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Abstract

The term "earworm," also known as Involuntary Musical Imagery (INMI), refers to the phenomenon of an uncontrollably repeating melody in one's head. Though ubiquitous, it is comparatively under-researched in music cognition. Most existing studies have identified the defining characteristics of earworms, rather than explore their underlying mechanisms. This study investigates the hypothesis that overt motor involvement (humming, singing, tapping) and imagined motor involvement (imagining a continuation to an interrupted melody) will induce INMI more frequently than passive music listening. Four groups of participants were given instructions for different types of responses while listening to music; then they completed the same monotonous activity. After the music-listening and visual tasks were over, participants were asked to report on any earworms that occurred during the session and answer general questions about earworm experience. Results indicated that vocal and physical involvement, but not an interrupted tune, increased the frequency of triggered INMI.

Background

Auditory and Musical Imagery History

Auditory imagery is a prevalent and important phenomenon. It not only provides the cognitive tools needed for musicians to advance their craft, but it allows audiences to recall the inflection and timbre of speech. This type of cognition is shared by all who can hear, and with it, people are able to remember and learn through sounds, from the softest whispers to the most bombastic cacophony. Intons-Peterson (1992) referred to auditory imagery as "the introspective persistence of an auditory experience, including one constructed from components drawn from long-term memory, in the absence of direct sensory instigation of that experience" (p. 46). Musical imagery is a specific type of auditory imagery. Bailes (2007) describes this particular experience as "imagining music in the 'mind's ear'" (p. 555) and defines musical imagery as the experience of imagining musical sound in the absence of directly corresponding sound stimulation from the physical environment.

Despite wide prevalence (Liikkanen, 2008), Involuntary Musical Imagery (INMI), a specific type of musical imagery, has only recently begun to attract attention in the laboratories of psychologists. The term INMI refers to the uncontrollable occurrence of repeating fragments of music in the brain and is often characterized as "intrusive" (Beaty et al., 2013). This phenomenon is more commonly known as "earworms," a term derived from the direct translation of the German word, ohrworms. In French they are known as musique entêtante, "stubborn music", and in Italian they are canzone tormentone, "tormenting songs" (Halpern & Bartlett, 2011). Earworms have also been called "stuck song syndrome" (Levitin, 2006), "brain worms" or "sticky music" (Sacks, 2007), "cognitive itch" (Kellaris, 2001), and "sticky tunes" (Williamson, Liikkanen, Jakubowski, & Stewart, 2014). Williamson et al. (2011) described INMI as "the experience whereby a tune comes into the mind and repeats without conscious control" (p. 259).

Previous INMI Research

In the past decade, significant strides have been made in INMI research. Brown (2006) documented his personal, near-constant musical imagery and coined the term Perpetual Music Track (PMT) to describe his intense, continual experience of imagined music. Though this study gave an extremely detailed account of his perspective and outlines some key qualities of musical imagery, Brown's account was purely descriptive.

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Most other studies on INMI also suffer this limitation. The first large-scale empirical work on INMI surveyed almost 12,000 participants online over a three-month period (Liikkanen, 2008). The study catalogued participant musical experience, listening, and activities. The researchers sought to gather information on INMI prevalence; they found that over 90% of their subjects experienced earworms at least once a week. Williamson et. al (2011) explored the everyday onset of INMI. They used data from anonymous callers to a BBC radio show to identify many detailed characteristics of typical INMI episodes. That study serves as a helpful categorization for subsequent research since it provides data that support a prime target attention state for the current experiment.

Previous research on INMI has involved probe-caught experience sampling methods (Bailes, 2007), questionnaires (Floridou, Williamson, & Müllensiefen, 2012; Likkanen, 2012b), surveys (Halpern & Bartlett, 2011; Hyman et al., 2013; Likkanen 2008; Williamson et al., 2011), journal entries (Beaman & Williams, 2010; Brown, 2006; Halpern & Bartlett, 2011; Hyman et al., 2013), and interviews (Williamson & Jilka, 2013). Liikkanen (2012a) claimed that the study of this topic as a whole would be greatly served if there was a method to bypass the need for self-reporting because self-reports raise a host of interpretive problems (Halpern & Bartlett, 2011). Beaman and Williams (2010) advised caution toward retrospective self-reports, the main method of data collection in previous INMI research. Beaman and Williams attempted to address these limitations by having participants record their INMI experiences as they occurred. Bailes (2007) similarly had participants provide immediate responses instead of retroactive reports. The current project adopted this methodology and used immediate reporting, building on the wealth of critical descriptive data from previous studies.

Earworm Induction History

The small body of existing non-descriptive work on INMI has been conducted quite recently. McNally-Gagnon, Hébert, and Peretz (2009) played five stimulus songs to 36 participants (18 musicians, 18 non-musicians) and provided recording devices and questionnaires for the subjects to use over the next several days. Participants vocally recorded their INMI episodes (referred to as "obsessive" songs in the study) in the 3.5 days following stimuli exposure; then they repeated the procedure after a two-week break. Results revealed that 47% of the subject pool experienced at least one of the target songs as INMI; the most common bit of songs reported was the chorus. In this particular study, non-musicians experienced significantly more INMI than musicians, a finding that is both supported (Liikkanen, 2008; Liikkanen, 2012a) and contradicted (Beaman & Williams, 2010; Hemming, 2008) in other INMI data. The musician/non-musician difference could have been due to a small sample size; the current study attempted to alleviate such bias with a large subject pool.

Another experiment that aimed to induce earworms was conducted by Hemming (2008), with 59 participants. Hemming distributed a CD with 20 "catchy" tunes, one per genre, and asked participants to listen to it as much as possible for up to six weeks; participants were asked to rate their liking for the title and genres of the songs. Subjects were asked in post-hoc interviews to give their own explanations of the phenomenon and recount any INMI tunes. Unlike McNally-Gagnon et al. (2009), musicians and non-musicians displayed no significant differences concerning INMI episodes. Hemming found the most common activities in which people in the study experienced earworms occurred when they were 'doing nothing special', engaging in background activities, traveling in a car/train, or waiting. This study probed some interesting details about the earworm experience; however it depended on retroactive self-report from participants.

In two experiments on the Internet, Liikkanen (2009) used a single-trial design and disguised the intent of INMI induction from 9,967 participants. Liikkanen aimed to trigger earworms using cued recall. In the first study, participants completed missing words from the lyrics of five contemporary songs; INMI induction was successful in 67.1% of cases; average familiarity was 71.5%. The second study was similar but replaced four of the five previous stimuli with classic songs with an average familiarity of 91.2%, but earworm induction success rate decreased to 49.6%. In the second study but not the first, a recency effect was demonstrated through a higher average INMI experience for the song in the last serial position. The method of recall used in this study by Liikkanen could be problematic in earworm investigations since participants were asked to fill in song lyrics. Later, Liikkanen (2012a) conducted a study to see if it was possible to experimentally induce INMI and to investigate the factors that influence its emergence; he once again employed methods of cued recall. Using written lyrical cues, Liikkanen worked on the assumption that memory activation might lead to INMI. With familiarity controlled, earworms were successfully triggered for over 50% of the participants. Liikkanen (2012c) recommended that future work adapting his induction methods should better control presentation time, stimulus, sequence, familiarity, and strategic selection of cues.

Hyman et al. (2013) attempted to induce earworms by playing music at the end of a seminar. They had participants record their preference and familiarity of the songs as well as any INMI occurrences. Results revealed that intrusive songs were more often those well liked and well known by the participants. Subjects experienced INMI both during low cognitive activities (e.g., walking, daily routines) and during mentally challenging activities (e.g., schoolwork). The connection to school was likely influenced by the setting in which the songs were originally heard; participants recorded that they were thinking of that particular class 65.8% of the times when a song returned. In another experiment included in Hyman et al. (2013), experimenters attempted to induce earworms in a lab setting. Participants were played songs; half were modern popular tunes and half were by The Beatles. Each subject heard three songs with the final song either interrupted or played through completely; then, they completed a five-minute distraction maze task. In congruence with the findings of Liikkanen (2009), researchers found that serial presentation order affected the percentage of time participants experienced earworms both immediately and in the next 24 hours.

In the first lab-based study of the induction of INMI, Floridou, Williamson, and Müllensiefen (2012) carefully attended to Liikkanen's (2012c) concerns; their experiments were extremely influential and helpful in the design of the current study. Floridou et al. used both within- and between-subjects 2 x 2 factorial design to test the "stickiness" of songs presented, to examine individual differences in INMI induction, to compare two procedures for triggering earworms, to examine serial position effects, and to investigate the relationship between memory/familiarity of the tunes and their ability to trigger earworms. An opportunity sample of 40 participants was tested in this single-blind experiment that involved a "Name That Tune" portion in which subjects heard (a) six songs over headphones and (b) a "Lyrics" portion in which they were asked to fill in missing lyrics of six songs. Stimuli were selected from a database of successful chart songs, half of which also appeared as INMI inducers in an earworm database ("earwormery") compiled by the researchers of the study. They successfully triggered IMNI through both musical and written cues presented in a counterbalanced order. Their choice of stimuli from top charts and a large earworm database addressed the importance of stimuli selection, a technique that is mimicked in the current project. Results from Floridou et al. indicated that INMI could be induced at comparable levels by both listening to a tune and recalling the lyrics, and it demonstrated that triggering earworms can be even more successful in a controlled lab setting.

Motor Involvement

The connection of motor involvement to music is often studied in terms of rhythmic perception or musical performance. In a review by Krumhansl (2000), the author concluded that the extant evidence suggests that an underlying temporal patterning in music provides a perceptual framework for remembering events in time. This supports the idea of the unique temporal aspect of musical imagery. Krumhansl also asserted that the existence of a fundamental pulse potentially suggests that a common internal oscillator may affect a variety of behaviors; this assumption carries with it an implied link between motor performance and the perception of rhythm. Chen, Penhune, and Zatorre (2008) conducted two functional magnetic resonance imaging (fMRI) studies to determine if motor regions of the brain were still involved during passive music listening. They found that perceptual events are often related in an inextricable manner to motor actions. Importantly, their work revealed that participants were primed for action when they heard music, regardless of whether they consciously planned to move or not. This study demonstrates the close tie between music listening and movement, a link important in the design, hypothesis, and conclusions of the current study.

There have been a number of studies in the past that have investigated the role of motoric involvement and music, but few have probed the interaction of this involvement with INMI. Williamson et al. (2011) classified rhythm as an associative memory trigger, observing that it can be comprised of heard or felt rhythmic activation. No INMI studies to date have directly investigated the potential relationship between movement and earworm likelihood; this is another shortcoming in the INMI literature that fails to move beyond descriptive data. Floridou et al. (2012) observed a positive correlation of INMI frequency and pleasantness with a body measure that explored musicality through bodily responses to music, from the Goldsmiths Musical Sophistication Index. The researchers discussed the idea that this correlation may potentially have another mechanistic role in the experience of earworms. "It may be that people who hum, sing, tap, or clap along with music experience more frequently INMI as a result of an increased activation of areas of the brain related to musical production" (p. 304). Chen et al. (2008) suggest that tapping synchrony engages the presupplementary motor area, the supplemental motor area, the dorsal premotor cortex, the dorsolateral prefrontal cortex, the inferior parietal lobule, and lobule VI of the cerebellum. These areas of the brain contribute to control of movement, planning movement, working memory, cognitive flexibility, interpretation of sensory information, and motor control. This elaborate cognitive activation could mean that engaging with music kinetically makes music more memorable, and thus induces earworms more easily. The present study included measures that examine how often participants move along to music and the levels of movement during the study.

Williamson and Müllensiefen (2012) discussed a hypothesis that "frequent activations of the brain areas with singing is related to more frequent spontaneous activations that are not under conscious control" (p. 1129). They asserted that the relationship between INMI occurrence and singing cannot be unidirectional and simple because previous research has not supported singers having the most frequent earworms. One study in Williamson and Müllensiefen (2012) used data gathered from 1,536 participants through the earworm database (earwormery.com). Researchers examined scores that investigated relationships among obsessive-compulsive (OC) tendencies, general experiences of INMI, and levels of musical experience and training. The primary analysis included latent factors of musical behavior (musical practice, music professionalism, listening engagement, singing) and INMI factors (frequency, length, unpleasantness, disturbance). Results revealed that the one behavior observed to retain significant predictive influence was singing.

Zeigarnik Effect

The condition characterized by melody truncation was included to investigate the Zeigarnik effect in the context of music. This effect describes how an interrupted task is more memorable than a completed one (Green, 1963). This effect, specifically in regards to music and INMI, has not been widely studied. Hyman et al. (2013) also investigated the Zeigarnik effect and found no difference between interrupted and uninterrupted songs. They did observe evidence of the effect based on participants imagining music immediately after hearing it, thus the tune being personally unfinished. When people continued to mentally "hear" songs after class ended, the tunes were more likely to mentally return before the next class. The current project aimed to observe the immediate Zeigarnik effect as noted in the Hyman et al. study. The idea is that an incomplete musical phrase will tend to carry on in the mind of the listener as he/she will be more actively imagining the tune in effort to complete it. Therefore, the assumption is that an incomplete phrase will "stick" more readily in the minds of participants as an earworm than will a completed phrase.

Hypotheses and Overview

The current study takes an experimental approach to earworm induction targeted at ascertaining factors not fully investigated in the extant literature. The studies described above suggest that it is possible to induce INMI in a lab setting, but this technique has not yet been harnessed to investigate the mechanisms that underlie earworms. This study aimed to examine the effect of motoric involvement (through vocal and physical participation) and melody truncation on the effectiveness of earworm induction.

The primary hypothesis claimed that any involvement (vocal or physical) with music would be more effective than passive listening in inducing earworms. A secondary hypothesis stated that a higher level of activeness in participation with the music would result in increased vividness of INMI and more frequent triggering of INMI. The second main hypothesis was based on the Zeigarnik effect; the truncated melody was predicted to achieve INMI induction more effectively than hearing it all the way through without participation. Despite passive listening, an unfinished melody was hypothesized to elicit a sort of pseudo-motor activity because the segment of song would insist completion as auditory imagery, and this would activate memory and recall functions in the participant. Other subsidiary points of interest involve the vividness, length of INMI, and number of fragments in regard to participation with music.

For this study, participants were recruited through Experimetrix (the scheduling system used to recruit General Psychology students) and by word-of-mouth advertising. A between-subjects design was used. The dependent variables related to INMI were: frequency of the INMI within conditions and within levels of participation, frequency of the stimuli occurring as INMI, length, vividness, and fragmentation. The independent variables were originally the presentation and directions given when the song played, but levels of participation later became an independent variable. One condition heard the full song played through and one heard the melody truncated in the middle of a line; these two listen-only conditions were instructed to "Remain still and listen carefully." The remaining two conditions also heard the complete song, but the instructions indicated to participate as the music played. One condition was told to "tap, dance, or sway" and the other condition was told to "sing, hum, or whistle" along.

Method

Participants

A sample of 123 participants took part in this experiment; three were excluded due to an over write in data. For all analyses, 120 participants (57 male, 63 female), aged 18–59 (M = 20.5, SD = 5.1), were included. Of this group, 10% identified as music majors; 40.8% stated they currently play an instrument, and 75% reported that they had played an instrument in the past. The range of time that participants reported listening to music was 1–72 hours per week (M = 15.7, SD = 14.4). Recruitment announcements of the experiment were made to music majors at Wednesday Recital Hour and were also announced for extra credit in Music Lecture classes. In addition, there were public announcements on several University of Arkansas social media groups calling for anyone to contact the experimenter if interested in the study. A majority of participants (N = 92) were recruited through Experimetrix and were compensated with 0.5 credit for a General Psychology course. Most of the subject pool were comprised of undergraduate students, but a few (less than five) who responded to the posts on social media were university faculty or members of the community. All subjects were randomly assigned to one of four conditions.

Materials

An electronic questionnaire was created in MediaLab for this study. Stimuli tunes were chosen based on several different aspects (see Table 1). Two songs ("Call Me Maybe" and "Who Let the Dogs Out") appeared frequently on online listings of prominent earworms posted over the past ten years, and one ("Royals") was chosen because of its recent popularity. Williamson and Müllensiefen (2012) analyzed a large group of songs to ascertain qualities of INMI; they described popularity and recency as two major factors that drive earworm occurrences. The last stimulus choice ("Ob-La-Di, Ob-La-Da") was made in order to include an older selection. This methodology resembles the selection technique used by Hyman et al. (2013) whereby they chose three songs from the Billboard Hot 100 and three songs by The Beatles. In that study, participants were equally likely to experience contemporary music and Beatles music as INMI. All songs chosen for the current study fulfilled the qualities of INMI listed by Kellaris (2001): repetition within the musical stimulus, simplicity, and incongruity. All songs were distributed equally among the four conditions during data collection.

A dot tracking task was created for this experiment. It was a five-minute video file that featured a large white dot (approximately 2.5 inches in diameter on the screen) meandering around a black screen at a slow to moderate tempo. Participants were asked to follow the dot as closely as possible with their cursor using the attached mouse. This task was designed to bore participants because low attention states have been shown to be most conducive to earworm induction. Williamson et al. (2011) classified one prime situation for earworm induction as "mind wandering" (p. 272), a low attention state also discussed by Williamson and Müllensiefen (2012). Data from Hyman et al. (2013) revealed that many activities during which INMI was experienced reflected a low cognitive load. The five-minute length reflects the length of interpolation tasks previously used in the literature (Floridou et al., 2012; Hyman et al., 2013).

Design

The questionnaire featured several different parts. The first was a basic demographic questionnaire given to all participants. After the demographic questions, participants were played a song with instructions varied according to one of the four conditions. No mention was made to dwell on the song after its completion. Participants in the Listen Only, Vocal, and Movement conditions heard the stimuli played all the way through. Those in the Truncation condition heard the stimuli played much of the way through (see Table 1 for exact times) with an abrupt end in the middle of a phrase. At the end of music exposure, participants were instructed to follow a dot around the screen for five minutes while sitting in silence. They were asked to try and keep the mouse as close to the center of the dot as possible and told they would have the first few seconds to put the mouse on the dot.

Table 1
Stimuli Information

Song	Artist	Length*	BPM	Reason Chosen
Call Me Maybe	Carly Rae Jepsen	3:12 & 2:46	120	recently popular, listed as popular earworm
Who Let the Dogs Out	Baha Men	3:14 & 2:42	129	prominently listed as popular earworm
Royals	Lorde	3:09 & 2:45	85	recently popular (top of many charts in 2013)
Ob-La-Di, Ob-La-Da	The Beatles	3:08 & 2:46	113	very popular artist, not recently popular

* Lengths were edited to remove silence at end of tunes and to end at approximately the same time upon completion. The shorter lengths indicate times for the Truncation condition.

Post task questions were intended to capture several dimensions of the earworm experience. Major points of interest included on the post task questionnaire were familiarity of stimuli, INMI induction (both during dot task and later in question session), what music had been imagined, and aspects of the experience such as vividness, length of time, and song fragments. The next set of queries differed by condition; these addressed the behavior of the participant during the music-listening portion at the beginning of the study. All participants were asked how active they participated vocally and with movement; they rated this on a Likert-type scale from 1–7. All subjects were also asked about their normal involvement (physically or vocally) with music, and they answered frequency on a 1–7 Likert-type scale. The final questions in this study explored their general earworm experience. Participants responded how frequently INMI occurs in their lives and how annoying they found the phenomenon. After the sound-attenuated booth portion of the experiment, subjects were debriefed by the experimenter and asked a question about any stress experienced during the dot tracking task.

Procedure

A single-trial design targeting only naive participants was used for this study. Participants completed this study using Sennheiser PXC 450 headphones in a sound-attenuated booth in the Music Cognition Lab. All subjects were assured that their information would be kept completely confidential and that they were free to withdraw from participation at any point and for any reason. Data collection took place over a period of approximately three weeks, starting on 14 February 2014 and ending on 9 March 2014. Sessions had a mean length of about 15 minutes, ranging from a little less than 8 minutes to a little over 21 minutes.

Results

A chi-square test revealed no significant difference of INMI induction during the dot task between the four conditions ($x^2 = .921$; $df = 3$; $p = .820$), but this does not nullify support of the first main hypothesis. The data from the questionnaire revealed that many people in each condition participated with the music in ways that caused overlap between the conditions. In the Listen Only and Truncation conditions, participants were explicitly instructed to “be still” and listen carefully; the Vocal condition was instructed to “sing/hum/whistle” along with the music, and the Movement condition was to “tap/move/dance” along with the music. Data from the questionnaire revealed a widespread compulsion to move along to the music. There were only 19 participants (31.6%) total who sat still and silent in the two conditions of passive listening (Listen Only and Truncation). Of the 60 subjects in these two conditions, the majority (n = 39) reported moving in some way to the music, and some (n = 17) reported participating vocally. In this same group, 15 participants (Listen Only n = 9; Truncation n = 6) participated both physically and vocally with the music. All but one (96.6%; n = 29) subject in the Vocal condition also moved during the music, and 36.6% (n = 11) of the Movement condition also participated vocally. Among all participants in the study, 55 people (45.8%) both moved and vocalized in some way during the listening portion. The inability to keep still among people in the study made it impossible to compare across conditions as intended.

During the dot task, 69 participants reported experiencing INMI. All but one reported that the stimulus song was playing in their heads, and seven participants imagined other music in addition to or instead of the stimuli. Of the 69 who experienced INMI during the dot task, all but three reported hearing fragments repeat. These 66 participants recorded fragment repetition numbers ranging from 3–50 with a mean of 13.14 fragment repetitions (SD = 11.57). Of all fragments reported, 55 participants recorded the chorus as either the repeating fragment or one of the repeating fragments. Out of all subjects, only 22 reported earworms during the dot only; the other 47 people who recounted dot task INMI also experienced it during the question session.

Though not significant, the relationship between conditions and INMI induction during the question session resulted in bigger differences than INMI induction during the dot task (see Table 2). Of the 70 participants who reported INMI during the question session, 23 experienced earworms during only that occasion and not during the dot task; 57 in this group reported imagining the stimulus song, and five subjects within this 57 imagined other music in addition to the stimuli. Of these 70 subjects, 65 reported hearing fragments repeat with mean of 11.91 (SD = 9.42) and range of 1–50 fragment repetitions. Most participants (n = 49) recorded the chorus as the fragment that repeated. Out of the participants who experienced INMI during the question session, 54.29% (38 subjects) recorded that the same music had played in their heads at the beginning of the set of questions. A large majority (89.47%) of this group reported imagining the stimulus song. Of the 32 who said their earworms were not present at the beginning of the questions, 23 (71.86%) reported imagining the stimulus song.

Due to the large population of participants who moved and/or vocalized despite instructions against it, the data were also reanalyzed according not to how the participants were instructed, but to what they actually did. This required a division of subjects into three different groups: participants who reported that they both moved and vocalized (n = 55; 45.8%), subjects who moved but did not vocalize or who vocalized but did not move (n = 45; 37.5%), and subjects who neither moved nor vocalized (n = 20). Those who only moved or only vocalized were grouped together because of the very small number of participants who participated solely vocally (n = 3; 16.67%) along with the music. The analysis of this grouping resulted in significant differences in INMI induction (see Table 3).

Table 2
INMI Induction by Condition

Those listed experienced INMI	**INMI at all during study**	**INMI during dot**	**INMI during questions**	**INMI during both**
Listen Only	22 subjects - 73.3%	16 subjects - 53.3%	17 subjects - 56.7%	11 subjects - 36.7%
Truncation	20 subjects - 66.7%	18 subjects - 60.0%	13 subjects - 43.3%	11 subjects - 36.7%
Vocal	26 subjects - 86.7%	19 subjects - 63.3%	21 subjects - 70.0%	14 subjects - 46.7%
Movement	24 subjects -80.0%	16 subjects - 53.3%	19 subjects - 63.37%	11 subjects - 36.7%
Chi-Square Tests	x^2 = 3.727 d.f. = 3 p = .293 not significant	x^2 = 0.921 d.f. = 3 p = .820 not significant	x^2 = 4.800 d.f. = 3 p = .187 trending towards sig	x^2 = 0.944 d.f. = 3 p = .815 not significant

Table 3
INMI Induction by Participation

*Those listed experienced INMI**	**INMI at all during study**	**INMI during dot**	**INMI during questions**	**INMI during both**
Moved AND Vocalized (N=55)	48 subjects - 87.3%	35 subjects - 63.6%	40 subjects - 72.7%	27 subjects - 49.1%
Moved OR Vocalized (N=45)	32 subjects - 71.1%	25 subjects - 55.6%	20 subjects - 44.4%	13 subjects - 28.9%
Neither (N=20)	12 subjects - 60.0%	9 subjects - 45.0%	10 subjects - 50.0%	7 subjects - 35.0%
Chi-Square Tests	x^2 = 7.340 d.f. = 2 p = .025 significant	x^2 = 2.196 d.f. = 2 p = .334 not significant	x^2 = 8.831 d.f. = 2 p = .012 significant	x^2 = 4.414 d.f. = 2 p = .110 trending towards sig.

*Percentages indicate INMI induction out of those who did move/vocalize, both, or neither.

To investigate the secondary hypothesis of activity level relating to vividness of INMI, a non-parametric Spearman's rank correlation coefficient was examined. Activeness of physical participation was not correlated with INMI vividness during the dot task (r_s = .048; *p* = .725) nor with INMI vividness during the question session (r_s = .041; *p* = .757). To investigate possible effect of participation on earworm vividness, a Spearman's rank correlation coefficient was used to analyze correlations among the aforementioned three groups (moved and vocalized, moved or vocalized, neither) and INMI vividness during the study. There was no significant correlation in regards to INMI vividness during the dot task (r_s = .132; *p* = .150) nor among the three participation groups and the question session INMI vividness (r_s = .173; *p* = .152).

The large percentage of people who moved made it necessary to analyze the amount they reported moving per condition. This led to several Mann-Whitney U analyses probing the activeness reported (Likert-type 1–7 scale) of both physical and vocal participation during the music listening portion of the study and possible significant differences between conditions. Surprisingly, the group instructed to move were more vocally active when compared to those instructed not to move. The Movement condition group was significantly more vocally active when individually compared to the Listen Only condition group (*U* = 19.0; *Z* = –2.388; *p* = .020) as well as more vocally active than the Vocal condition group (*U* = 95.0; *Z* = –2.096; *p* = .040), but it was only marginally significantly different from the Truncation condition (*U* = 21.0; *Z* = –1.947; *p* = .062). Contrastingly, those in the Vocal condition who were instructed to sing/hum/whistle reported significantly less physical participation during the music portion (see Table 4). On average, the Vocal condition participants were significantly less active in tapping/moving/dancing when compared to all other groups individually (compared with: Listen Only *U* = 198; *Z* = –2.131; *p* = .033, Truncation *U* = 154; *Z* = –2.142; *p* = .032, Movement *U* = 265.0; *Z* = –2.621; *p* = .009). Activity level of physical participation was found to be unrelated to experiencing earworms at any point in the study (*U* = 680.0; *Z* = –.815; *p* = .415). Activity level of vocal participation was also analyzed, and no significant difference was found (*U* = 133.5; *Z* = –.275; *p* = .290).

Another factor queried in the study concerned the usual amount of physical and vocal participation with music per participant. In two separate questions, subjects answered "yes" or "no" to normally engaging with music by humming/singing/whistling and tapping/moving. Based on chi-square analyses, those who normally move (x^2 = 6.300; *df* = 1; *p* = .012) or normally vocalized (x^2 = 8.392; *df* = 1; *p* = .004) were significantly more likely to experience earworms at some point during the study. Those who normally moved (*n* = 106) then ranked the frequency of their general participation with each by choosing: Always, Very Often, Often, Sometimes, Rarely, Very Rarely, Never. Though there was no statistical significance found with a Mann-Whitney U test comparing how often people generally move and contraction of earworms during the dot task (*U* = 1229.5; *Z* = –.838; *p* = .402), there was a significant relationship between general movement frequency and INMI induction during the questions (*U* = 940.5; *Z* = –2.774; *p* = .006). Those who reported moving more often in general experienced more earworms during the questions. Those who reported they normally participated vocally with music (*n* = 99) also marked how often they generally sang/hummed/whistled along with music using the same scale used for movement activity. Similar to the comparison of physical participation frequency, there was only a trend towards significance between the vocal participation frequency with INMI during the dot (*U* = 935.0; *Z* = –1.679; *p* = .093), but there was a significant relationship between how often participants participated vocally with music on average and INMI induction during the questions (*U* = 770.0; *Z* = –2.915; *p* = .004). Just as with the frequency of physical participation with music, those who normally vocalize with music experienced more earworms.

Gender was found to have a significant effect (x^2 = 6.277; *df* = 1; *p* = .013) on earworm induction during the dot task using a chi-square test. A total of 43 female participants (68.3% of women) experienced INMI during the dot task, but only 26 male participants (45.6% of men) successfully had earworms during the dot. Unlike during the dot task, the influence of gender was not significant during the question session (x^2 = 1.452; *df* = 1; *p* = .228) nor for having INMI at all during the entirety of the experiment (x^2 = 1.362; *df* = 1; *p* = .243). Females were significantly more likely to report experiencing earworms during both inquiry points in the questionnaire; 50.8% of women in the study (*n* = 32) did, and only 26.3% of men (*n* = 15) recorded experiencing INMI during both the dot task and during the question session. Number of hours of reported music listening per week was not correlated with earworms

Table 4
Activity Level Relations to Instruction

	Movement activity level	Vocal activity level
Instructed to move (30 moved; 11 vocalized)	mean rank - 55.62; others = 46.04 U = 806.5; Z= -1.574; p.=.115	mean rank = 40.73; others = 26.87 U = 135; Z= -2.491; p.=.013
Instructed to vocalize (29 moved; 30 vocalized)	mean rank - 36.28; others = 54.43 U = 617; Z= -2,955; p.=.003	mean rank = 40.73; others = 26.87 U = 389.5; Z= -.483; p.=.629
All Mann-Whitney U reports are in comparison to all those not instructed to move or vocalize.		

induction at any point in the study (*U* = 1142.5; *Z* = –.899; *p* = .369). Music majors and non-music majors showed no significant difference (x^2 = 1.677; *df* = 1; *p* = .195) in INMI experience at any point in the study. The same held true for those who reported presently playing instruments versus those who do not (x^2 = 1.142; *df* = 1; *p* = .285); there was also no significant difference between those who played instruments in the past and those who did not (x^2 = 0.248; *df* = 1; *p* = .618). Familiarity with the stimuli (measured on a 1–7 Likert-type scale) also did not have a significant effect on INMI induction at any point in the experiment (*U* = 1273.0; *Z* = –.097; *p* = .923). Familiarity rating was only presented to those who had heard the song before. For three of the songs, over 90% of participants had heard the tune before the experiment. For the selected Beatles song, only 37% of participants (*n* = 10) who were played that selection had ever heard it before. The songs did not display significant differences in regard to triggering earworms.

The self-reported INMI experience frequency had a significant relationship to INMI induction. Using a Mann-Whitney U test, earworm induction at any point in the study was significantly higher (*U* = 634.5; *Z* = –4.331; *p* = .000) in those who reported more frequent INMI experience in general. The measure included: Several times a day, Every day, Weekly, Monthly, More seldom, Never. Of the sample, 55 subjects reported experiencing earworms multiple times a day; 41 recorded experiencing them every day. Together, every day and several times a day comprised 80% (*n* = 96) of all participants. Only 20 people (16.7%) reported weekly earworms. Just two participants said they experience INMI monthly, one person recorded experiencing INMI more seldom than monthly, and one reported never experiencing earworms before. Average INMI frequency was also significantly correlated with hours spent listening to music per week in a non-parametric Spearman's rank correlation coefficient (r_s = –.325; *p* = .000).

Of all participants, 36 reported some amount of stress or excess focus (hereafter, "dot stress") during the dot tracking task; this defeated the purpose of this low attention task. Those who experienced dot stress were significantly different in INMI during the dot task (x^2 = 9.628; *df* = 1; *p* = .002), but this population was not significantly different during the question session (x^2 = 0.163; *df* = 1; *p* = .686). Of the 36 participants who reported dot stress, only 36.1% (*n* = 13) experienced INMI, and 66.7% (*n* = 56) of the non-dot stress population reported earworms during the dot task.

Discussion

It was hypothesized that physical and vocal participation with music would increase the amount of INMI in participants. Though the conditions were not very useful in analyses, the primary hypothesis was supported by the data. Participants' unanticipated struggle in following instructions made it difficult to analyze the data according to the original condition assignments (see Table 5). Half the participants (those in Listen Only and Truncation conditions) were clearly instructed to "be still" as they heard the stimulus song. For the two participation conditions (Vocal and Movement), the caveat likely stemmed from the wording of the instructions; the Vocal group was not explicitly told to be still and the Movement group was not explicitly told to be silent. This was planned in the design because of fear that excessive restriction would cause participants to not engage naturally with the music. Due to the high number of subjects who moved, vocalized, or both, analyses relating to the conditions were pertinent only when looking at the level of activity in which people engaged during the music exposure portion of the study. In consideration of INMI induction in general, those who moved and vocalized were more likely than those who did not, and people who participated in one way were more likely than those who did neither. The sample that neither moved nor vocalized at all was considerably smaller than the other two (see Table 3), but both participation groupings were quite comparable in number.

Table 5
Physical and Vocal Participation by Condition

	Participated physcially	Particpated vocally	Both	Followed directions	Total Number
Listen Only	12	0	9	9	30
Trunca-tion	11	2	6	11	30
Vocal	---	Instructed to	29	1	30
Movement	Instructed to	---	11	19	30

It was interesting that participants in this study were so compelled to move to the music. Though activity level varied, the number of participants moving in any amount was approximately the same across all conditions and songs. Chen, Penhune, and Zatorre (2008) asserted that music may be catalytic in stimulating rhythmic movements based on their research and on work by Synder and Krumhansl (2001) and others; people often spontaneously synchronize actions with the beat of a tune through tapping feet or nodding along, regardless of musical training or ability. This was strongly supported by the data in the current study. The unsolicited movement and singing were inconvenient in consideration of conditions and random assignment, but it was fascinating from an observational research perspective. The tendency of participants to move and/or sing created the new groupings of data; this meant the division of the subject pool was no longer random. These participatory individuals may have gotten more earworms because of their general involvement with music or related background factor.

The second major caveat of the study was the notable dot stress experienced by 30% (n = 36) of participants. The purpose of this interpolation activity was to reach a low attention state, and the majority of subjects were successfully bored. Unfortunately, the wording and nature of the task caused some people to think of it as a game or view it as a test of vigilance. Those who experienced "immense" stress or "excessive" focus had far fewer earworms than those who did not during the dot task. This seems logical given that the purpose of the task was nullified by the dot stress, and thus the target attention state left unachieved by 36 participants. For this reason, INMI induction rate during the question session was additionally considered on its own, as a pair with the dot task, and for INMI experienced at all in the study.

One concern similar to that expressed by Liikkanen (2012a) should be considered; he noted that attempting to induce INMI at all might be criticized as a conceptual paradox. How could something "involuntary" be experimentally controlled or triggered? Liikkanen (2012a) points out the differences between involuntary memory recall and spontaneous or automatic or controlled memory recall, and he compares it to a administering an irritating skin paste that induces a rash. The paste provides a method of reliably triggering a rash even if the causal mechanisms are not well understood. In the present study, the purpose of analyzing INMI induction during the question session was in part to provide more data with which to compare to individual difference factors, such as frequency of earworms and normal amount of participation with music, to the two potential occurrences of earworms in the study. It was also useful in looking at possible correlations for those who experienced INMI at both points in the study. Liikkanen (2012a) suggested the need for future study on the phenomenology of "induced" versus "spontaneous" INMI experiences (p. 231); the current project attempted to do just that.

A greater percentage of participants reported experiencing the stimuli tunes as INMI during the dot task (98.6%) than during the question session (81.4%). This difference is most likely due to the recency of the song in relation to the dot task, but it is worth noting because of the difference between spontaneous and induced (cued recall) INMI. In the inquiry about current earworms during the post-task questions, no mention was made to the song previously played in the study. During debriefing, several participants mentioned that a song "popped into" their heads when the question was asked. Though cued by written words, this musical imagery still qualifies as INMI. It differs from the INMI experienced during the dot task in that nothing about the dot task could have cued the imagery. Earworms triggered in that task were theoretically due to recent exposure, to the low attention state, and potentially to familiarity and previous exposure. The fact that far fewer participants who felt dot stress experienced INMI supports the suggestion that less stressful activities seem to encourage more INMI occurrences.

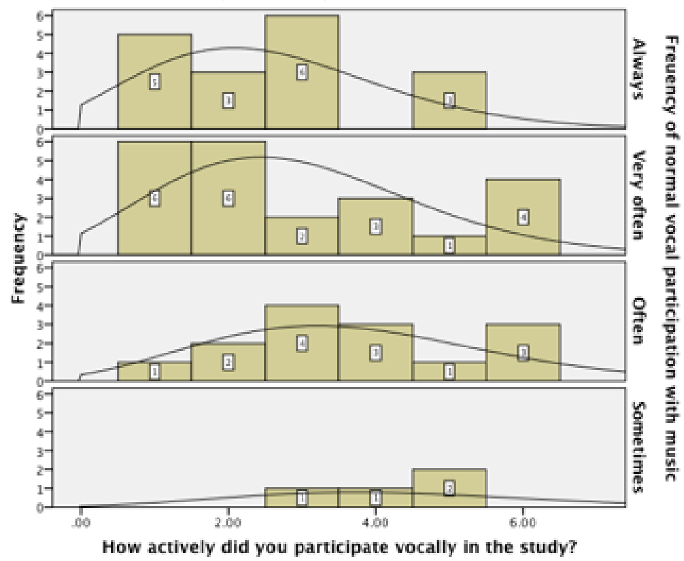
The main hypothesis was about the effect of outward motoric involvement on INMI induction, the second hypothesis was about how an unfinished phrase of music (as presented in the Truncation condition) would trigger a mental continuation of the melody. This pseudo-motor activity, supposedly through the Zeigarnik effect, was thought to have a bigger influence on inducing INMI during the dot task since it was directly after the music exposure. The idea was that the mind would finish the phrase; the incompletion was hypothesized to create repetitions that could influence later episodes of INMI. As evidenced by the existing, albeit scant, research, the data in this study revealed no support for the Zeigarnik effect influencing earworm induction. The familiarity of the tunes may affect potential Zeigarnik effects. This was the supported by low familiarity of one song that also had a low INMI rate in the Truncation condition. Since Ob-La-Di, Ob-La-Da was not as familiar, participants were less likely to continue the unfinished phrase once the music stopped abruptly (see Table 6).

Table 6
INMI During Dot Task by Song and Condition

Successful INMI during dot task		Conditions: Listen Only	Truncation	Vocal	Movement	Total
Song Heard: Call Me Maybe	Count	3	5	3	2	13
	% within Song Heard	23.1%	38.5%	23.1%	15.4%	100.0%
	% within Conditions	18.8%	27.8%	15.8%	12.5%	18.8%
	% of Total	4.3%	7.2%	4.3%	2.9%	18.8%
Who Let the Dogs Out	Count	4	6	3	4	17
	% within Song Heard	23.1%	23.1%	23.1%	23.1%	23.1%
	% within Conditions	18.8%	18.8%	18.8%	18.8%	18.8%
	% of Total	4.3%	4.3%	4.3%	4.3%	4.3%
Oh-La-Di, Ob-La-Da	Count	4	2	7	5	18
	% within Song Heard	22.2%	11.1%	38.9%	27.8%	100.0%
	% within Conditions	25.0%	11.1%	36.8%	31.3%	26.1%
	% of Total	5.8%	2.9%	10.1%	7.2%	26.1%
Royals	Count	5	5	6	5	21
	% within Song Heard	23.8%	23.8%	28.6%	23.8%	100.0%
	% within Conditions	31.3%	27.8%	31.6%	31.3%	30.4%
	% of Total	7.2%	7.2%	8.7%	7.2%	30.4%
Total	Count	16	18	19	16	69
	% within Song Heard	23.2%	26.1%	27.5%	23.2%	100.0%
	% within Conditions	100.0%	100.0%	100.0%	100.0%	100.0%
	% of Total	23.2%	26.1%	27.5%	23.2%	100.0%

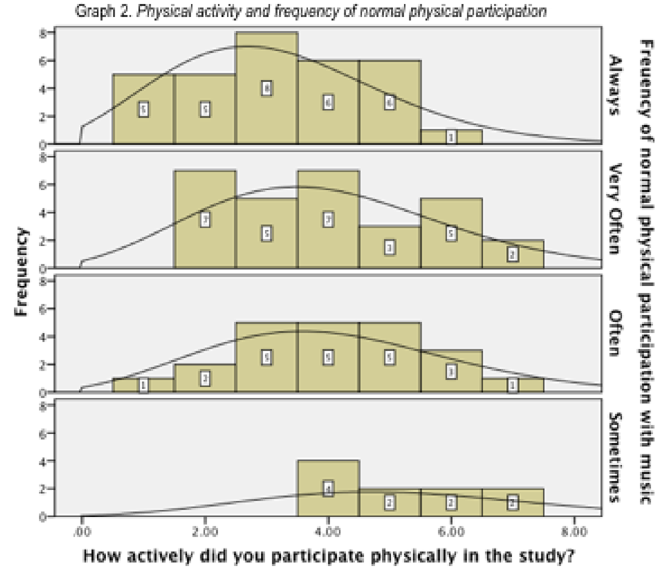
Details about how people moved and vocalized with the music revealed some interesting correlations. Almost everyone (96.7%) in the Vocal condition moved, but they had a lower mean average of activity level in physical involvement. This is perhaps because the instructions for that condition told participants to engage in a particular way, so though they were inclined to move spontaneously with the music, their vocal activity likely detracted from attention to their movement. Those in the Movement condition had an opposite reaction; those who vocalized reported to have done it more actively in comparison to the other conditions. This could have occurred because while they were already tapping or dancing along, participants might have been

Graph 1. *Vocal activity and frequency of normal vocal participation*



primed to get completely into the groove by singing or humming as well. These two observations of activity level could also be explained in another way; it could be due to relativity in perception. The Vocal group likely could have been more attentive to their singing/humming/whistling during the task. Later on during the questions, they were queried about their physical involvement, and thinking back they realized they did in fact move while they vocalized. Focus on vocal participation might have overshadowed an accurate rating of physical participation. Relative perception might also explain the difference in the Movement; that group was being physically active already, so they may have perceived their vocal participation as more active. These

Graph 2. *Physical activity and frequency of normal physical participation*



results may also speak to how people perceive vocal and physical activity differently.

Usual physical or vocal participation with music was very common among participants, and a large percentage of those who normally move/sing along to music experienced INMI throughout the study. No participants responded that they participated in either way Rarely, Very Rarely, or Never. Interestingly, participants who reported more frequent participation with music tended to report less active movement in the experiment. This is another potential correlation due to relative perception. Those reported only a moderate frequency (Sometimes; 4 on a 1–7 Likert-type scale) of usual movement had a higher mean activity level (see Graph 2). This could be explained by the fact that their physical participation in the study, whether instructed or spontaneous, felt like a great amount of activity relative to their customary participation. The effect, though not significant with vocal participation, does seem to follow a similar trend to the physical involvement. The lack of statistical power could be due to the smaller sample that participated vocally at all (see Graph 1).

A potential issue with the ratings for activity level is the scale and wording used in the experiment. Participants were asked to rate several measures on a 1–7 Likert-type scale. In retrospect, it may have been a better idea to include different anchor terms for activeness other than "minimally/maximumly active." The distribution patterns found in the song comparison suggest that at least some of the rating differences were likely due to speed of movements. This scale was chosen to avoid classifying length over amount (or vice versa) and to account for the many different ways participants may choose to physically/vocally participate with music, but the vagueness of the measure had weakness as well. The effect of vividness of INMI was part of a secondary hypothesis. Data revealed no significant correlations between vividness, and this probably had a lot to do with the vagueness of this scale as well. Vividness is a term that needs to be clearly operationalized in the design of the study to yield useful results; this is something future INMI studies can work to improve.

Bailes (2007) reported that the majority of musical imagery episodes recorded were a "repeated fragment" instead of a full run through (p. 562). The majority of participants reported hearing a fragment repeated as INMI, and most of these heard the chorus. This held true both during the dot task when almost all imagined the stimuli songs and during the question session when more experienced other songs as INMI. This finding coincides with previous earworm research that had noted the fragmented quality of INMI (Brown, 2006; Halpern & Bartlett, 2011) and the prevalence of the chorus (Beaman & Williams, 2010; Hyman et al., 2013). Margulis (2013) made interesting observations about how music tends to repeat in the mind:

> The unusual repetitiveness of musical imagery parallels and exaggerates the unusual repetitive ness of actual music in the world. The relationship between earworms' repetitive loop ing and the uncommon repetitiveness of actual music seems striking, yet to my knowledge this connection has not been pointed out or investigated. (p. 76)

The present study queried about repetitive fragments in efforts to extend the knowledge base on this area, but there were potential problems with the chosen measures. Number of fragments was requested in the questionnaire, but the number could be a confusing one to calculate if the earworm had persisted from the dot task through the question session. Self-report also causes problems; it was not necessarily easy for participants to answer the number of fragments of an INMI episode over five minutes of a boring task. It might have been even more difficult during the questions, while they were working on answering other inquiries, to accurately estimate the number of times a fragment repeated. A better measure is needed to calculate the true repetitiveness of earworm fragments.

Those who reported more frequent INMI in life tended to have more earworms in the study and tended to listen to more music per week. This finding supports previous research that suggests a high level of association exists between musical exposure and INMI frequency (Bailes, 2007; Hyman et al., 2013; Liikkanen, 2012b; Williamson & Müllensiefen, 2012). The "at least weekly" reports of INMI experience (96.7%) reported in this experiment were higher than the often-cited statistic (91.7%) observed by Liikkanen (2008) in a very large Internet survey sample. The much smaller sample size in the current study might account for this difference.

Music majors experienced approximately the same amount of INMI as non-majors, and playing an instrument currently or in the past had no effect. The lack of musician/non-musician variance contrasts some previous findings (Hyman et al., 2013; Liikkanen, 2012a) but supports others (Beaman & Williams, 2010). The current study did not use the same types of scales to delineate musicians and non-musicians as previous studies, so comparison is more general. The role of gender has received mixed support in the extant INMI literature. The current project revealed a significant difference between females and males in earworm induction. In congruence with the work of Liikkanen (2012a), females contracted more earworms, a difference that was not present in works by Beaman and Williams (2010) nor in Hyman et al. (2013). The gender difference was not significant in the question session, but it was in both the dot task and in INMI induction overall. This difference between dot task INMI and question session INMI suggest potential gender bias in cued recall versus spontaneous earworm experiences. Future earworm research should investigate this possibility.

Involuntary Musical Imagery is an extremely common, multi-faceted human experience. The present study has added to the small body of experimental earworm induction with details about the INMI experience such as frequency, vividness, and repetition. This experiment investigated aspects relevant to both pseudo- and outward motoric involvement with music and its effect on contracting earworms. Induction of INMI in a controlled lab setting was very successful with songs of various familiarity, recency, and popularity. Evidence did not support the Zeigarnik effect in music as a method that increases probability of experiencing INMI. More careful consideration should be taken concerning the selection of measures for activity levels and fragmentation, and future studies should elaborate on the effect of participation with music on INMI induction. The conclusions drawn from the current data are that individual differences such as general INMI experience frequency and amount of music heard per week do affect the success of earworm induction, and that physical and vocal involvement with music increases the likelihood of triggering INMI.

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