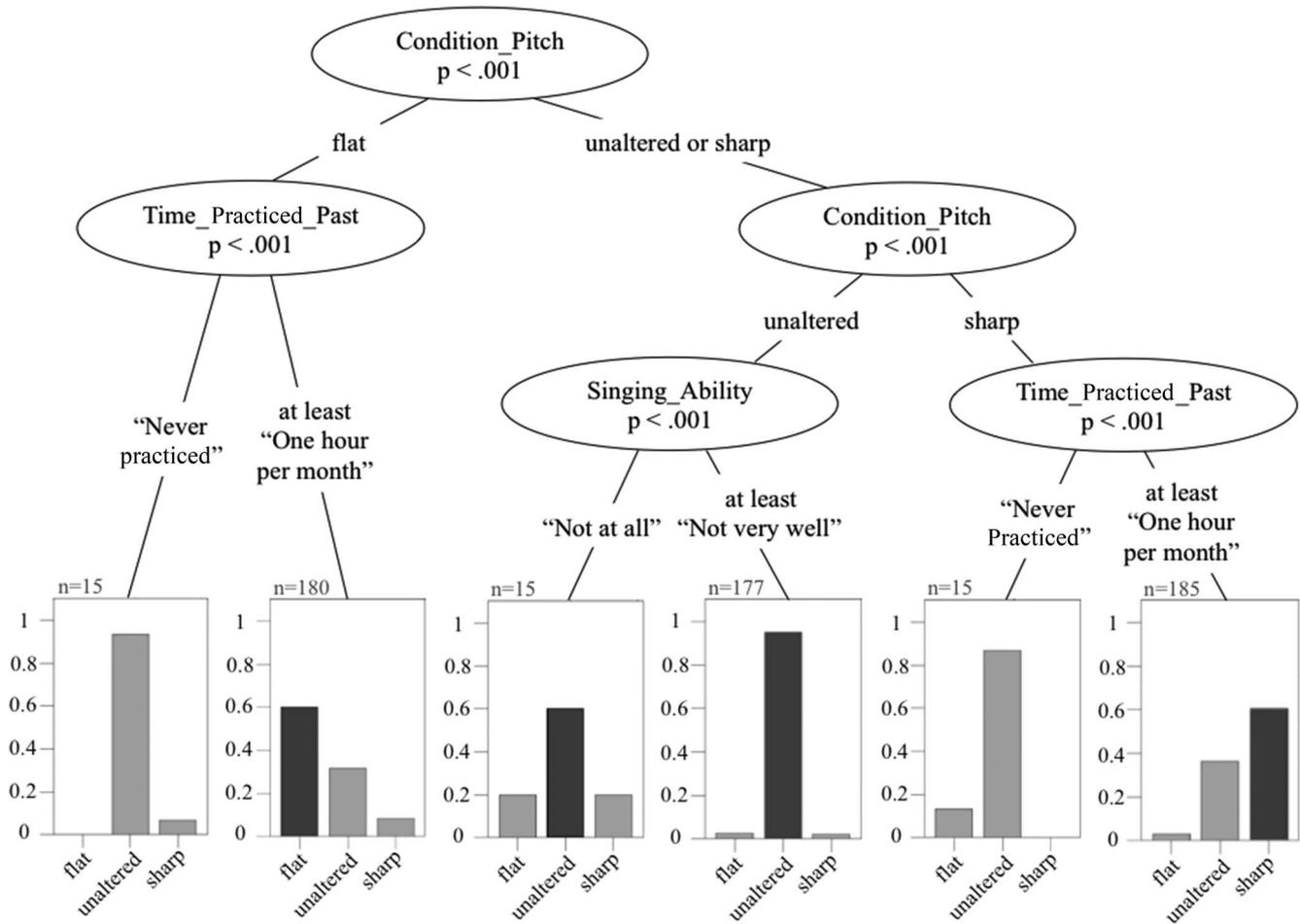


Figure 1. Classification tree model of the pitch responses ($N = 587$). The bar plots in the terminal nodes of the tree represent the distribution of responses for the three different response categories “flat,” “unaltered pitch,” and “sharp.” The correct response is indicated by the dark gray bar in each of the barplots, that is, the light gray bars indicate the relative amount of incorrect responses. See in-text description for an interpretation of the model.

The tree model can be interpreted by starting at the top and following each branch down, to arrive at a final node containing the distribution of responses. For example, follow the first “condition-pitch” node down the “flat” branch (left side of the model), which descends to the left at the “time practiced past” node down the “Never practiced” branch. This branch can be interpreted as follows: when the music is flat and the participant has never practiced an instrument then the response is very likely to be “unaltered pitch.” However, when presented with a flat trial a participant with musical expertise (the right branch labeled “at least one hour per month”) will have a much higher chance of correctly responding “flat.”

Going down the right branch of the top node, the experimental conditions “unaltered pitch” and “sharp pitch” are distinguished. In “unaltered pitch” trials, participants with a higher self-rated singing ability identify the unaltered pitch correctly in almost all instances whereas participants with lower self-rated singing abilities are more likely to incorrectly respond “flat” or “sharp.” For experimental trials where the music returns one semitone sharp (right-most branch), the participants with musical experience have a much higher chance of responding “sharp” correctly.

Taken together, the model shows the strong bias for musically untrained participants to respond “unaltered pitch” regardless of the experimental trial, while participants with a minimum of musical training and practice are more able to identify sharp and flat trials correctly on the basis of their VMI. Note that the tree model for pitch responses only reflects interactions between experimental conditions, self-rated singing ability, and the amount of time practiced in the past: no interaction was found with INMI experience, amount of active musical listening, song familiarity, or the experimental timing condition.

A second tree model was created for the VMI timing responses and can be seen in Figure 2. The model has a classification accuracy of 44.4%, which is lower than the pitch tree model but again is significantly higher than the accuracy expected from a random model (33.3%: $p < .001$, binomial test) and the accuracy of a model classifying all observations to the largest response class (“unaltered timing” responses; 39.7%; $p < .011$ on a binomial test). The timing tree model only made use of the experimental timing condition and the participant’s subjective familiarity with the song.

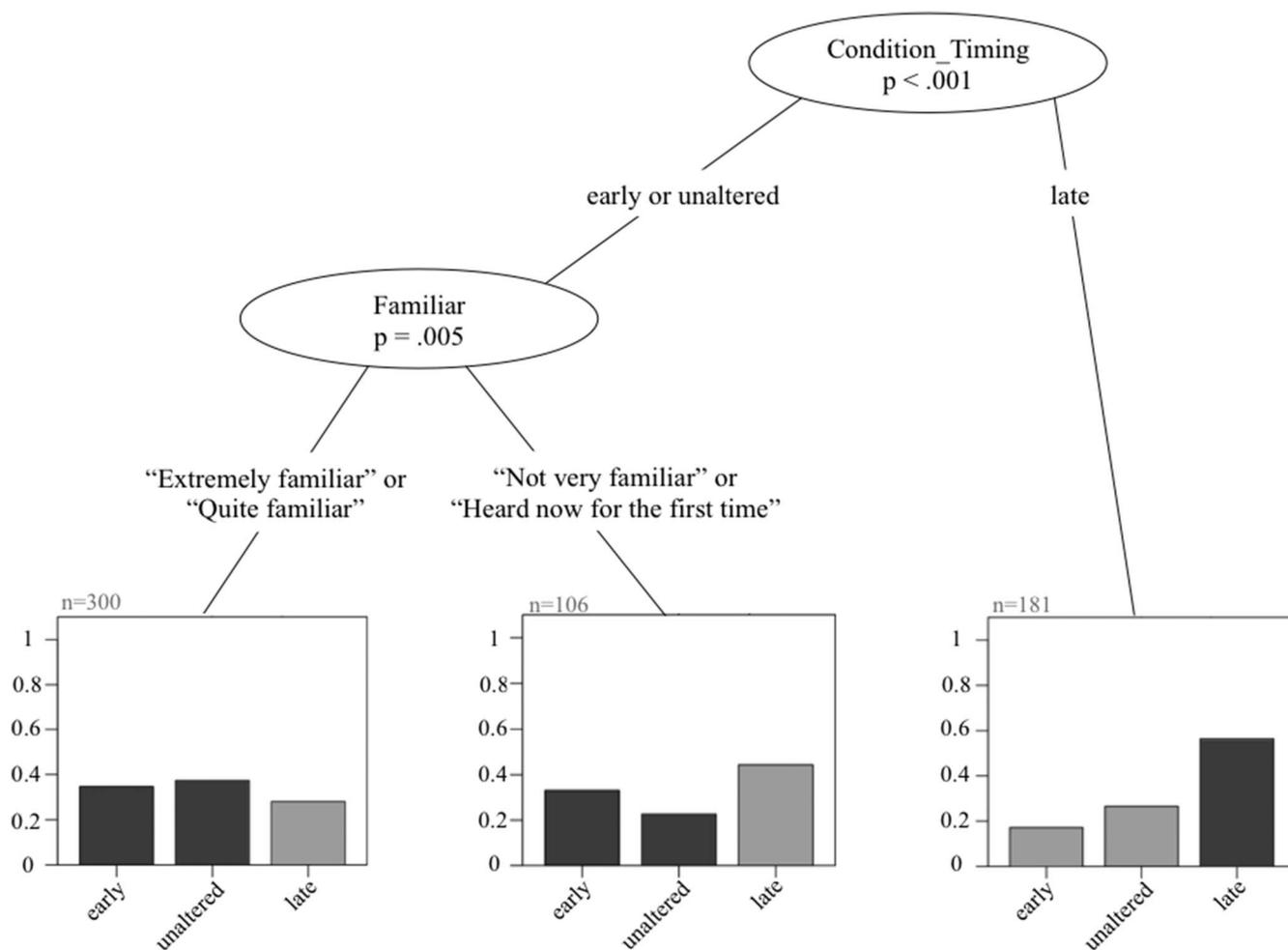


Figure 2. Classification tree model of the timing responses ($N = 587$). The bar plots in the terminal nodes of the tree represent the distribution of responses for the three different response categories “early,” “unaltered timing,” and “late.” See in-text description for an interpretation of the model.

The model in Figure 2 shows that the majority of participants tend to identify late trials correctly (the right-most branch). However, for trials where the music comes in early or at the unaltered timing (the left branch), the response is modulated by the degree of song familiarity. The timing of songs that were not very familiar or heard for the first time tended to be classified as late, while for songs that were extremely or at least quite familiar the response categories were more evenly distributed, with “late” responses being less common. Note that this finding applies regardless of whether the experimental condition was “early” or “unaltered timing.” The tendency to incorrectly respond “late” can therefore be regarded as a bias that is introduced by unfamiliarity with the stimulus.

Discussion

This study explored VMI ability and its potential relations to an individual’s level of musical training and practice experience or their regular experience of INMI. We predicted an association

between musical expertise and VMI accuracy (Aleman et al., 2000; Bishop, Bailes, & Dean, 2013), and further hypothesized that a similar improvement in VMI ability may be found in people who experience extreme INMI, due to the common underlying factor of musical imagery repetition in memory.

Accuracy of pitch and timing VMI judgments were tested in a realistic, online pop music listening paradigm. The paradigm assumes that participants use their memory for the song tested to perform the mental imagery task. We found evidence for this assumption from a significant association between song familiarity and accuracy, indicating that participants made use of musical memory when performing the experimental task.

In terms of the main hypotheses we found that, musical practice was positively related to VMI pitch ability, as was expected. This finding is consistent with the VMI pitch results found by Aleman et al. (2000) and is aligned with the findings of increased VMI loudness accuracy in experts reported by Bishop et al., (2013). The present study also extends the work by Aleman et al. (2000) to include a real time VMI pitch

listening task, inspired by the studies of Bailes and Bigand (2004) and Kraemer et al. (2005).

This main result implies that the new online VMI paradigm was sensitive enough to detect the expected group expertise effect in VMI ability. Using this same paradigm, we found no evidence that people with extreme INMI possessed more accurate VMI pitch ability compared with those with much less extreme INMI experiences. Therefore, we find no evidence to support the theory that increased involuntary mental repetition of musical imagery in general drives an improvement in VMI ability.

The follow-up analysis of participants' responses at the trial level (tree models) revealed information about the ways musicians outperformed nonmusicians on the VMI pitch task. Participants with no musical training showed a strong bias to respond "unaltered pitch" in all conditions. By comparison, participants with musical practice experience made more appropriate distinctions between flat, sharp, and unaltered pitch levels. Again, this result confirms the findings reported by Aleman et al. (2000) and Bishop et al., (2013) regarding an association between VMI accuracy and musical expertise, but also provides the insight that nonmusicians make more mistakes in a VMI task, as they are unable to confirm when a pitch shift has occurred.

When interpreting the failure of nonmusicians to detect pitch modifications in the VMI task, it is worth noting that the VMI pitch task comprises at least two separate components; the ability to imagine the continuation of the song, drawing on memory resources, as well as a mental comparison between the imagined and heard pitch. From the present data it is not possible to infer whether it is the imagination, memory, or the comparison component or another factor that is associated with poorer performance in nonmusicians compared with musicians.

In addition to musical practice, self-rated singing ability was associated with improved performance on the VMI pitch task, specifically to an increased ability to identify "correct" pitch trials. Singing is a voluntary musical production activity that is closely related to the corresponding VMI and which need not relate to musical practice in a formal sense (Halpern, 1989; Zatorre & Halpern, 2005; Zatorre et al., 2010). The positive association between singing and performance on the present VMI pitch task corroborates this relationship.

The present study did not identify any variables associated with overall VMI timing accuracy of the participants. VMI timing performance was worse than that on the VMI pitch task. These findings are consistent with Janata and Paroo (2006), who suggested that temporal images are more susceptible to distortion than pitch images, and with the finding that the neural substrates differ for temporal and pitch judgments (Hyde & Peretz, 2004). However, it is worth noting that we are not able to claim that the timing manipulation in the present paradigm (time shift by 2 beats) is of equivalent difficulty level to the pitch manipulation (pitch shift by 1 semitone). For a follow-up experiment, it would be useful to equate difficulty levels for both response tasks in a prior calibration experiment, using an item response approach (de Ayala, 2009).

The tree model on the VMI timing data at trial level confirmed that neither musical practice nor singing ability, nor any other indicator of musical activity, had any impact on performance on the timing task. This result is somewhat contrary to findings in the beat perception literature, where a positive relationship has been

noted between musical expertise and beat perception abilities (Repp, 2010). However, the present VMI timing task is of a different nature to the beat perception tasks used in previous studies. Hence, studies that compare individual differences on comparable timing and beat perception tasks, with and without imagery components, would be necessary to identify where the timing advantages of musical expertise are to be located.

Overall, the present study offers no evidence for the hypothesis that musical practice activity and INMI have a similar "training" effect on VMI ability by virtue of increasing the repetition of musical imagery in memory. This conclusion does not rule out the possibility that individual differences in INMI experiences may relate to differences in musical memory. Research has established that musicians have a superior memory for many aspects of musical sounds compared with nonmusicians (for reviews see Schulze & Koelsch, 2012; Williamson, Baddeley & Hitch, 2010). Therefore, improved musical memory could be one factor that drives the positive association between musical practice and VMI pitch ability in musicians. Future research investigating the relationship between INMI and memory could test whether people who experience extreme INMI (regardless of musical background) have a better short-term or long-term memory for music, either familiar or novel, compared with people who rarely experience INMI.

One limitation of the present study is the difficulty of assessing the extent of musical activity and INMI that participants experience. The present study utilized questionnaires that were available at the time of testing. An improved approach for the future would be to use new, valid and reliable self-report instruments (e.g., the Gold-MSI, Müllensiefen, Gingras, Musil, & Stewart, 2014 and the IMIS, Floridou, Williamson, Stewart, & Müllensiefen, this issue) to obtain more precise measures of musical engagement and quantifiable aspects of INMI experiences. Another concern with INMI measurement in the present study is the reliance on recent reports of activity compared with lifetime assessment of experiences. Future studies could aim for increased control across the conditions by using INMI report methods akin to those employed in music expertise research, such as asking participants to report on long-term patterns of INMI activity, or testing VMI ability at different life stages (for a review see Strait & Kraus, 2014).

In summary, the present study comprised a new experimental paradigm that examined VMI pitch and timing abilities using highly familiar pop music. We found no differences in VMI ability in pitch or timing between people that experience extreme INMI and people that experience infrequent, short INMI. Our conclusion is that while active musical practice is related to improved VMI pitch ability, extreme INMI is not.

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Appendix

Musical Stimuli Used in the Experiment

Table A1
Songs Used in Imagery Experiment, With Edit Times

Song title	Artist	Start (s)	Dropout (s)	Return (s)	End (s)
Hound Dog	Elvis Presley	0	19.5	28.4	37.8
I Wanna Hold Your Hand	The Beatles	0	11.4	19.0	30.8
I'm a Believer	The Monkees	4.8	17.1	27.3	35.8
Kung Fu Fighting	Carl Douglas	49.9	70.7	81.5	89.6
What a Wonderful World	Louis Armstrong	22.7	57.4	68.6	76.8
Beat It	Michael Jackson	14.4	31.7	41.2	48.4
Baby One More Time	Britney Spears	20.5	58.0	70.5	84.1
Hey Ya	Outkast	0	26.2	34.4	46.8
I Gotta Feeling	Black Eyed Peas	15.2	33.4	44.8	56.4

Received June 16, 2014

Revision received March 9, 2015

Accepted March 14, 2015 ■