The Idiosyncrasy of Involuntary Musical Imagery Repetition (IMIR) Experiences: The Role of Tempo and Lyrics

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Abstract

Involuntary musical imagery repetition (IMIR), colloquially known as “earworms,” is a form of musical imagery that arises involuntarily and repeatedly in the mind. A growing number of studies, based on retrospective reports, suggest that IMIR experiences are associated with certain musical features, such as fast tempo and the presence of lyrics, and with individual differences in music-related training and engagement. However, research to date has not directly assessed the effect of such musical features on IMIR and findings about individual differences in music-related training and engagement are mixed. Using a cross-sectional design (Study 1, *n* = 263), we examined IMIR content in terms of tempo (fast, slow) and presence of lyrics (instrumental, vocal), and IMIR characteristics (frequency, duration of episode and section) in relation to 1) the musical content (tempo and lyrics) individuals most commonly expose themselves to (music-listening habits), and 2) music-related training and engagement. We also used an experimental design (Study 2, *n* = 80) to test the effects of tempo (fast or slow) and the presence of lyrics (instrumental or vocal) on IMIR retrieval and duration. Results from Study 1 showed that the content of music that individuals are typically exposed to with regard to tempo and lyrics predicted and resembled their IMIR content, and that music-related engagement, but not music training, predicted IMIR frequency. Music training was, however, shown to predict the duration of IMIR episodes. In the experiment (Study 2), tempo did not predict IMIR retrieval, but the presence of lyrics influenced IMIR duration. Taken together, our findings suggest that IMIR is an idiosyncratic experience primed by the music-listening habits and music-related engagement of the individual.

Key words: involuntary musical imagery repetition, “earworms,” tempo, lyrics, involuntary memory

The human mind generates countless thoughts every day. Many of these thoughts are formed voluntarily when we intentionally choose to think of a specific event in the past or the future. However, a large proportion of thoughts emerge involuntarily in the mind (McVay, Kane, & Kwapil, 2009; Song & Wang, 2012). Musical imagery, the ability to imagine a melody or song (Weber & Brown, 1986), is a ubiquitous example of a thought that can be retrieved voluntarily or involuntarily (Beaty et al., 2013). When research in the field began, there was a focus on voluntarily retrieved musical imagery studied under controlled experimental conditions in the laboratory (Halpern, 1988; Hubbard & Stoeckig, 1988). Advancements in naturalistic probe and self-caught experience sampling methods have since led to increased study of both voluntary and involuntary musical imagery as they are retrieved (i.e., occur) in everyday life (Bailes, 2006; 2007; Beaty et al., 2013; Cotter & Silvia, 2017; Jakubowski et al., 2018). Lately, the main focus of research has been on involuntarily retrieved musical imagery forms (Liikkanen & Jakubowski, 2020; Wammes & Barušs, 2009). These are similar to other cognitive forms such as involuntary autobiographical memories (Vannucci et al., 2019) that are proposed to be universal, frequent, and a basic mode of remembering, rather than an indication of pathology (Berntsen, 2010).

The term *involuntary musical imagery* (INMI) was first introduced to refer to so-called “earworms” and was defined as any musical imagery that is retrieved involuntarily and repeatedly in the mind (Liikkanen, 2008). However, Williams (2015) suggested that the term INMI should embody a multitude of typical and nonpathological involuntary musical imagery forms (Williams, 2015), such as *musical mind-pops,* which are one-off occurrences, (Kvavilashvili & Anthony, 2012), *earworms*, which are repetitive (Liikkanen, 2012), and, lastly, atypical and pathological musical imagery forms, such as *musical obsessions* (Taylor et al., 2014) and *hallucinations* (Kumar et al., 2014). As research on the topic grows, there is a need to be extremely clear on the experiences being studied. We therefore propose the use of the term *involuntary musical imagery repetition* (IMIR) in the scientific literature instead of INMI and earworms, since INMI is now used as an overarching concept (Williams, 2015) and lacks specificity, and earworms is both too colloquial and carries negative connotations. IMIR takes into account and highlights the involuntary and the repetitive nature of this form of typical and nonpathological musical imagery. It is an amalgamation of previous efforts to establish a new term (Floridou, 2011, 2016) and is intended to reduce biases, being modeled on data that indicate that the experience is mostly neutral and often pleasant (Beaman & Williams, 2010; Halpern & Bartlett, 2011; Floridou & Müllensiefen, 2015; Liikkanen, 2012; Williamson & Jilka, 2014). IMIR is used to describe typical and nonpathological musical imagery that is retrieved spontaneously and repeatedly, and that occurs offline (i.e., in the absence of the corresponding musical stimulus).

The most commonly studied characteristics of IMIR are frequency (i.e., how often it is retrieved in a given period) and duration (of the episode and the section). IMIR is a regular experience for the majority of the population, with over 90% of individuals reporting experiencing it at least once a week (in fact many report IMIR several times a week or even daily), and with episodes lasting for up to hours (Beaman & Williams, 2010; Halpern & Bartlett, 2011; Liikkanen, 2012). Research has shown that the most frequently reported section of music experienced as IMIR is the chorus or refrain of popular music pieces (Beaman & Williams, 2010; Liikkanen, 2012), and that the typical contents of IMIR music are lyrics, instrumentation, isolated melodies, and rhythms (Floridou et al., 2015).

The IMIR experience can be conceptualized as an interplay between musical features, individual traits, and context. However, IMIR research to date has tended to focus on individual differences in personality traits (Beaman & Williams, 2013; Cotter & Silvia, 2017;

Floridou et al., 2012), and music-related training and engagement (Beaman & Williams, 2010; Floridou et al., 2015). Research on the role of context in IMIR retrieval shows that the most common and effective cues that trigger IMIR are recent and repeated exposure to the music, although nonmusical cues, such as words and images (Williamson et al., 2012), and undertaking activities that require low cognitive load (Floridou et al., 2017; Hyman et al., 2013), can also influence IMIR retrieval. Finally, one of the most popular questions about IMIR, that remains largely unexplored, relates to the musical features that act as cues, and that influence the likelihood of a particular musical piece being retrieved involuntarily and repeatedly in the mind. The present research examines some of these previously underexplored factors by investigating the musical features, individual traits, and context that influence IMIR.

IMIR and Musical Features: Tempo

Only a handful of studies have explored the musical features of IMIR. Williamson and Müllensiefen (2012) used a database and selected pieces that were named as IMIR in an online survey and compared them with non-IMIR pieces (that were not reported as IMIR in the survey) matched in genre, artist, and chart ranks with the aid of a computational tool for extracting melodic features (FANTASTIC: Feature ANalysis Technology Accessing STastistics; Müllensiefen, 2009). The authors employed a binary logistic regression model to explain the classification of IMIR pieces (compared to non-IMIR pieces). The model included melodic structural features such as rhythm, pitch, melodic contour, intervals, and repetition as the predictor variables. The music most commonly reported as IMIR was characterized by two particular melodic features compared to non-IMIR pieces; namely, smaller pitch intervals and relatively longer note durations. An explanation put forward by the authors was that these melodic characteristics might make pieces easier to sing along with. Interestingly, this interpretation was in line with their additional finding from retrospective report data showing that both singing abilities, and frequency of singing along with pieces, correlated mildly with increased IMIR frequency and duration.

With the same software but more powerful statistical modeling techniques, Jakubowski et al. (2017) used a dataset of 202 songs (named as IMIR in an online survey by a sample of 3,000 participants) to determine the extent to which melodic features and context (i.e., the popularity of the song) predicted the likelihood of IMIR retrieval. They found that IMIR music content had melodic contours that were more common globally: the manner in which the pitches rose and fell, the intervallic jumps, and the melodic turning points[1] were similar to patterns found in popular songs in the charts. Further, while only at a trend significance level, IMIR content generally contained faster tempi: an average of 124.10 beats per minute (bpm) compared to non-IMIR pieces, which had an average of 115.79 bpm. The researchers suggested a possible relation of fast tempo to sensorimotor and entrainment processes since it has also been reported that IMIR retrieval is associated with repetitive movement, such as walking (Jakubowski et al., 2015). An additional finding pointing to the importance of the context, rather than the music per se, was that the pieces experienced as IMIR were ranked higher and remained longer in the UK Music Charts. This implies that the music that participants had high exposure to was very likely to be retrieved as IMIR.

In contrast to the above study, which used retrospective trait-level IMIR reports to explore tempo, other studies (Jakubowski et al., 2015; Jakubowski et al., 2018) have used experience sampling methods to investigate state-level IMIR. Participants wore wrist

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[1] Melodic turning points were measured by examining the gradient of melodic lines and calculating how quickly and how far pitches in the melody ascended or descended. Pieces with more common melodic contour shapes (and thus more likely to become IMIR) had pitches that moved stepwise or repeated the same notes.

accelerometers and tapped on them the beat of any IMIR that occurred. In Jakubowski et al. (2015), IMIR tempo ranged from 42 bpm to 196.5 bpm between participants, the mean tempo being 100.9 bpm, while in Jakubowski et al. (2018) tempo ranged from around 50 bpm to approximately 200 bpm, with a mean of 98.36 bpm. Interestingly, IMIR tempo in these studies had a greater range and lower mean of bpm in comparison to the study relying on retrospective reports (Jakubowski et al., 2017). However, the difference in the methods used for the studies may explain this discrepancy: in the study that used computational modeling techniques and retrospective trait-level IMIR reports, the identification and quantification of the beat was derived from the actual piece itself (Jakubowski et al., 2017), while in the experience sampling method studies participants enacted the beat the moment IMIR was retrieved (Jakubowski et al., 2015; Jakubowski et al., 2018). Thus, the discrepancy might reflect inconsistencies in how the beat was estimated. Furthermore, the difference in the results of the two studies could also reflect an incongruity between what participants report as the cue of their IMIR and the content of the subsequent IMIR (seen for other involuntarily retrieved cognitive forms, Berntsen, 1996, 2001; Berntsen & Hall, 2004).

Taken together, the studies above provide some initial evidence of an association between faster tempo and IMIR. Yet, it remains unclear if the faster tempo seen for pieces reported as IMIR is due to the individuals' exposure to music with faster tempo (as reflected in their individual music-listening habits and their subsequent IMIR), or to a particular effectiveness of this specific musical feature as an IMIR cue. On the one hand, priming has been proposed as a cognitive process that is potentially responsible for the retrieval of other involuntary cognition forms, such as autobiographical and semantic memories (Kvavilashvili & Mandler, 2004; Mace, 2005). Effects of recent and repeated exposure to music (repetition priming) are well documented in IMIR research (Byron & Fowles, 2015; Hyman et al., 2013;

Liikkanen, 2012; Williamson et al., 2012). Similarly to involuntary autobiographical and semantic memories (Kvavilashvili & Mandler, 2004; Mace, 2005), the retrieval and content of IMIR is not random, but is related to, or primed by, recent music exposure. This is in line with evidence that the most common cues that trigger IMIR are recent and repeated exposure to music (Floridou & Müllensiefen, 2015; Jakubowski et al., 2017; Williamson et al., 2012). Furthermore, research on the recency effect in relation to IMIR may offer further insights. There it has been demonstrated that, when exposed to several pieces, there is a higher likelihood for the last piece heard to prime IMIR (Floridou et al., 2012; Floridou et al., 2017; Likkanen, 2012). Findings that the repertoire of the music retrieved as IMIR is extremely variable and that there is little convergence between or within individuals regarding the pieces they report as IMIR (Beaman & Williams, 2010, Halpern & Bartlett, 2011, Jakubowski et al., 2015; Likkanen, 2012, Williamson et al., 2012) beg the question of the precise role that music-listening habits and priming play, as well as the extent to which specific tempo is an effective cue. To clarify this role, the current research both explored whether tempo of the content of music individuals are most commonly exposed to (music-listening habits) is reflected in their IMIR content, and experimentally manipulated tempo to test the extent to which it acts as an effective cue in IMIR retrieval.

IMIR and Musical Features: Lyrics

The presence of lyrics in IMIR has been another key area of interest in the field. While Sacks (2007) claimed: "it seems to make little difference whether catchy songs have lyrics or not" (p. 44) in the IMIR chapter of his book, *Musicophilia*, subsequent studies using retrospective surveys and behavioral measures have shown that pieces experienced as IMIR tend to have lyrics. Halpern and Bartlett (2011) and Liikkanen (2012) found that 83% and

91% of participants tested, respectively, reported IMIR for pieces that contained lyrics. Although they did not directly manipulate the presence of lyrics, Floridou et al. (2017) reported that, between two film trailers with prominent soundtracks that were used to experimentally induce IMIR, a vocal piece with lyrics was twice as likely as an instrumental one to be retrieved as IMIR. Analogously to tempo, there are at least two explanations for the fact that the content of music reported as IMIR typically has lyrics: namely, that these reflect the music-listening habits of the individuals tested, and therefore priming effects, or that the presence of lyrics is, in itself, an effective cue to prime IMIR. On the one hand, the majority of popular pieces in the charts contain lyrics, speaking to the possibility of a priming effect. On the other hand, when lyrics are added to melodies, they are voluntarily retrieved more effectively than when heard separately from the melody since learning memory for one enhances memory for the other, especially in expert singers (Ginsborg & Sloboda, 2007), speaking to the possibility of lyrics as an effective IMIR cue. Furthermore, lyrics might increase sing-along behaviors and, as noted earlier, singing (frequency of singing along with pieces and self-report singing abilities) is linked with increased IMIR frequency and duration (Williamson & Müllensiefen, 2012). To allow us to draw firmer conclusions on the influence of the presence of lyrics on IMIR, our research 1) investigated whether the extent to which lyrics are present in the content of the music that individuals listen to (music-listening habits) is reflected in IMIR content, and 2) experimentally tested the effectiveness of the presence of lyrics as a cue for IMIR retrieval.

IMIR and Individual Differences in Music-Related Training and Engagement

One of the first questions in IMIR research was about the traits of individuals who frequently experience this form of imagery (Kellaris, 2001). The most commonly studied of such individual traits are demographic factors such as age and sex (Beaman & Williams, 2010; Liikkanen 2012), and personality traits and thought processes such as neuroticism and mind-wandering (Floridou et al., 2012; Floridou et al., 2015). However, much research has focused additionally on the relation between IMIR and music-related training and engagement.

Individual differences in the amount of formal music training that someone has received throughout their lifetime, and how much they informally engage with music in daily life (e.g., how much they listen to music, go to gigs and concerts, and write about music in blogs), have been found to be related to IMIR characteristics (Floridou et al., 2012; Liikkanen 2012; Müllensiefen et al., 2014). Yet, the findings are equivocal. Some studies show an association between IMIR frequency and duration, and both music training and engagement with music (Floridou et al., 2015; Liikkanen, 2012), while others suggest an exclusive link with active engagement with music (Beaman & Williams, 2010; Floridou et al., 2012; McCullough Campbell & Margulis, 2015; Müllensiefen et al., 2014) or music training (Hyman et al., 2013). Such previous studies have used a variety of different definitions and criteria for IMIR, music training, and active music engagement, as well as varied measurement instruments and statistical analyses. Therefore, the results are largely noncomparable and more systematic research is needed.

A pertinent question is whether those with more music training might experience IMIR content that is instrumental. Interestingly, it has been shown that musicians, despite not experiencing IMIR more frequently than nonmusicians, report a larger proportion of IMIR with instrumental music content (Liikkanen, 2012; Williamson & Jilka, 2014). Furthermore, individuals with the highest levels of music training are more likely to experience instrumental IMIR with complex imagery (such as symphonies) than are individuals with less music training (Williamson & Jilka, 2014). That such differences are driven by the relatively higher percentage of instrumental music that musicians are frequently exposed to (compared to nonmusicians) would be consistent with a key role of priming in IMIR retrieval. Further research is necessary to replicate and clarify the relation between IMIR and music-related training and engagement. Such research would shed more light on the role of priming in the music listened to as part of music training or recreationally. Furthermore, the IMIR related findings of such research have the potential to reveal any nuanced differences between music-related training and engagement in terms of the sensory, cognitive, and practice and learning effects that may be specific to the former.

The Present Research

The first aim of the current research was to examine the relation between characteristics of IMIR and the musical features of tempo and lyrics as reflected in (a) individual music-listening habits, and (b) a given musical piece itself. A second aim was to investigate further a previously reported relation between IMIR and music-related training and engagement. We set out to address these aims with two studies: the first study was an online survey with retrospective trait-level self-reports that used a large sample to investigate tempo and lyrics in the content of IMIR in relation to the music content individuals are most commonly exposed to (music-listening habits), and IMIR characteristics in relation to their music-related training and engagement. The second study was a behavioral experiment in the laboratory with state-level self-reports where we directly manipulated the tempo and presence of lyrics in a musical piece as cues on IMIR retrieval and duration.

Our studies sought to increase understanding of the priming and retrieval processes of IMIR specifically, but also involuntary memory more generally. Furthermore, our research has implications with regard to the use of music as a mnemonic tool that can use specific features to enable encoding and facilitate retrieval of information: for example, in educational settings (e.g., songs for introductory statistics, Lesser et al., 2019), when learning languages (Kang & Williamson, 2014), as well as in the music industry where artists and advertisers are often seeking to make their music and thus products memorable (subsequently increasing their sales). Finally, this research has value for informing future IMIR studies with respect to the suitability of musical stimuli used as cues for effective IMIR priming and retrieval.

Study 1

In Study 1, we investigated individual differences in the music content individuals are most frequently exposed to (music-listening habits) and IMIR content in terms of tempo and lyrics, IMIR characteristics (i.e., frequency and duration), and levels of music-related training and active engagement. We developed custom items measuring the frequency of exposure to music and experiencing IMIR with specific content (fast or slow tempo, and instrumental or vocal music). Further, we used psychometrically validated retrospective questionnaires to probe IMIR characteristics (the Involuntary Musical Imagery Scale; Floridou et al., 2015) and music training and engagement (the Goldsmiths Musical Sophistication Index - GMSI; Müllensiefen et al., 2014). In this way, we sought to determine if (a) the frequency of exposure to certain music content, and (b) the type and extent of music-related training and engagement can predict IMIR content and characteristics respectively: questions that speak directly to whether priming plays a role in the retrieval of IMIR.

We hypothesized that the content of the music that individuals are exposed to, in terms of tempo and lyrics, will predict the content of IMIR retrieved more frequently: that is, the content of music that people listen to more frequently in terms of tempo and lyrics will predict the content of their most frequently experienced IMIR in terms of tempo and lyrics (Hypothesis Group 1). Furthermore, we predicted that individuals with increased music training and active engagement with music will experience more frequent and longer IMIR (Hypothesis Group 2), and that those with increased music training will report more frequent instrumental IMIR (Hypothesis Group 3).

Method

Participants

Participants were recruited through advertisements on Facebook, email, word of mouth, and a recruiting website (callforparticipants.com). A total of 336 individuals commenced the online survey. We excluded 73 participants based on the key criteria that were set in advance of data collection: 1) survey completion duration (less than one third of the median time to complete the survey; $n = 23$), 2) incorrectly answering the attention filter in the survey ($n = 10$), 3) rating their English language skills as below advanced ($n = 0$), 4) answering "yes" to having current significant hearing loss that causes difficulty in everyday life ($n = 12$), and 5) for not completing each page of the survey ($n = 28$). The final sample that was included in the analysis was 263 participants (191 female, 1 nonbinary, 1 chose not to disclose their gender) ranging in age from 18 to 71 years ($M = 34.27$, $SD = 13.24$). Four participants reported never experiencing IMIR. The sample was primarily from the United States of America (53.60%) and the United Kingdom (22.80%) and represented 34 different nationalities overall. The most frequent participants' highest completed education levels were undergraduate/bachelor's degree (41.10%), postgraduate/master's degree (22.80%), and GCSE/CSE/O-levels/High School/GED equivalent (9.90%). Over 50% of the sample had completed 16 or more years of education. All of the participants were volunteers but were entered in a prize draw to win a £12 Amazon voucher.

Ethics Statement

The study protocol was approved by the Ethics Committee of the Department of Psychology of Goldsmiths, University of London. All participants provided online consent in the form of checkboxes before commencement of the study.

Materials

Demographic information: A demographics section was used to gather information on age, gender, country of nationality, speaking level of English (beginner, advanced, fluent), highest level of schooling completed ("Did not complete GCSE/CSE/O-levels/High School," "Completed GCSE/CSE/O-levels/High School (or GED equivalent)," "Completed post-16 vocational course," "A-levels/Scottish Highers," "Undergraduate Degree/Bachelor's Degree," "Postgraduate Degree/Master's Degree," "Doctoral Degree," "I'm still in education," "None of the above"), years of education (from "less than 6" to "more than 16"), any periods of prolonged or profound hearing difficulty (yes or no), or of experiencing significant hearing loss (yes or no).

Custom IMIR content questions: We developed items to measure the frequency of experiencing IMIR (using the term "earworm" only when providing instructions to participants) content in terms of tempo, ("My earworms are of upbeat, energetic, or fast music" and "My earworms are of slow and relaxing music") and the presence of lyrics ("My earworms contain music that has lyrics" and "My earworms contain music that is instrumental, i.e., there are no words"). We used a 5-point Likert frequency response scale (1 = *Never*, 2 = *Not very often,* 3 = *Sometimes,* 4 = *Most of the time,* 5 = *Always*).

The Involuntary Musical Imagery Scale (IMIS; Floridou et al., 2015) consists of 15 items and measures various IMIR phenomenological characteristics. The factors it measures are: *Negative Valence* (IMIS-NV, α = .91; e.g., "I wish I could stop my earworms"), *Movement* (IMIS–MVMNT, α = .88; e.g., "When I get an earworm I move to the beat of the imagined music"), *Personal Reflections* (IMIS – PR, α = .76; e.g., "Personal issues trigger my earworms"), and *Help* (IMIS–HLP, α = .84; e.g., "I find my earworms help me focus on the task that I'm doing"). The response scale is from 1 (*Never*) to 5 (*Always*). In addition, there are three items, complementary of the scale, which measure 1) frequency ("On average, I experience earworms": response scale from 1 (*Never*) to 6 (*Almost continuously*)), 2) duration of the section ("On average, my earworm (the section of music that is stuck) lasts": response scale from 1 (*Less than 5 seconds*) to 5 (*More than 1 minute*)), and 3) duration of the episode ("On average, one earworm episode (a period of time when one particular piece gets stuck) lasts"; response scale from 1 (*Less than 10 minutes*) to 5 (*More than 3 hours*)).

Custom music content/music-listening habits questions: We developed items to measure the frequency of exposure to music content in terms of tempo ("I listen to music that is upbeat, energetic, or fast" and "I listen to music that is slow and relaxing") and presence of lyrics ("I listen to music that contains lyrics" and "I listen to music that is instrumental, i.e., there are no words"). We used a 5-point Likert frequency response scale (1 = *Never*, 2 = *Not very often,* 3 = *Sometimes,* 4 = *Most of the time,* 5 = *Always*).

The Goldsmiths Musical Sophistication Index (GMSI; Müllensiefen, Gingras, et al., 2014): We used only the factors *Musical Training* (α = .90; e.g., "I would not consider myself a musician") and *Active Engagement* (α = .87; e.g., "I spend a lot of my free time doing music related activities") out of the five factors that GMSI consists of (*Perceptual Abilities, Singing Abilities, Emotional Engagement*). Seven items measure *Musical Training* (e.g., "I have had formal training in music theory for __ years”) and the response scale measures an amount of time (e.g., “0 / 0.5 / 1 / 2 / 3 / 4-6 / 7 or more years”), while *Active Engagement* consists of nine items and the response scale ranges from 1 (*Completely disagree*) to 7 (*Completely agree*).

Procedure

The survey was implemented in Qualtrics (https://www.qualtrics.com). First, participants were presented with an information page about the purpose of the study and provided their consent to participate in the study. Participants then completed the demographics section, followed by the IMIS and IMIR content-related questions, and finally the GMSI and music content (music-listening habits) questions in identical order. Finally, a debrief page was shown to participants. The median completion duration of the survey was 8.70 min.

Results

Descriptive Statistics

Descriptive statistics for all measures are presented in Table 1. On average participants reported experiencing IMIR several times a week. Descriptives and Cronbach’s alpha reliability values for IMIS and GMSI factors are comparable to those found in the original measurement validation studies as reported in the Materials section. The average reported duration of an IMIR episode was between half an hour and one hour, and the average reported duration of the section of music experienced as IMIR was between 10 and 30 s. The average score for the IMIR content experienced was highest for vocal IMIR (M = 3.76) and fast tempo IMIR (M = 3.45). The average score for music content exposure was higher for vocal music (M = 3.90) and fast tempo music (M = 3.48).

Table 1

Descriptive Statistics for All Variables of Study 1

	M	***SD***	**Skewness**	**Kurtosis**	**α**
IMIR Frequency (*n* = 263)	3.91	1.10	-0.40	-0.21	N/A
IMIR Duration (Section) (*n* = 259)	3.04	1.11	0.38	-0.66	N/A
IMIR Duration (Episode) (*n* = 259)	2.84	1.35	0.22	-1.19	N/A
GMSI-Active Engagement (*n* = 263)	38.37	10.23	-0.15	-0.53	.84
GMSI-Musical Training (*n* = 263)	27.17	12.47	-0.23	-1.22	.92
Vocal IMIR (*n* = 259)	3.76	0.74	-0.47	1.16	N/A
Instrumental IMIR (*n* = 259)	2.64	0.84	-0.12	0.05	N/A
Fast Tempo IMIR (*n* = 259)	3.45	0.64	-0.17	0.29	N/A
Slow Tempo IMIR (*n* = 259)	2.52	0.64	-0.39	-0.18	N/A
Vocal Music (*n* = 263)	3.90	0.72	-0.64	1.38	N/A
Instrumental Music (*n* = 263)	2.74	0.78	-0.09	0.30	N/A
Fast Tempo Music (*n* = 263)	3.48	0.64	-0.38	0.86	N/A
Slow Tempo Music (*n* = 263)	3.0	0.57	0.25	1.82	N/A
IMIS-NV (*n* = 259)	15.65	5.40	0.55	0.37	.91
IMIS-MVMNT (*n* = 259)	8.56	2.50	0.03	-0.28	.84
IMIS-PR (*n* = 259)	5.81	2.25	0.50	-0.25	.78
IMIS-HLP (*n* = 259)	4.72	1.79	0.23	-0.38	.81

Note. M = Mean, SD = Standard Deviation, and α = Cronbach's Alpha

GMSI Goldsmiths Musical Sophistication Index, *IMIS-NV* Involuntary Musical Imagery Scale - Negative Valence, *IMIS-MVMNT* Involuntary Musical Imagery Scale - Movement, *IMIS-PR* Involuntary Musical Imagery Scale - Personal Reflections, *IMIS-HLP* Involuntary Musical Imagery Scale - Help

Individual Differences in Music-listening Habits, Music Training and Engagement, and IMIR

We used structural equation modeling (SEM) from correlation matrices (see Supplementary Material Table 1 and 2 accompanying this paper at mp.ucpress.edu) using the R package "sem: Structural Equation Models" (Fox, 2006). SEM allowed us to model our hypotheses and create more complex models than other types of analyses would allow us (e.g., multiple regression) including having multiple independent and dependent variables (see Loehlin & Beaujean, 2017 for further reading on SEM). According to SEM guidelines a sample size of 200 is recommended (Hoyle, 1995; Kline, 2015). Therefore our sample size ($n = 263$) was deemed appropriate. After visual inspection of the data, which was not conclusive, normality was estimated using the Kolmogorov-Smirnov statistic and showed our data were not normally distributed ($p < .001$ for all variables, except GMSI-Active Engagement where $p = .087$). Therefore, and because the variables we used were ordinal, we ran Spearman correlations. The conventional cutoff criteria for goodness-of-fit-indices that were used were those of Hu and Bentler (1999), which suggest values close to .95 for Bentler's Comparative Fit Index (CFI), .06 for RMSEA, and .08 for SRMR. The information criteria that we used to compare and choose between models were BIC and AIC where lower values indicate better model fit (Hastie et al., 2001). We created three structural equation models according to the Hypotheses Groups: 1) paths from the music content in terms of tempo and presence of lyrics in the music-listening habits of individuals to the respective content of IMIR, 2) paths from the GMSI factors "Musical Training" and "Active Engagement" to IMIR characteristics (frequency, and duration of the section and duration of the episode), and 3) paths from the GMSI factors "Musical Training" and "Active Engagement" and exposure to instrumental music content to instrumental IMIR content.

Tempo and Lyrics in the Content of Music and IMIR (Hypothesis Group 1)

In the first SEM model, four latent variables were created based on the custom-made items for music content and IMIR content based on tempo (fast, slow) and presence of lyrics (instrumental, vocal). The model included paths from the two latent variables for music content (tempo: fast, slow; presence of lyrics: instrumental, vocal) to the two latent variables for IMIR content variables (tempo: fast, slow; presence of lyrics: instrumental, vocal). The goodness-of-fit metrics indicated an acceptable fit to the data, $\chi^2(16) = 56.05$, $p < .0001$; CFI = .92; RMSEA = .003; SRMR = .05; BIC = 3900.200; AIC = 3814.836. The model is depicted in Figure 1. There, it can be seen that each music content latent variable predicts the corresponding IMIR content latent variable.

Music Training and Engagement and IMIR Characteristics (Hypothesis Group 2)

We specified a new SEM model with paths from the latent GMSI factors "Musical Training" and "Active Engagement" to IMIR characteristics (frequency, duration of the section, and duration of the episode). The goodness-of-fit metrics indicated a very good fit to the data, $\chi^2(5) = 1.56$, $p = .91$; CFI = 1; RMSEA = 0; SRMR = .03; BIC = -26.29; AIC = 21.56. After removing all nonsignificant variables the fit of the new model was substantially better, $\chi^2(10) = 6.74$, $p = .75$; CFI = 1; RMSEA Index = 0; SRMR = .04; BIC = -48.98; AIC = 16.75. As can be seen in Figure 2, "Musical Training" predicted only the duration of IMIR episodes and "Active Engagement" predicted IMIR frequency.

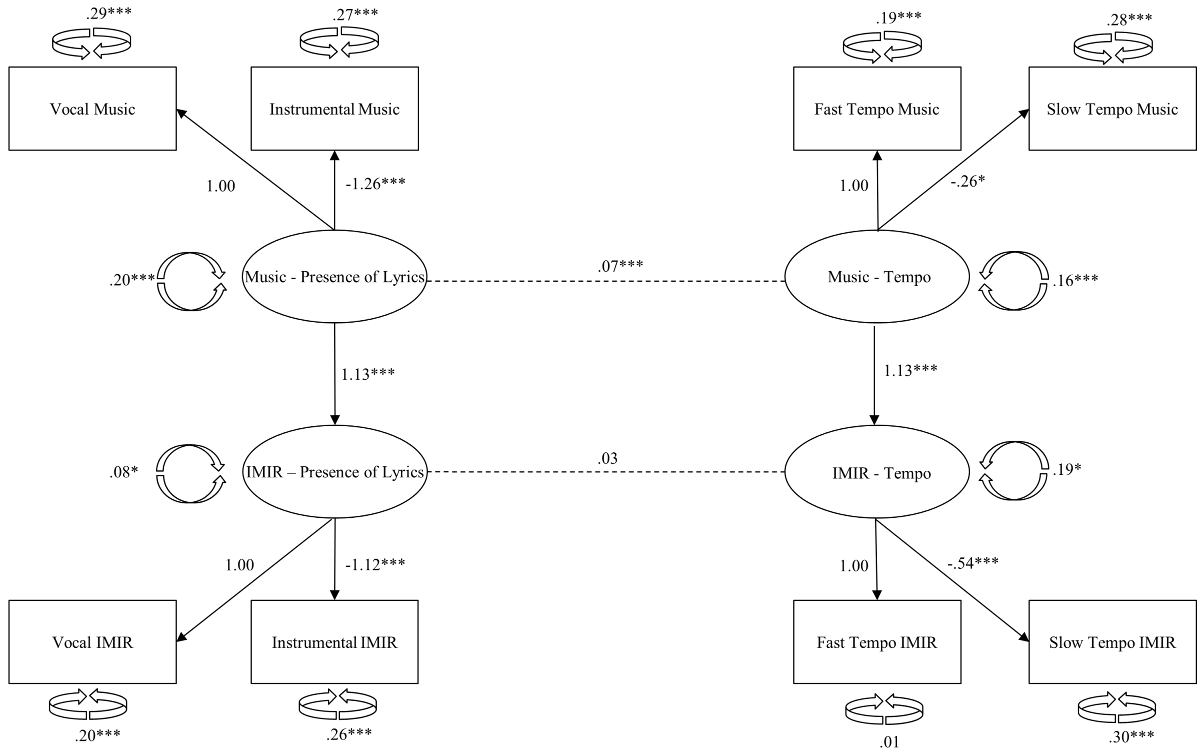

Figure 1. Graphical representation of the structural equation model exploring individual differences in music listening habits in relation to music content (tempo and presence of lyrics) and IMIR content (tempo and presence of lyrics). In accordance with common conventions, observed variables are presented in rectangles and latent variables in ellipses. Single-headed arrows between different variables represent regression coefficients, double-headed arrows within the same variable are variances, and dashed lines between different variables are covariances.

*$p < .05$ ***$p < .001$

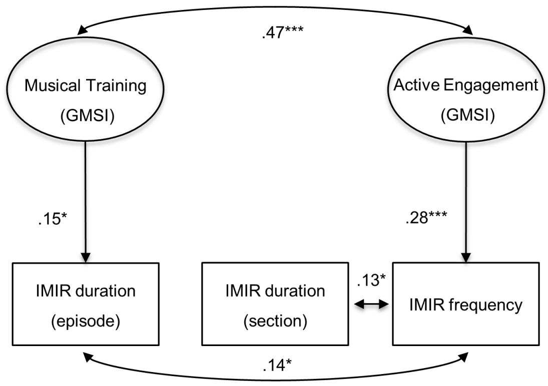

Figure 2. Graphical representation of final structural equation model exploring individual differences in music-related training and engagement and IMIR characteristics, after removing all nonsignificant paths. In accordance with common conventions, observed variables are presented in rectangles and latent variables in ellipses. Single-headed arrows between different variables represent regression coefficients and double-headed arrows between different variables are correlation coefficients.
$*p < .05$ $***p < .001$

Music-related Training and Engagement and Instrumental IMIR: Hypothesis Group 3

Finally, we specified a SEM model with paths from the GMSI factors "Musical Training" and "Active Engagement" and the exposure to instrumental music content variable to the instrumental IMIR content variable. The goodness-of-fit metrics indicated a good fit to the data, $\chi^2(4) = 17.37$, $p = .002$; CFI = .94; RMSEA = .11; SRMR = .10; BIC = -4.92; AIC = 29.37. As can be seen in Figure 3, only exposure to instrumental music predicted instrumental IMIR content.

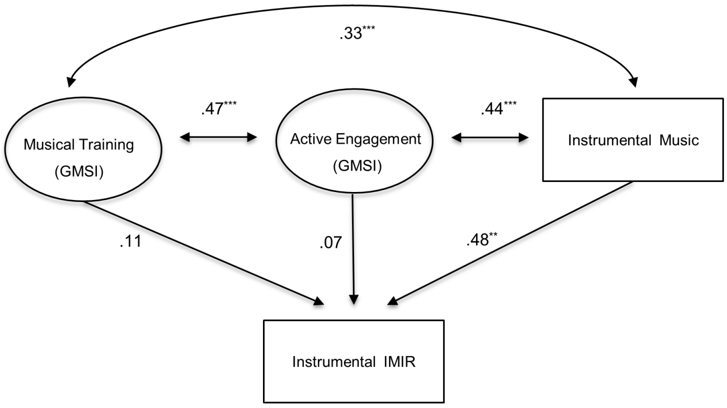

Figure 3. Graphical representation of final structural equation model exploring individual differences in music-related training and engagement as well as music and IMIR content. In accordance with common conventions, observed variables are presented in rectangles and latent variables in ellipses. Single-headed arrows between different variables represent regression coefficients and double-headed arrows between different variables are correlation coefficients.

*$p < .05$ ***$p < .001$

Discussion

In Study 1, we sought to explore how individual differences in exposure to fast and slow tempo and instrumental and vocal music content (music-listening habits) predict the content of IMIR, as well as how music-related training and engagement act upon IMIR characteristics and content. We used SEM to model our predictions and in line with our hypotheses, we found that the music-listening habits of individuals with respect to the content of music they are most frequently exposed to in terms of tempo (fast, slow) and presence of lyrics (instrumental, vocal), predict the respective content of their IMIR. Furthermore, our results with regard to music-related training and engagement and IMIR characteristics were partially in line with our hypotheses, since only active engagement with music (i.e., not also music training) predicted the reported IMIR frequency. Music training, however, predicted the increased duration of IMIR episodes. Also interesting was that exposure to instrumental music content, but not music training, predicted instrumental IMIR content.

The present results are consistent with the idea that the content of IMIR (fast or slow tempo, and the presence or not of lyrics), are a reflection of the music-listening habits of individuals, and thus support the priming hypothesis of how IMIR is retrieved. To explore whether musical features play a role in influencing IMIR, independently of such individual differences, we designed a study in which we directly controlled tempo and the presence of lyrics in music content heard across different conditions and examined the likelihood of IMIR retrieval as a function of these conditions.

Study 2

Having demonstrated that variations in tempo and the presence of lyrics in the music content one is exposed to predict their respective IMIR content, we sought to examine what effect, if any, tempo and the presence of lyrics have as cues to prime IMIR, independently of music-listening habits. We employed an experimental paradigm that has previously been used to covertly induce and sample IMIR effectively in a controlled laboratory setting (Floridou et al., 2017; Floridou et al., 2018). To conceal the aim of the study, the experiment was advertised as being about “Attention in Advertisements.” During the encoding phase and across four experimental conditions, participants were exposed to the same visual stimulus, the advertisement clip. To test for the effects of tempo and presence of lyrics as IMIR cues, the same musical piece was presented to all participants in one of four versions differing in tempo (fast, slow) and presence of lyrics (instrumental, vocal). Post exposure, participants completed the *Advertisement Appraisal Questionnaire* which measured familiarity and liking of the visual and musical stimuli. Next, participants carried out a resting period where they sat relaxed with their eyes closed for 3 min and let their mind wander. The resting period served as the IMIR retrieval phase since previous research has shown that IMIR is more likely to be retrieved during periods of low cognitive load (Floridou et al., 2017; Hyman et al., 2013). Finally, following the resting period, participants completed the *Mind Activity Questionnaire*, which covertly measures IMIR.

Based on preliminary findings of previous research that used retrospective reports, we hypothesized that IMIR would be elicited more frequently after exposure to music with faster tempo (Jakubowski et al., 2017) and to vocal music with lyrics (Liikkanen, 2012) than to music with slower tempo and to instrumental music without lyrics. By experimentally examining the influence of tempo and lyrics, the study allowed us to elucidate between the unique contribution of these specific musical features and the impact of priming (previous exposure) on IMIR.

Method

Design

The study used a 2 x 2 between-participants factorial design to measure the effects of tempo (fast: 152 bpm, slow: 108 bpm) and the presence of lyrics (instrumental, vocal) on IMIR retrieval and duration. There were four conditions relating to the piece heard in the study: 1) fast vocal, 2) slow vocal, 3) fast instrumental, and 4) slow instrumental. Individuals were randomly allocated to one of the four conditions resulting in 20 participants per condition.

Participants

A total of 84 individuals participated in the study. Four participants who guessed the aim of the study were excluded from the analyses. The final sample were 80 participants (52 female) ranging from 18 to 62 years of age (*M* = 26.33, *SD* = 7.33). Participants were an opportunity sample of students and visitors at Goldsmiths, University of London. The sample size per condition was modeled after previous research (Byron & Fowles, 2015; Floridou et al., 2012; Floridou et al., 2017; Floridou et al., 2018). Participants received £2–4 as compensation.

Stimuli

Visual stimulus: A Coca-Cola TV advertisement (Coca-Cola, 2017), which lasted 1 min, was used to expose participants to the music, while concealing the true purpose of the study. The advertisement was chosen because it did not contain any spoken content that may have distracted from the music and then later interfered with IMIR retrieval. The visual stimulus remained constant in all 4 conditions. Post hoc analysis showed that the average familiarity rating with the visual content was *M* = 1.69 and *SD* = 1.19 (on a 5-point Likert response scale), indicating that, overall, participants had not seen the advertisement before. Therefore, there was minimal risk that participants would remember the original clip and music and that they would be able to identify our manipulation of the music.

Musical stimuli: We replaced the original soundtrack of the Coca-Cola TV advertisement with the vocal and instrumental versions of the piece "What I'd Give Up" by the band The Classic Crime (MacDonald, 2012, track 11; MacDonald 2015, track 11). The first criterion that guided the choice of musical stimulus was for the piece to be available as a professional recording in high quality instrumental as well as vocal versions. As the band published an instrumental version of their album, *Phoenix* (containing the exact same tracks without lyrics), this provided an ideal group of tracks to choose from. The second criterion was to avoid potential familiarity confounds by choosing a piece that was likely to be unknown to the participants. A familiar vocal piece with lyrics would mean that, even if the piece heard during the experiment was instrumental, awareness of existing lyrics could lead to the later experience of IMIR. We accounted for this by asking participants about their familiarity with the music on the Advertisement Appraisal Questionnaire. Post hoc analysis showed the average familiarity rating of the piece was $M = 1.45$ ($SD = 0.71$; on a 5-point Likert response scale), confirming that on average participants did not find the piece familiar. We used the chorus of the pieces as the stimuli since previous studies have found this section to be the most likely to be retrieved as IMIR (Beaman & Williams, 2010; Liikkanen, 2012).

Audacity software (Audacity Team, 2014) was used to alter the tempo of both the instrumental and vocal versions of the musical piece. The original tempo was approximately 130 bpm and was increased and decreased by 15% to create both the instrumental and vocal excerpts and ultimately to provide the musical stimuli for all four conditions (152 bpm in the fast conditions and 108 bpm in the slow conditions). The tempo changes were selected according to the literature and were large enough to be perceptible while not affecting the identity of the musical track. The audiovisual stimuli were of equal duration (1 min) in all conditions, however the fast tempo chorus lasted 30 s and therefore was presented twice to fit the one-min video (2 full choruses), while the slow tempo chorus lasted approximately 40 s and thus was presented 1.5 times to fit the video (one full chorus and a half of a chorus). The visual and musical stimuli were combined using *FFmpeg* (FFmpeg team, 2000) to create the final audiovisual stimuli.

Materials

The Advertisement Appraisal Questionnaire was adapted from the previously used Film Appraisal Questionnaire (Floridou et al., 2017; Floridou et al., 2018), thus allowing us to assess participants' engagement (i.e., "The advertisement was very engaging"), stimuli familiarity (i.e., "I have heard this music and know it well" and "I have seen this advertisement and know it well"), liking (i.e., "I like the visuals in the advertisement" and "I like the music in the advertisement"), and willingness to buy the music (i.e., "The advertisement made me want to buy the product"). The last item was included to reinforce the cover story that the experiment was about advertising and was thus not included in any analyses. We used a 5-point Likert response scale measuring agreement for all items (1 = *Strongly disagree*, 2 = *Moderately disagree*, 3 = *Neither agree nor disagree*, 4 = *Moderately agree*, 5 = *Strongly agree*).

The Mind Activity Questionnaire (Floridou et al., 2017; Floridou et al., 2018) was adapted and used to indirectly sample for IMIR. The questionnaire included three sections about visual, musical, or speech mental imagery during the post-exposure resting period (retrieval phase) of the session. Each mental imagery section included items about (a) mind-wandering in response to the corresponding imagery aspect of the advertisement, which was measured by answering yes or no and with an open-ended question in which participants provided a brief description of the imagery retrieved, (b) participants' control over the imagery on a 7-point scale ranging from 1 (*I deliberately generated it*) to 7 (*It happened outside of my control*), (c) the duration of imagery, as measured using an open-ended question in which participants provided a percentage of time for which each type of imagery was retrieved during the 3 min post-exposure period, and (d) the repetitiveness of the imagery ("imagery appeared more than once?") by answering yes or no. A final question was included in which participants were asked whether they knew the aim of the experiment in order to determine if they guessed the true nature of the study. If so, participants were asked to describe their thoughts.

We also used the IMIS, GMSI, and additional IMIR and music content (music-listening habits) questions, as described in Study 1.

Procedure

The experiment was advertised as being about “Attention in Advertisements” to conceal the aim of the study and sessions were conducted in a classroom-like setting with the researcher present throughout. After reading the information sheet and signing the consent form, the encoding phase commenced whereby participants watched the advertisement clip on a projector through a video embedded in a Microsoft PowerPoint presentation and listened to the music through speakers in the room. Participants in all conditions watched the same visual stimulus, the Coca-Cola advertisement, but heard one of the four versions of the piece as previously described. When the encoding phase ended, participants were asked to complete the Advertisement Appraisal Questionnaire. Next, the retrieval phase commenced with a resting period, where participants were instructed to sit relaxed with their eyes closed for 3 min and to allow their mind to wander. The resting period was used to allow for IMIR retrieval as previous research has shown that the likelihood of IMIR retrieval is higher during periods of low cognitive load (Floridou et al., 2017; Hyman et al., 2013). Participants were alerted by the researcher when the 3 min were up and were then instructed to complete the Mind Activity Questionnaire. Lastly, participants were fully debriefed on the actual aims of the study and were asked to fill out the IMIS, GMSI, and additional IMIR and music content questions. The experimental session lasted approximately 15 min. A visual representation of the experimental procedure can be seen in Figure 4.

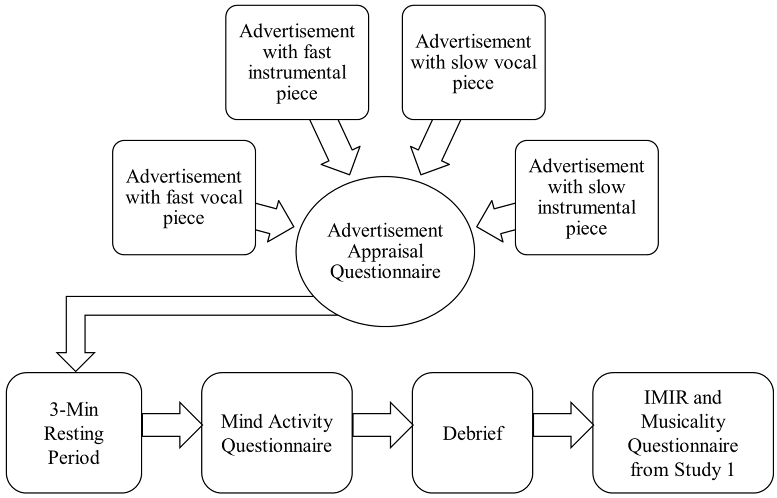

Figure 4. Visual representation of the experimental procedure for Study 2.

Data Coding

The main data for IMIR were generated from the Mind Activity Questionnaire. IMIR retrieval (yes = 1, no = 0) was determined by three criteria, that is, if participants 1) answered “yes” to experiencing musical imagery, 2) rated the experience as happening outside of their control (a 4 or above on the 7-point control over the imagery scale), and 3) answered “yes” to the experience appearing more than once.

Results

A total of 49 out of 80 participants (61.3%) experienced some form of musical imagery during the experiment, for example, musical mind-pops (11.3%) or voluntary musical imagery (12.5%). IMIR was experienced in 30 of those participants, resulting in a 37.5% total retrieval rate. Figure 5 shows the numbers of participants that did or did not experience IMIR in each condition. The number of IMIR that was experienced in each condition was: fast tempo/vocal (n = 5; 25%), slow tempo/vocal (n = 11; 55%), fast tempo/ instrumental (n = 6; 30%), and slow tempo/instrumental (n = 8; 40%). When examining the conditions based on tempo or presence of lyrics, IMIR was retrieved in 11 participants for fast tempo and 19 for slow tempo conditions. In the vocal and instrumental conditions, 16 and 14 individuals retrieved IMIR respectively. During the retrieval phase, the average reported IMIR duration, shown in Figure 6, was M = 48.0% of the time (86.4 s) in the fast tempo/vocal condition, M = 64.82% (116.68 s) for slow tempo/vocal, M = 23.33% (41.99 s) for fast tempo/instrumental, and M = 44.75% (80.55 s) in the slow tempo/instrumental condition.

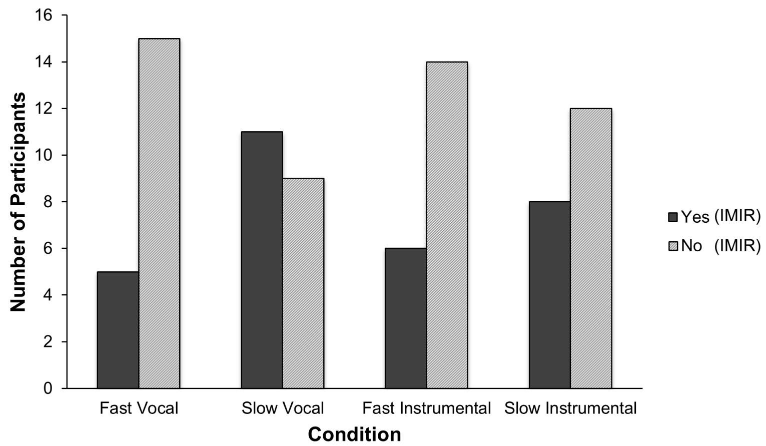

Figure 5. Number of participants that did and did not experience IMIR in each condition in Study 2.

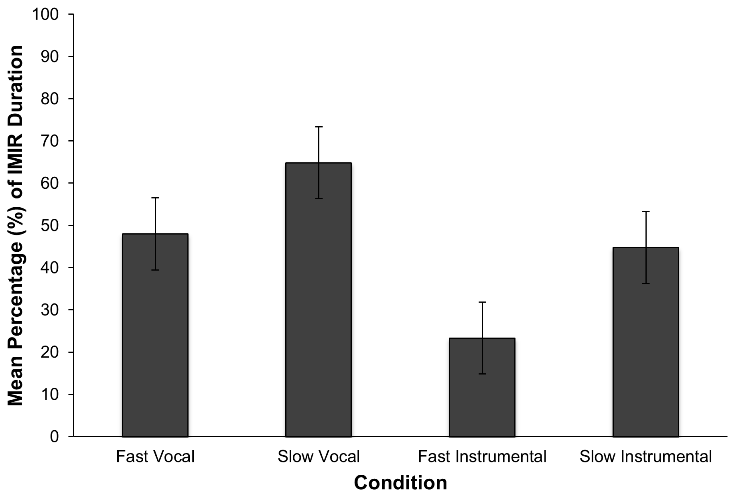

Figure 6. Average IMIR duration as a percentage of the retrieval phase for each condition in Study 2. Error bars indicate standard errors.

Tempo and Lyrics as Cues for IMIR Retrieval and Duration

A binomial logistic regression was used to predict IMIR retrieval based on tempo (fast or slow), the presence of lyrics (vocal or instrumental), and an interaction between tempo and presence of lyrics. Fast tempo and vocal music were used as the reference categories. The model was not statistically significant, $\chi^2(2) = 3.67$, $p = .160$, and it explained 6.10% (Nagelkerke R^2) of the variance in IMIR retrieval and correctly classified 65.0% of cases. None of the variables significantly predicted IMIR retrieval. Tempo showed only a trend towards significance ($p = .067$) whereby slower tempo was associated with an increase in the odds of IMIR retrieval. Listening to the slower tempo piece increased IMIR retrieval likelihood 2.39 times relative to listening to the fast tempo piece. IMIR was 0.80 times less likely to be retrieved when exposed to the instrumental piece than when exposed to the piece with lyrics.

A two-way ANOVA was conducted to determine if tempo or presence of lyrics had an effect on IMIR duration. Participants in whom IMIR was not retrieved were necessarily removed for this part of the analysis, given that they did not provide any IMIR duration data. There was no significant interaction effect between tempo and presence of lyrics on IMIR duration, $F(1, 26) = .06$, $p = .811$, partial $\eta^2 = .002$. However, there was a significant main effect of lyrics on IMIR duration, $F(1, 26) = 5.50$, $p = .027$, partial $\eta^2 = .175$, indicating that exposure to the piece with lyrics was associated with longer lasting IMIR. There was also a trend towards significance for the main effect of tempo on IMIR duration, $F(1, 26) = 4.02$, $p = .056$, partial $\eta^2 = .134$, whereby hearing the piece with a slower tempo seemed to relate to having longer lasting IMIR.

Exploratory analyses were carried out to test the effects of liking the music ($M = 3.44$, $SD = 1.10$) and familiarity with the music ($M = 1.45$, $SD = .71$) on IMIR retrieval and duration. A binomial logistic regression was conducted with music liking as a covariate. The model was not statistically significant, $\chi^2(3) = 4.16$, $p = .244$, explained 6.90% (Nagelkerke R^2) of the variance in IMIR retrieval, and correctly classified 66.30% of cases. IMIR was 0.85 times less likely to be retrieved when exposed to the instrumental relative to the piece with lyrics. Exposure to the fast tempo piece was 2.48 times more likely to be followed by IMIR than listening to the slow tempo piece. Using familiarity as a covariate also yielded a statistically nonsignificant model, $\chi^2(3) = 4.15$, $p = .246$, which explained 6.90% (Nagelkerke R^2) of the variance in IMIR retrieval, and correctly classified 66.30% of cases. IMIR was 0.75 times less likely to be retrieved when exposed to the instrumental piece relative to the piece with lyrics. Exposure to the fast tempo piece was 2.44 times more likely to be followed by IMIR retrieval relative to exposure to the slow tempo piece. These findings indicate that IMIR retrieval was not affected by liking or familiarity with the music.

Additional two-way ANCOVAs were also conducted using liking and familiarity with the music as covariates. With liking as a covariate, no significant interaction effects were found between tempo and presence of lyrics on IMIR duration, $F(1,25) = 0.00$, $p = .99$, partial $\eta^2 = .00$. Significant main effects of lyrics were found, $F(1, 25) = 4.77$, $p = .039$, partial $\eta^2 = .160$ showing an association between longer IMIR duration and exposure to the vocal music. Also main effects of tempo were found, $F(1, 25) = 4.75$, $p = .039$, partial $\eta^2 = .160$, in which hearing the slower tempo music was related to longer IMIR duration. Using familiarity as a covariate, no significant interaction effects were found between tempo and presence of lyrics on IMIR duration, $F(1,25) = 0.05$, $p = .829$, partial $\eta^2 = .002$. Only a significant main effect of presence of lyrics was found on IMIR duration, $F(1, 25) = 5.28$, $p = .030$, partial $\eta^2 = .133$, indicating a relation between exposure to the music with lyrics and reporting longer IMIR duration, while no effect of tempo was found, $F(1,25) = 3.85$, $p = .061$, partial $\eta^2 = .174$.

Discussion

The aim of Study 2 was to investigate experimentally how tempo and the presence of lyrics influence IMIR retrieval and duration. We hypothesized that exposure to music with a faster tempo and presence of lyrics would increase the retrieval and duration of IMIR relative to slower tempo and instrumental music. The results revealed that neither tempo, nor the presence of lyrics, had a significant effect on IMIR retrieval, but the presence of lyrics had a large effect on IMIR duration. These results extend the findings from Study 1, demonstrating that IMIR retrieval may not be as affected by variations of tempo and presence of lyrics per se as by previous music exposure, as indicated by the 37.5% retrieval rate. We found no significant effects of liking or familiarity with the music on IMIR retrieval. However, there were significant main effects of vocal music on longer IMIR duration when controlling for liking and familiarity, and slow tempo music on longer IMIR duration when controlling for liking.

General Discussion

Across two studies using trait and state-level measures, we provided novel insights into the factors influencing IMIR. First, we found that tempo and lyrics may not be an IMIR retrieval cue per se but that, through music-listening habits of individuals, they play a critical role in priming IMIR. Second, we showed that active engagement with music predicted IMIR frequency while music training alone influenced IMIR duration. Lastly, we found that only exposure to instrumental music content predicted greater frequency retrieval of instrumental IMIR, and not music training nor active engagement with music. We now discuss these findings in relation to the existing literature and comment on their implications for future research.

IMIR and Musical Features

Previous studies had indicated that the tempo and the presence of lyrics may be important components in IMIR experiences (Halpern & Bartlett, 2011; Jakubowski et al., 2017; Liikkanen, 2012). We extend these findings by demonstrating that IMIR retrieval is affected by the music-listening habits of the individual with respect to tempo and lyrics (Study 1) but not with respect to tempo and the presence of lyrics in a given piece of music per se (Study 2). Habitual exposure to vocal and instrumental music content predicted increased rates of IMIR with vocal and instrumental content. A similar pattern between music content and the content of IMIR was found for tempo, where habitual exposure to fast and slow tempo music predicted increased frequency of slow and fast tempo IMIR. These results confirm findings that exposure to music is an effective cue for IMIR (Byron & Fowles, 2015; Filippidi & Timmers, 2017; Hyman et al., 2013; Liikkanen, 2012; Williamson et al., 2012) and provide further support for the priming account of involuntary memories (Kvavilashvili & Mandler, 2004; Mace, 2005), such as IMIR, according to which recently encountered cues in everyday life result in the subsequent involuntary retrieval of memories related to the same cues. The findings of Study 2 provide further support to this conclusion, since we observed effective IMIR retrieval post-music exposure but a lack of a significant influence of tempo and presence of lyrics on IMIR retrieval.

The absence of a tempo effect on IMIR retrieval in Study 2 is at odds with previous research on tempo, which has shown that music reported as IMIR has (albeit at trend significance level) a faster tempo (124.10 bpm) than non-IMIR music (115.79 bpm) (Jakubowski et al., 2017). We offer three potential resolutions to this apparent contradiction: First, we note that a possible explanation could lie in the fact that in Jakubowski et al's study, the slower tempo found in non-IMIR pieces, was based on pieces that were not reported as IMIR in their database. However, this might not necessarily be an indication that these pieces, and consequently that slow tempo, are not experienced as IMIR, but rather that they were not reported in the database. In diary studies that used accelerometers to track IMIR tempo, although the estimation of beat was measured in a different way, the reported averages were 100.90 bpm (Jakubowski et al., 2015) and 98.36 bpm (Jakubowski et al., 2018), which are closer to the 108 bpm tempo used in our slow tempo condition. Potentially a wide range of tempo could prime IMIR, and this could explain why we did not observe a tempo effect. Furthermore, while in these studies tempo was measured based on participants' IMIR experiences as opposed to the actual tempo of the original recording (as in Jakubowski et al., 2017), it might not necessarily be an indication of the tempo range that has the potential to optimally prime IMIR, but instead reflect the music individuals are habitually exposed to. Second, IMIR state-level reports (the moment IMIR is retrieved) similar to ours and previous studies (Jakubowski et al., 2015; Jakubowski et al., 2018) and trait-level, retrospective reports (Jakubowski et al., 2017) might result in tempo variations. This could be investigated in research combining state-level and trait-level 24h follow-up studies. A third explanation for the discrepancy between our findings and those of Jakubowski et al. (2017) is related to the potentially mediating role of motor activity in IMIR and sensorimotor synchronization (i.e., synchronizing actions with predictable tempo-changing sequences), a link that has been established by previous studies (Floridou et al., 2012; Floridou et al., 2015; Jakubowski et al., 2015; McCullough Campbell & Margulis, 2015). Tempo, besides being a crucial feature of music, is also important in the corporeal behaviors associated with music, such as clapping and dancing. Faster tempo pieces could increase the tendency of listeners to move to the beat of the music, which in turn has been found to be associated with IMIR retrieval (Floridou et al., 2015; McCullough Campbell & Margulis, 2015). This could account for the observation by Jakubowski et al. (2017) of a faster tempo in IMIR priming pieces. Future studies could test this suggestion and clarify the relative importance of motor activity and tempo in IMIR by using the same tempo conditions we used in Study 2 but with additional conditions in which participants are asked to move to the music (e.g., to tap to the beat of the music or clap along).

Interestingly, when controlling for liking there were significant effects of tempo on IMIR duration (whereby when liked, the slower tempo piece led to longer IMIR duration). Future studies could use stimuli of the same tempo to test the effect on IMIR duration of phrase lengths and/or number of beats/and or note duration. This would allow more precise determination of the characteristics that are related to IMIR duration and whether longer IMIR duration is because of tempo per se, or because of the additional elements that make up a piece. It is important to note that the slower tempo was different from the fast tempo condition in that it ended partway through the chorus. Therefore, longer IMIR duration may be due to the so-called Zeigarnik effect, whereby the interrupted presentation of stimuli leads to better ability to retrieve these stimuli as memories (Zeigarnik, 1938). It is worth noting that studies to date have not supported this hypothesis (Floridou et al., 2017; Hyman et al., 2013; Hyman et al., 2015; for a review see Liikkanen & Jakubowski, 2020). However, the possibility of its role here cannot be excluded.

We have found that habitual exposure to music content with and without lyrics predicts more frequent IMIR for that content, but that the presence or absence of lyrics has no effect on IMIR retrieval. Furthermore, the descriptive results of our study support a dominance of vocal music in the content of IMIR, which are in line with previous research (Floridou et al., 2017; Halpern & Bartlett, 2011; Liikkanen, 2012). Future studies could test the effect of familiar vocal pieces on IMIR retrieval since in our study familiarity was intentionally kept to a minimum. An interesting finding was that listening to vocal music primed longer IMIR duration. Additionally, there were significant main effects of vocal music after controlling for liking and familiarity on IMIR duration. One possible explanation is that, although vocal music is not associated with increased likelihood of IMIR retrieval, IMIR primed by vocal music promotes involuntary or voluntary continuation and maintenance of the musical imagery as inner singing, especially if the piece is familiar and liked. This is in line with findings that singing (propensity to sing or hum along to music and self-report singing ability), more than music training and engagement, is associated with longer IMIR duration (Müllensiefen et al., 2014; Williamson & Müllensiefen, 2012), meaning that individuals who sing more in everyday life could experience longer IMIR because they tend to engage in internal singing when IMIR is retrieved. This explanation is supported by previous studies, which established a connection between longer IMIR, vocal system activity, and inner singing (McNally-Gagnon, 2016; Müllensiefen et al., 2014). If music containing verbal information such as lyrics promotes singing (internal or external), which is processed in the phonological loop component of verbal working memory (Baddeley & Hitch, 1974) and refreshed through the articulatory rehearsal component, this could result in sustained maintenance and longer musical imagery of singing. We note, however, that it is not yet clear whether nonverbal information such as instrumental and vocal music are processed by the same or different subsystems (a "musical loop," Berz, 1995; or a "tonal loop," Pechmann & Mohr, 1992), and the current explanation stands only if the former is true. Future studies could test this hypothesis by using the vocal experimental conditions we used, providing participants with the lyrics and asking them to sing along (internally or externally), and the instrumental experimental condition, and compare IMIR duration in both conditions.

We found no significant effects of familiarity or liking on IMIR retrieval, an observation which is in line with reports from previous studies (Byron & Fowles, 2015; Floridou et al., 2017). The absence of familiarity effects in our study is not surprising as we specifically selected the piece to be unknown to participants to avoid creating associations with the lyrics, even if the piece heard was instrumental. Nevertheless, the absence of familiarity effects was also reported in other studies that tested IMIR using familiar instrumental music (Floridou et al., 2017; Moeck et al., 2018). Williamson et al. (2012) reported IMIR was retrieved after just one exposure to the music, regardless of whether the individual liked or disliked the piece and there are also reports in the literature of novel musical imagery (Bailes, 2007; Floridou, 2016; Liikkanen, 2012).

IMIR and Individual Differences

In line with prior studies, we found that only increased active engagement with music (i.e., not also music training) resulted in increased reported IMIR frequency, thus partly contradicting our hypotheses based on previous literature (Floridou et al., 2015; Liikkanen, 2012). However, it should be noted that in the correlation matrix (see Supplementary Material accompanying this paper at mp.ucpress.edu), on which our SEM model was based, increased IMIR frequency was positively associated with both active engagement with music and music training, although less strongly, which is according to our expectations and part of previous literature. Therefore, the discrepancies between previous findings and ours might also result from different types of statistical analysis since correlation could yield different results than SEM. Müllensiefen et al. (2014), who also used SEM to model individual differences in music-related behaviors and IMIR, reported a unique contribution of music-related engagement on IMIR frequency and not music training. Findings thus suggest a crucial role of recent exposure to music and priming in IMIR through informal exposure to music. Furthermore, our findings do not support a unique or an additional contribution of music training, something that would implicate additional processes and mechanisms (e.g., mental and physical practice) in the retrieval of involuntary memories with musical content.

Interestingly, only increased exposure to instrumental music predicted experiencing more instrumental IMIR. There was no effect of music training or active engagement with music. However, the correlational matrix on which this SEM was based showed that both increased music-related training and active engagement with music were associated with a tendency to experience instrumental IMIR. While SEM is more reliable, because it allows specific hypotheses to be tested as models, comparing these against similar models to determine which has the best fit, this pattern of results once more suggests that variations in analytic approaches may account for various discrepancies in the literature. Future studies could explore whether specific training as an instrumentalist or vocalist is associated with instrumental music and vocal IMIR content, respectively. The GMSI includes an item asking about the instrument an individual plays best (including voice), which could be used to investigate the above-mentioned link.

Limitations

A few limitations of the research need to be acknowledged. One is that the tempo used in the slow condition of Study 2, although below the average of non-IMIR pieces reported in Jakubowski et al. (2017) study, falls roughly on the lower range of what might be considered as fast music, often labeled as "allegretto" (i.e., fairly fast and lively). Future studies wishing to test the effect of tempo further should use a wider range of tempi and measure more fine-grained effects. Furthermore, although we did not observe a direct effect of tempo on IMIR duration (only an association between slow tempo and longer duration when accounting for how much the piece was liked), it is important to note that in our experimental conditions the slower tempo was different from the fast tempo condition in that the piece ended partway through the chorus. This was a result of us prioritising equality of duration of the musical presentation in all conditions. However, future research could undertake a manipulation of fast and slow tempo by presenting the same content while keeping the duration of the piece similar. Finally, an inherent limitation to all studies measuring trait-level cognitive experiences is the retrospective nature of self-reports that could suffer from memory biases. In the present study, we took all necessary precautions to limit this bias by using standardized and validated measures, by having a quality control of participants' reports, by using a range of exclusion criteria and, where possible, seeking to replicate our findings under laboratory conditions.

Concluding Remarks

To our knowledge this is the first empirical investigation of the potential effect of tempo and the presence of lyrics as IMIR retrieval cues. Results point to the importance of music exposure as a cue for priming IMIR as opposed to the importance of specific features of the music per se. Tempo and the presence of lyrics are important to the extent that such music is habitually listened to by the individual, rather than as unique predictors of the likelihood of IMIR retrieval. However, we do not preclude the possibility that other elements of tempo and lyrics may increase the likelihood of IMIR retrieval and there are several promising avenues for future research and development, such as investigating the phrase lengths, number of beats, note duration, the degree of lyrics repetition, alliteration, the emotional content of words in lyrics, and cue/lyrics distinctiveness (Staugaard & Berntsen, 2019). Finally, other musical features of relevance might include genre, instrumentation dynamics, timbre, and type of chord progressions used.

Our results thus indicate that IMIR in everyday life is an interplay of multiple, interacting, and context-dependent systems that reflect individual music listening habits and engagement levels. This finding has important theoretical and practical implications and opens up avenues for future research not only on IMIR but also on other types of everyday involuntary memories. Overall, our findings suggest that IMIR is an idiosyncratic experience strongly related to the music which the individual is most frequently exposed to.

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