Inducing and manipulating earworms

A novel indirect method for capturing involuntary musical imagery under varying cognitive load

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Abstract

Involuntary musical imagery (INMI), or “earworms”, refers to the ubiquitous experience of a musical fragment coming into the mind without effort and then repeating. Studies have provided conflicting reports regarding the relationship between INMI and cognitive load, such the effect of a systematic cognitive load increase on INMI occurrence and duration remains unknown. In the present study, 200 participants watched and immediately evaluated two non-dialogue, music-only film trailers. Subsequently, they either closed their eyes for 5 mins (Baseline), or engaged in one of three dot tasks (Easy, Medium, and Hard) of varying challenge and attentional demand (low, medium and high cognitive load, respectively). Finally, they completed a novel “Mind Activity Questionnaire”, which allows for indirect sampling of INMI experiences rather than direct questioning. A second Mind Activity Questionnaire was completed 24 hours later. Overall, a significant negative linear trend was found. At Baseline, 65% of people reported an experience of INMI. This rate reduced to 32.5% in the Easy condition with further reductions observed in both Medium and Hard conditions, which did not differ significantly from each other. Measures of INMI frequency, the number of tunes experienced as INMI, and INMI duration followed the same pattern as the induction rates. In the 24-hour follow-up, 21% of participants reported INMI experiences. This study supports the hypothesis that INMI occurrence, frequency, and duration relate to spare cognitive capacity and demonstrates an ecologically valid laboratory paradigm for covertly inducing and documenting INMI experiences.

Keywords: spontaneous cognition, involuntary musical imagery, earworms, cognitive load

Introduction

A large proportion of our thoughts are spontaneous in nature (Killingsworth & Gilbert, 2010; Song & Wang, 2012). Within this broad category, involuntary musical imagery (INMI hereafter) is experienced by over 90% of people at least once a week (Liikkanen, 2012a). Colloquially known as “earworms”, INMI describes the internal experience of a short musical piece, which comes to the mind unintended and then repeats itself (Floridou, Williamson, Stewart, & Müllensiefen, 2015; Williamson et al., 2012).

To date, research on INMI has focused on the phenomenological experience. The duration of an INMI episode is reported to range from a few minutes to several hours (Beaman & Williams, 2010) and familiar music with lyrics is experienced as INMI more often than instrumental music (Liikkanen, 2012a). The valence attributed to INMI is mostly positive (Beaman & Williams, 2010; Floridou & Müllensiefen, 2015; Halpern & Bartlett, 2011; Hyman et al., 2013) although people can be significantly troubled by the experience and employ amelioration strategies such as listening to the INMI music or distracting themselves with other music or verbal activities (Williamson et al., 2014).

Several factors are associated with the onset of the INMI experience. Williamson et al. (2012) found that recent and repeated exposure to the music is a prevalent INMI trigger. This finding accords with Liikkanen’s (2012a) and Beaman and Williams’ (2010) reported associations between INMI frequency and everyday musical engagement. Other factors related to INMI onset as reported by Williamson et al. (2012) are memory triggers (association, recollection, and anticipation), affective states (mood, stress, and surprise) and low attention states (dreams and mind wandering).

Retrospective and experience sampling studies have found a propensity for INMI to occur in low attention states (Floridou & Müllensiefen, 2015, Liikkanen, 2012a, Williamson et al., 2012), where individuals are engaged in monotonous and undemanding tasks. Similar mind states have been identified as a trigger for other forms of spontaneous cognitions such as involuntary autobiographical memories, involuntary semantic memories, and mind wandering (Berntsen, Staugaard, & Sorensen, 2013; Killingsworth & Gilbert, 2010, Kvavilashvili & Mandler, 2004; Mazzoni, Vannucci, & Batool, 2014; McKiernan, D'Angelo, Kaufman, & Binder, 2006; Shlagman & Kvavilashvili, 2008; Vannucci, Batool, Pelagatti & Mazzoni, 2014; Vannucci, Pelagatti, Hanczakowski, Mazzoni, & Rossi Paccani, 2015). In controlled lab studies, undemanding low attention tasks (e.g. looking at a fixation cross) have been used successfully to induce a resting state associated with the onset of mind wandering (Mason et al., 2007; McVay & Kane, 2009; Teasdale et al., 1995).

While much can be learned about INMI from self-report and diary studies, it is important to be able to induce INMI within a controlled laboratory context in order to investigate the reliability of retrospective self-reports and to learn more about the cognitive factors that play a role in its onset, maintenance or termination. So far, three studies that have attempted to induce INMI in the laboratory have reported their induction rates, indicating, for the most part, that INMI can be triggered easily in the majority of people (32% induction rate, Byron & Fowles, 2013; 65%, Floridou, Williamson, & Müllensiefen, 2012; 75%, Hyman et al., 2013).

Floridou et al. (2012) compared two INMI induction procedures, namely music exposure and memory triggers, where participants were asked to complete written missing song lyrics. We selected songs that were either high or low in their potential to trigger INMI, based on INMI reports from a retrospective survey (http://www.earwormery.com; see Floridou et al., 2015; Müllensiefen et al., 2014; Williamson et al., 2012; 2014). Post induction, participants complete a 5 min visual task and were then asked if they had experienced INMI during that time. Both induction paradigms and sets of songs were equally successful in inducing INMI. There was also a global recency effect indicating that the last heard song was most likely to be experienced as INMI.

Building on these findings Byron and Fowles (2013) investigated the effect of music exposure timeline (recent and repeated) and levels of processing (autobiographical and semantic) on INMI induction. Participants were exposed to high or low familiarity songs and answered questions about either the song's connection to their life (autobiographical) or general questions about the song (semantic). At the end of the session participants reported on INMI occurrence and triggers. Reports were collected 6 times a day for the following 3 days, and the results revealed INMI induction effects of song familiarity and recency, but not levels of processing.

Taken together, these studies have established the following findings that both align with self-reports and that are related to the design or analysis of the present study: INMI induction through music exposure is highly effective; recency, the tendency to experience INMI relating to the last piece of music heard, is a common and consistent feature of INMI induction; familiarity with music improves the chances of INMI induction; INMI can appear many hours after an initial induction.

Laboratory studies have also investigated the cognitive factors that influence successful INMI induction. Hyman et al. (2013) investigated the role of cognitive load, the extent to which a task requires executive resources such as working memory. After a period of music exposure, participants completed either easy or challenging Sudoku puzzles or easy or challenging anagrams. They then reported on the duration of songs replaying in their head during the tasks. In both experiments, the authors found that INMI duration was higher during both easy and challenging tasks. While this finding seems, at first sight, counterintuitive, the authors suggest that spare cognitive resources were present in both conditions, due to boredom (easy condition) or task abandonment (challenging condition).

Thus, while the easy and challenging tasks were intended to reflect conditions of low and high cognitive load respectively, the levels of load across the two tasks had similar effects. This situation precludes any clear conclusions from being drawn concerning the impact of cognitive load on INMI induction and motivates further enquiry into this question looking not only INMI duration, but also occurrence and frequency.

The present study

The main aim of the present study was to investigate the role of graded cognitive load on INMI induction following musical exposure. Drawing on working memory theory (Baddeley & Hitch, 1974; Baddeley, 2002) we designed a dot task which, according to the instruction given, involved sustained attention throughout the tasks and more specifically (1) visual attention only, (2) visual attention and phonological memory, or (3) visual attention, phonological memory, and executive control. These three tasks equated to conditions of low, medium, and high cognitive load and will henceforth be referred to as “Easy”, “Medium”, and “Hard” conditions, respectively. By comparing INMI occurrence, frequency, and duration across these three conditions, as well as a “Baseline” condition in which there was no cognitive task, we sought to test the hypothesis that INMI diminishes as cognitive load increases.

An additional aim of the present study was to introduce a method of probing participants about their INMI experiences in an indirect (covert) way, in contrast to all previous INMI laboratory induction studies (Beaman et al., 2015; Byron & Fowles, 2013; Campbell & Margulis, 2015; Floridou et al., 2012; Hyman et al., 2013) where, at the point of probing, participants were aware that INMI was the focus of interest because they were asked whether the music they had been exposed to had been “stuck” in their mind. An indirect approach, where the participant is unaware of the experimental goals, is preferable to direct questioning regarding INMI and is more comparable to studies of involuntary memory related phenomena such as mind-pops, mind wandering, and involuntary autobiographical memories where participants are asked to report general task unrelated thoughts (Kvavilishvili & Mandler, 2004; Schooler et al., 2011; Vannucci, Pelagatti, Hanczakowski, Mazzoni, & Rossi Paccani, 2015). Furthermore, comparative research between INMI and spontaneous cognitions in other modalities (visual, verbal) will enhance understanding about INMI's unique characteristics, as well as providing indications as to their function. In the present study both a direct and an indirect approach to INMI probing were employed, in order to allow comparison of both methods.

Method

Participants

A total of 200 participants (116 female), ranging in age from 17-65 (M = 23.9, SD = 8.2) took part, either for course credit or £5 compensation. They were first year undergraduate psychology students or self-selected students, staff or visitors of Goldsmiths, University of London. The study protocol was approved by the Ethics Committee of Goldsmiths, University of London, UK. All participants gave written informed consent for their participation in the study.

Stimuli

For the music exposure, two original film trailers with prominent soundtracks were used. For variety and balance we selected one film trailer that contained music with lyrics (film “Pretty Woman”, 1990) and the other featured instrumental music (film “Casino

Royale", 2006). The clips were matched in duration (approximately 90 seconds) and neither had any verbal content.

Material

A "Film Appraisal Questionnaire" (see Appendix A) was developed, to measure participants' familiarity, liking, engagement, and emotional response to different aspects of the film clips, using a 5-point Likert scale.

In order to probe indirectly for INMI experiences, a new "Mind Activity Questionnaire" was developed (see Appendix B). This assessment method first probed participants about general mind wandering ("Did your mind wander to any aspect of the film during the period of silence/while playing the dot game?"). If the answer was "yes" then the remaining questions prompted participants to report any visual, musical or speech-based mental imagery, respectively, that had occurred during the 5-min post exposure task. Information regarding non-musical imagery (visuals and speech) was requested in order to support the covert nature of the study and mask our specific interest regarding INMI. Participants were also asked to estimate how much of the 5 min time period had been occupied by each type of imagery, to report the specific content of any imagery, and to indicate the level of control they felt in the initiation of the imagery. For the last question a 7-point rating scale was used (1. "I deliberately generated this imagery" – 7. "The imagery happened outside of my control").

For the direct paradigm (see Appendix C) participants were asked if they had experienced any INMI during the silence period and if 'yes', they were also asked to report the percentage of time they had been occupied by the INMI as well as to identify the music (artist and/or title) that was experienced as INMI.

Inducing and manipulating earworms

A version of the “Mind Activity Questionnaire” was created to capture participants’ thoughts in the 24 hours period after the end of the experimental session and the time they received the e-mail prompt to complete the questionnaire (Appendix D).

Procedure

One hundred and sixty participants were randomly assigned to one of each of the four ‘Indirect’ conditions (Baseline, Easy, Medium, Hard; 40 participants each). Participants were randomly allocated and tested in groups and were told that the experiment was about “Films and Attention”. All participants watched both trailers (Pretty Woman and Casino Royale) with order of presentation counterbalanced. Immediately following each trailer, participants were given a Film Appraisal Questionnaire form to complete.

After filling in the Film Appraisal Questionnaire, participants completed one of the four 5-min post exposure tasks, which corresponded to their assigned attention and cognitive load manipulation (Baseline, Easy, Medium, and Hard). In the Baseline condition, participants closed their eyes for 5 min and were alerted by the experimenter when the task was completed. In the Easy, Medium, and Hard conditions participants engaged in a version of a 5-min dot task. All dot tasks involved the presentation of a single dot on a screen, one per 1 second (the pace of which did not match the beat of the film trailer music); either blue or red in colour. For the Easy condition (low cognitive load), red and blue dots were presented in strict alternation at the set rate of one per second and participants were asked to make a mark on their paper every time they saw a blue dot. At the end of the presentation they were asked to add up the total number of marks they had made and write the total on their response form. For the Medium condition (medium cognitive load), the red and blue dots were presented in random order and participants were asked to count the blue dots silently in their mind (making no marks) and report the total at the end of the task. For the

Hard condition (high cognitive load), red and blue dots were presented in random order and participants were asked to count backwards in threes from one thousand each time they saw a blue dot. At the end of this task participants reported the last number they had counted.

After all groups had completed their 5 min post-exposure task they were given the Mind Activity Questionnaire to complete in silence. Following the Mind Activity Questionnaire, participants were asked if they knew the purpose of the experiment, and if so to volunteer details about the supposed aim.

In addition to these four conditions, a fifth group of 40 participants took part in the 'Direct' condition, which was identical to the Baseline condition but instead of completing the Mind Activity Questionnaire, they responded to direct questions about their INMI, in a manner comparable to previous INMI induction studies. This allowed for a comparison of Baseline INMI rates between the more traditional direct questioning versus our novel indirect method.

Following completion of the Mind Activity Questionnaire (N = 160) or the direct questioning (N = 40), participants were asked for consent to be contacted 24 hours later. Those in the Indirect conditions who gave consent received an online link 24 hours after the end of the experimental session, prompting them to complete the Mind Activity Questionnaire with respect to the content of their thoughts during the past 24 hours since the end of the testing session ('Indirect' paradigm; responses received - Baseline: N = 7, Easy: N = 14, Medium: N = 12, Hard: N = 20). Once again participants were asked to report if they knew the purpose of the study. Participants of the Direct paradigm were sent an online link asking them directly if they experienced INMI in the last 24 hours, how frequently and which tune (responses received – "Direct": N=8). Finally, all participants were debriefed and compensated for their participation. A visual representation of the procedure can be seen in Figure 1.

---------------- Figure 1 about here -----------------

Experimental checks

The three dot counting tasks were trialed in advance of the main study in order to confirm that they effectively manipulated cognitive load. Forty individuals who did not take part in the main study completed an online survey where they participated in all three tasks, in counterbalanced order (no film trailers were presented). After completing each dot task, participants rated two statements using a 5-point Likert scale to indicate how (a) challenging and (b) attentionally demanding they found each task. Two repeated measures ANOVA with a Greenhouse-Geisser correction indicated significant differences between all three conditions (challenge: $F(1.75, 68.27) = 52.47$, $p< 0.001$; attention: $F(1.61, 62.77) = 39.33$, $p< 0.001$). Post hoc tests using Bonferroni correction revealed that the Easy condition was significantly different compared to the Medium condition (challenge: 1.80 ± .91 vs. 2.30 ± 1.18, $p=.015$; attention: 3.20 ±.91 vs. 3.70 ± 1.0, $p=.024$) and the Hard condition (challenge: 3.85 ± 1.23, $p< 0.001$; attention: 4.52 ±.784, $p< 0.001$). There was also a significant difference between the Medium and Hard conditions (challenge: 1.80 ± .91 vs. 3.85 ± 1.23, $p< 0.001$; attention: 3.20 ±.91 vs. 4.52 ±.784, $p< 0.001$). The same pattern was seen regardless of whether participants were rating tasks on level of challenge or attention required. In the Easy condition, 26 people were 100% accurate, 12 people within a 10% above or below the right score, and 2 above or below that 10%. In the Medium condition, 19 people were 100% accurate, 17 were within a 10% below or above the correct score, and 4 were above or below that 10%. In the Hard condition, only 7 were 100% accurate, 22 were within 10% below or above the correct answer and for 11 their scores were above or below that 10% criterion. These results showcase the fact that the results from the three cognitive load tasks did not reach the criteria for a ceiling effect.

Results

INMI occurrence

The data of primary interest for the hypothesis came from the Mind Activity Questionnaire. Successful INMI induction was deemed to have occurred if a participant reported musical imagery during the 5 min post induction session (or in the following 24 hours) where they also experienced a lack of control in its initiation (rated 4 and above on the 7-point controllability scale). As a result a binary variable was created for successful INMI induction (Yes=1) and unsuccessful INMI induction (No=0). In addition to this binary data, participants gave estimates of the percentage of time they had experienced INMI during the 5 min post-trailer period, and the title and/or artist of the music experienced as INMI.

Baseline induction rate for the Direct questioning method was 60% versus 65% for the Mind Activity Questionnaire. INMI induction rates as measured by the Mind Activity Questionnaire" across the Easy, Medium, and Hard conditions were 32.5%, 25%, and 20% respectively. Overall INMI induction rate for all 4 indirect conditions together was 35%. The Pretty Woman soundtrack accounted for 63.1% of INMI experiences while Casino Royale accounted for the remaining 36.9%.

Effect of Cognitive Load on INMI Occurrence and Frequency

Three binomial logistic regressions were performed to predict INMI occurrence using cognitive load (4 levels; Baseline, Easy, Medium, and Hard) as a predictor and a different reference category for the contrast each time (1^{st}=Baseline, 2^{nd} = Easy, 3^{rd} = Medium).

The model was statistically significant $\chi^2(3)=21.05$, $p<.001$, explained 17% (Nagelkerke R^2) of the variance in INMI occurrence, and correctly classified 71.7% of the cases. Sensitivity was 45.6% and specificity 86.3%. This effect was driven by a difference between the Baseline condition and the other conditions (Baseline vs. Easy, p = .006; Baseline vs. Medium, p <.001; Baseline vs. Hard, p <.001). There were no significant differences between the Easy and Medium (p = .42), Easy and Hard (p = .18), or Medium and Hard (p = .59) conditions.

A Poisson regression model was run to predict INMI frequency (counts for each INMI tune; 0, 1, and 2) based on varying levels of cognitive load. The means and variances of INMI Frequency within each level of cognitive load are similar, satisfying the assumption of equidispersion. Cognitive load in the model, overall, is statistically significant χ^2 (3) = 25.91, p < .001 and while cognitive load increased in each condition, INMI frequency decreased (Baseline (95% CI, 2,09 to 9,68), Easy (95% CI, .73 to 4.17), Medium (95% CI, .49 to 3.16). Pairwise comparisons using Bonferroni corrections indicated that the Baseline condition differed significantly from the Easy (p = .01), Medium (p = .001), and Hard (p < .001) conditions. There were no further significant differences between any of the remaining conditions. INMI frequency counts for each condition can be seen in Figure 2.

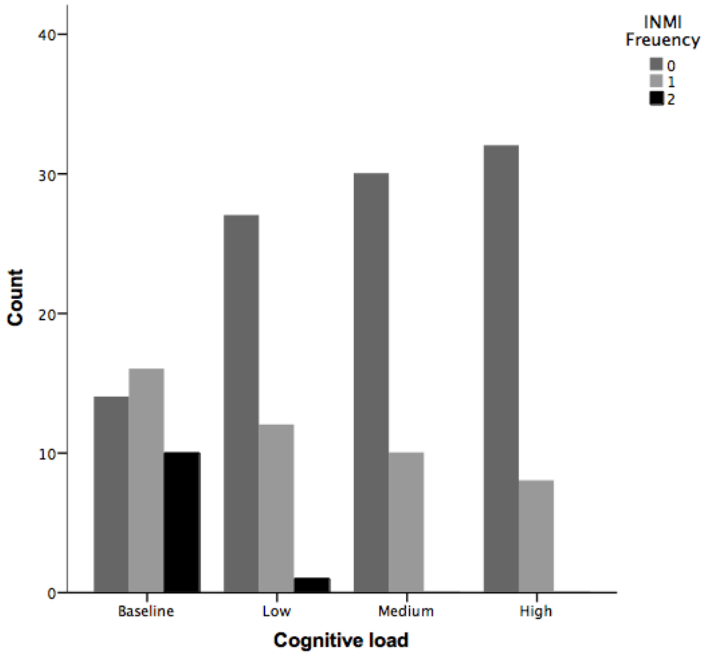

Figure 2. INMI frequency (0 = No tune experienced as INMI; 1 = One tune from the induction experienced as INMI; 2 = Both tunes from the induction were experienced as INMI) per cognitive load condition.

Effect of Cognitive Load on INMI Duration

The variable of interest for INMI Duration comes from a 0%-100% open-ended rating scale in the Mind Activity Questionnaire, which asked people to rate 'Percentage of time on musical imagery'. Data were not normally distributed so Kruskall-Wallis H was conducted to compare the effect of cognitive load on INMI duration (4 levels: Baseline, Easy, Medium, and Hard). Values are mean ranks unless stated otherwise. Distributions of INMI Duration were not similar for all conditions, as assessed by a visual inspection of a boxplot. There was a significant effect of cognitive load on INMI duration, $\chi^2(3) = 23.35$, $p<.0005$. Post hoc pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. The post-hoc analysis showed that the main effect was driven by a difference between the Baseline condition (103.6) and the other conditions (Easy: 77.17, $p = .02$; Medium: 67.16, $p < .001$; Hard: 67.44, p < .001). There were no further significant differences between INMI duration and any other condition. A Jonckheere Terpstra trend analysis on INMI duration confirmed the existence of a significant, negative linear trend, J (3) = 3,437, z = -4.37, p < .0005, indicating that as cognitive load increased, median INMI duration decreased. This result can be seen in Figure 3.

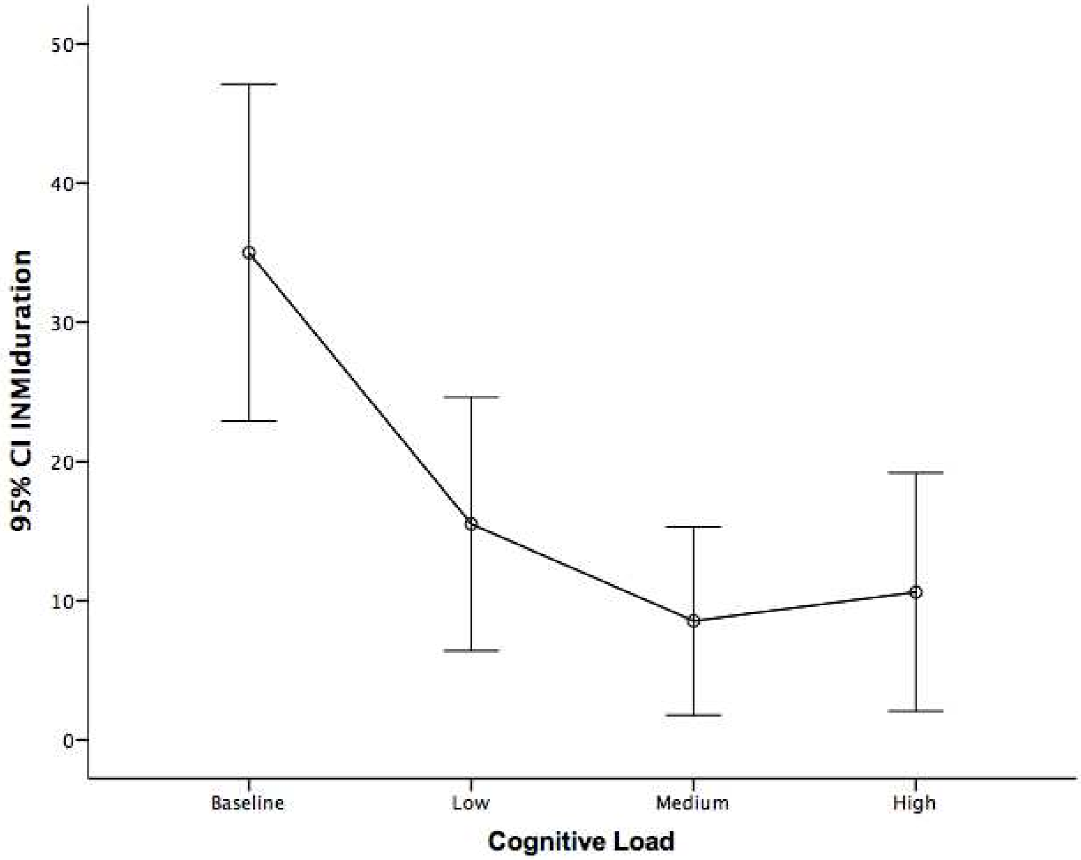

Figure 3. Median duration and confidence intervals (95%) of mean INMI duration per cognitive load condition.

---------------- Figure 3 about here ----------------

Effects of Film Appraisal on INMI Occurrence

As part of the Film Appraisal Questionnaire participants were asked about their familiarity and liking for aspects of the film trailers including the visuals and the music, as well as their levels of engagement and emotional response. Binary logistic regression revealed that only one factor significantly influenced INMI occurrence; the degree to which participants reported liking the visuals of the first film they had seen (either Pretty Woman or Casino Royale) ($p = .04$) predicted INMI occurrence. The more participants liked the visuals of the first film the more likely they were to report experiencing INMI for that music during the 5 min after watching that film clip. The same relationship was not observed for the second film in the order of presentation.

24-hour Follow-up

A follow-up was conducted to determine the impact of the INMI induction in the 24 hours following the testing session. 11 out of the 54 participants who completed the second Mind Activity Questionnaire (online version) reported experiencing INMI after the testing session (21%). All of the INMI reports were related to the film trailers that had been viewed the previous day. A binomial logistic regression was performed to predict INMI occurrence in the following 24-hour period, similarly to the analysis on INMI occurrence in the lab. The model yielded no significant effect of cognitive load in regard to the 24 hour subsequent INMI occurrence $\chi^2(3)=3.12$, $p = .37$.

A Fisher's Exact Test was run to examine if individuals who reported experiencing INMI in the lab straight after induction would be more likely to experience it again in the 24 hour period after the experimental session. There was no significant association between INMI reported in the lab and occurrence of INMI 24 hours later p = .075.

Recency effect

Given the prevalence of recency effects in the INMI induction literature, a post hoc check was performed to determine if presentation factors within the Indirect paradigm revealed any systematic differences. A chi-square test of goodness-of-fit was performed to test for the presence of a recency effect on INMI occurrence, whereby the music from the second film trailer was more likely to be reported as INMI (30 times; 69.8%) compared to the music from the first trailer (13 times, 30.2%). Again, the data from the two presentation orders were not equally distributed, ($\chi^2(1, N=43) = 12.3$, $p < .002$), indicating a significant recency effect.

Discussion

Involuntary musical imagery (INMI) is a ubiquitous experience that people often report in situations of low cognitive load (Floridou & Müllensiefen, 2015; Hyman et al., 2013; Liikkanen, 2012a; Williamson et al., 2012), a pattern also observed in other forms of spontaneous cognition (Berntsen, Staugaard, & Sorensen, 2013; Killingsworth & Gilbert, 2010, Kvavilashvili & Mandler, 2004). However, a recent empirical study (Hyman et al., 2013) found that INMI duration was longer at both the low and high ends of a cognitive load continuum. A re-examination of the relationship between INMI occurrence, frequency, and duration and cognitive load was necessary in order to ascertain the impact of a graded cognitive load increase on INMI experience.

The present study employed a novel, ecologically valid INMI induction procedure, based on previous INMI induction techniques (Byron & Fowles, 2013; Floridou et al., 2012; Hyman et al., 2013), whereby participants were exposed to music. In the present paradigm the music was heard as part of two film trailers, in order to mask the musical nature of the study. Our paradigm also used a novel method for covertly probing INMI experience, in contrast to previous studies, which have all used direct questioning. The resulting Baseline of 65% INMI induction rate compares favorably to the rates reported in direct paradigms, which include 65% (Floridou et al., 2012) and 75% (Hyman et al., 2013). An exception to this pattern is the 32% direct induction rate obtained by Byron and Fowles (2013). This discrepancy could be attributed to experimental design. The present study probed for INMI while participants were still in the lab (as in Floridou et al., 2012 and Hyman et al., 2013) while Byron and Fowles' (2013) induction rate comes from post-experimental questioning. The rate they obtained is, in fact, more comparable to the 24-hour INMI induction rate of 21% obseved in the present study. This finding speaks to the decay rate of INMI in memory after music exposure.

The 65% Baseline induction rate obtained in the present study suggests that the INMI film induction paradigm functioned as an effective INMI trigger. It is notable that none of the participants guessed the aim of the experiment, owing to the covert nature of the paradigm, combined with the indirect questioning afforded by the Mind Activity Questionnaire. The occurrence of INMI in the present study cannot, therefore, be attributed to response demand characteristics. In general, the nature of experimental instructions regarding involuntary processes is an important factor to consider in future research, as studies of involuntary autobiographical memory have confirmed that suggestions within instructions can change the frequency and characteristics of such memories (Barzykowski, 2014; Vannucci, Batool, Pelagatti, & Mazzoni, 2014).

There are several additional positive aspects to the new Mind Activity Questionnaire. The occurrence of induced INMI was comparable to that obtained by direct questioning using the same film induction paradigm (65% vs. 60%), suggesting that the Mind Activity Questionnaire would be an effective tool for future INMI laboratory studies where indirect probing would be critical, including for within-subjects designs and longitudinal work. Furthermore, the Mind Activity Questionnaire allows participants to rate their level of perceived control in the initiation of their musical imagery enabling researchers to differentiate between involuntary and voluntary musical imagery, and potentially to compare these two experiences. Another advantage of the Mind Activity Questionnaire is that it can be used to compare INMI to other involuntary memory experiences that are primarily visual or verbal in nature.

The main empirical findings from the present study relate to the comparison of INMI experiences across the indirect conditions (Baseline vs. Easy, Medium, and Hard conditions). It is evident that even a low level of attention and cognitive load was sufficient to significantly reduce INMI occurrence in the present paradigm, as reflected in the significant difference in INMI rates between the Baseline and Easy condition (65% versus 33%), compared to the lower rates of INMI induction for the Medium and Hard conditions (25% and 20% respectively). Our second measure, INMI frequency, followed a similar pattern where the Baseline condition was significantly different from the other 3 cognitive load conditions. Finally, our third measure of INMI duration also showed a significant negative linear trend with increasing cognitive load. Taken together, these findings indicate that low attention state is a basic requirement that precedes increased chance of INMI occurrence, replicating a finding from a probe-caught experience sampling study (Floridou & Müllensiefen, 2015). These trends are also in accordance with self-reports from the INMI literature (Liikkanen, 2012a), and findings from the broader Task Unrelated Thought (TUT) literature where TUTs were significantly reduced when secondary tasks were relatively simple and low in load, and then increased consistently with larger cognitive load (Mason et al., 2007; Teasdale et al., 1993; Teasdale et al., 1995).

A key difference between the Baseline and the other three conditions relates to the presence or absence of basic visual input since the Baseline condition required eyes to be closed. We attempted to isolate the impact of basic visual input on INMI by adding a post hoc condition where 40 people were asked to keep their eyes open and simply watch the dots. Despite clear instructions to the contrary however, 60% of participants reported that they were unable to refrain from stimulus monitoring, making the task akin to the Easy condition. This issue will require a specific methodological focus in any future research that investigates the role of basic visual input during INMI induction.

There is a contrast of note between the findings of the present study and the results of Hyman et al. (2013) who reported a quadratic trend across two levels of load manipulation, whereby INMI duration was longer at both high and low ends of the cognitive load continuum. This discrepancy can be explained by the challenges associated with manipulating task-related cognitive load. One such challenge is maintaining a consistent level of load across a task. In our study attention was required consistently throughout the 5 min post exposure period, in order to successfully perform the dot counting task; by contrast in Hyman et al.'s (2013) study, where either Sudoku tests or anagrams were used, it was not possible to guard against wavering attention as time elapsed. Additionally, wavering boredom/ anxiety induced by perceived levels of varying intra-task difficulty could be a factor. Since these factors are impossible to control across each participant, there is a strong argument for the use of multiple cognitive load conditions (such as the four used in the present study), a task that requires constant focus, and the use of large participant samples.

It is notable that our Medium and Hard conditions placed additional demands on phonological processing compared to Baseline and Easy conditions due to the requirement to keep a mental count on the dots presented, and that these tasks were associated with the lowest INMI induction rates. This is interesting in view of literature concerning the circumstances under which INMI may be suppressed or terminated. In a naturalistic study, using self-report data, Williamson et al. (2014) found that distraction via phonological-based tasks such as reading, word puzzles and conversing were reported as effective in reducing or eliminating unwanted INMI. The similarity between suppression of INMI at the point of induction (i.e. the present study) and cessation (Williamson et al., 2014) leads to the hypothesis that INMI may have a cognitive origin within the phonological memory system. This hypothesis is supported by Hyman et al. (2013), who found that verbal distractions (anagram task) lead to shorter INMI durations compared to visual distractions (Sudoku task) and by Beaman et al. (2015) who reported that articulatory suppression (gum chewing) was associated with fewer reports of INMI compared to a motor activity that was unrelated to the phonological system (finger tapping). Future studies of this hypothesis would need to systematically manipulate the phonological content of secondary tasks to be tested at the point of INMI induction and as part of INMI cessation attempts.

In addition to our hypothesis regarding the impact of increasing cognitive load on INMI occurrence, we carried out post hoc analysis to determine if INMI induction was affected by our choice of stimuli or method of presentation. Although we did not directly control or test for the type of music used in the induction paradigm, the film trailer that contained music with lyrics (Pretty Woman) was reported as INMI on roughly twice as many occasions compared to the film trailer containing instrumental music (Casino Royale). It is impossible to draw conclusions about the type of the music experienced as INMI since we did not use a range of music with and without lyrics however, our finding agrees with previous studies that have shown music with lyrics is experienced more frequently as INMI compared to instrumental music (Halpern & Bartlett, 2011; Hyman et al., 2013; 2015).

The recency effect observed in the present study is also in accordance with previous findings (Beaman & Williams, 2010; Byron & Fowles, 2013; Hyman et al., 2013; Floridou et al., 2012, Liikkanen, 2012b). Furthermore, the absence of any relationship between familiarity or liking of the music in the film trailers and INMI patterns of occurrence accords with reports that some music is reported as INMI after only one exposure, even when said music is disliked (Williamson et al. 2012). The lack of consistency between liking and familiarity effects and INMI is also in agreement with Byron and Fowles' (2013) report of a recency effect for unfamiliar music.

In summary, the present paper has presented a novel and effective paradigm for inducing and indirectly probing INMI experiences, as well as a method for modulating their likelihood of occurrence, frequency, and duration via systematic change in cognitive load. We have replicated several INMI induction features and have demonstrated a direct linear relationship between reduced INMI occurrence, duration and frequency, and increasing cognitive load. Overall, the data suggest that even a slight increase in cognitive load is sufficient to help prevent INMI, supporting the hypothesis that INMI occurrence characteristics relate to spare cognitive capacity.

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Appendices

A. Film Appraisal Questionnaire

Rate the film clips

Please circle a number from the following scale for each statement:

1) Strongly agree
2) Moderately agree
3) Neither agree nor disagree
4) Moderately disagree
5) Strongly disagree

Please focus on the **film clip content** rather than the quality of the recording.

Film 1

The film clip was very engaging	1	2	3	4	5
The film clip was very emotional	1	2	3	4	5
I liked the music in the film clip	1	2	3	4	5
I liked the visuals in the film clip	1	2	3	4	5
I have seen this film and know it well	1	2	3	4	5
I have heard this music and know it well	1	2	3	4	5

Film 2

The film clip was very engaging	1	2	3	4	5
The film clip was very emotional	1	2	3	4	5
I liked the music in the film clip	1	2	3	4	5
I liked the visuals in the film clip	1	2	3	4	5
I have seen this film and know it well	1	2	3	4	5
I have heard this music and know it well	1	2	3	4	5

B. Mind Activity Questionnaire

Profile of Mental Activity

It is perfectly normal for the mind to wander while your eyes are closed. You may have been thinking of things on purpose or thoughts may have popped into your head outside of your control.

1) Did your mind wander to any aspect of the film clips during the period of silence/when you were playing the dot game? (please circle Yes or No)

YES NO

If "NO", then please skip to the next page and **Question 2**

If "YES", then please fill out the following sections to tell us which aspects of the film clips entered your thoughts

Visual mental imagery (V) - "thoughts in the form of images"

- Percentage of time on visual imagery ....%

- What images did you see (if any)? Please provide a brief description.

....

....

....

- Rate the level of control over these thoughts from 1 (I deliberately generated this imagery) to 7- (the imagery happened outside of my control)

1 2 3 4 5 6 7

Language mental imagery (L) - "Imagined speech"

- Percentage of time on speech imagery ....%

- What speech did you hear (if any)? Please provide a brief description including name of speaker if you know them (including if it was your own voice).

....
....
....
....

- Rate the level of control you had over the imagery from 1 (I deliberately generated this imagery) to 7- (the imagery happened outside of my control)

  1 2 3 4 5 6 7

Musical mental imagery (M) - "Imagined melody, song and/or a rhythm"

- Percentage of time on musical imagery
  ....%

- What music did you hear (if any)? Please identify or describe the music if the title/ artist is unknown to you.

  ....
  ....
  ....

- Rate the level of control you had over the imagery from 1 (I deliberately generated this imagery) to 7- (the imagery happened outside of my control)

  1 2 3 4 5 6 7

Question 2

Do you have any preconceived ideas as to what this experiment is about? (please tick one answer)

_____ No, I have not considered the purpose of the experiment other than what I was told

_____ Yes, I have thought about the purpose of the experiment

If you ticked YES above then please provide a summary of your thoughts

"I think the experiment was about
....
....

....
....
....

Follow up request

We would like to be able to contact you by email in around 24 hours time to ask you a small number of follow-up questions, similar to those which you have answered today. You are under no obligation to respond but we would really appreciate your help to complete our study.

We will never pass on your email address and your responses would remain completely confidential at all times.

If you would like to volunteer to help with the follow up then please write your email here

....
....

C. Direct Paradigm Questionnaire

Did you experience any earworms during the period of silence?
An "earworm" (or Involuntary Musical Imagery) is a short section of music that comes into your mind without effort (it is involuntary; without any intention to retrieve or recall the music) and then repeats by itself (immediately repeated at least once, on a loop, without you consciously trying to replay the music).

YES NO

If "YES", then please fill out the following section to tell us more information about the music that entered your mind.

- Percentage of time during the silence period that you experienced an earworm/earworms
.....................................%

- What music did you experience as an earworm/earworms? Please identify the tune or do your best to describe the music if the title/ artist is unknown to you

....
....

....
....
....

Follow up request

We would like to be able to contact you by email in around 24 hours time to ask you a small number of follow-up questions, similar to those which you have answered today. You are under no obligation to respond but we would really appreciate your help to complete our study.

We will never pass on your email address and your responses would remain completely confidential at all times.

If you would like to volunteer to help with the follow up then please write your email here

....
....

D. 24-hour "Mind Activity Questionnaire"

"It is perfectly normal for your mind to have wandered back to the film clips that you saw yesterday. You may have been thinking about the film clips on purpose or thoughts about them may have popped into your head outside of your control. In this questionnaire we are interested in any mental imagery (thoughts) that you have experienced in relation to the film clips, since seeing them yesterday. Have you thought about the content of the film trailers over the last 24 hours? (i.e. the sights or the sounds)"

In the last 24 hours have you experienced any thoughts containing visual mental imagery in relation to the film clips?

Yes No

What images did you see? Please provide a brief description.
....
....

Rate the level of control over these thoughts from 1 (I deliberately generated this imagery) to 7 (the imagery happened outside my control).

1 2 3 4 5 6 7

How frequently would you estimate that your mind wandered to this visual imagery? From 1 (very infrequently) to 7 (very frequently).

1 2 3 4 5 6 7

In the last 24 hours have you experienced any thoughts containing musical mental imagery in relation to the film clips?

Yes No

What music did you hear? Please identify or describe the music if the title/artist is unknown to you.

....

Rate the level of control over these thoughts from 1 (I deliberately generated this imagery) to 7 (the imagery happened outside my control).

1 2 3 4 5 6 7

How frequently would you estimate that your mind wandered to this musical imagery? From 1 (very infrequently) to 7 (very frequently).

1 2 3 4 5 6 7

In the last 24 hours have you experienced any thoughts containing speech mental imagery in relation to the film clips?

Yes No

What speech did you hear? Please provide a brief description including name of the speaker if you know them (including if it was your own voice).

....

Rate the level of control over these thoughts from 1 (I deliberately generated this imagery) to 7 (the imagery happened outside my control).

1 2 3 4 5 6 7

How frequently would you estimate that your mind wandered to this speech imagery? From 1 (very infrequently) to 7 (very frequently).

1 2 3 4 5 6 7

Have you had any additional thoughts or ideas about the nature or aim of this study? If yes, then please describe; if no, then type "no".

Figure Captions

Figure 1. Visual representation of the experimental procedure.

Figure 2. Mean INMI duration (in percentage) in the 5-minute post exposure task for each condition.