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Environmental and mental conditions predicting the experience of involuntary musical imagery: An experience sampling method study

Georgia A. Floridou *, Daniel Müllensiefen

Department of Psychology, Goldsmiths, University of London, New Cross Road, New Cross, London SE14 6NW, United Kingdom

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ABSTRACT

An experience sampling method (ESM) study on 40 volunteers was conducted to explore the environmental factors and psychological conditions related to involuntary musical imagery (INMI) in everyday life. Participants reported 6 times per day for one week on their INMI experiences, relevant contextual information and associated environmental conditions. The resulting data was modeled with Bayesian networks and led to insights into the interplay of factors related to INMI experiences. The activity that a person is engaged was found to play an important role in the experience of mind wandering, which in turn enables the experience of INMI. INMI occurrence is independent of the time of the day while the INMI trigger affects the subjective evaluation of the INMI experience. The results are compared to findings from earlier studies based on retrospective surveys and questionnaires and highlight the advantage of ESM techniques in research on spontaneous experiences like INMI.

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1. Introduction

Involuntary cognitions, in the form of memories, thoughts and future planning, constitute a significant fraction of mental activity in people's everyday lives (Killingsworth & Gilbert, 2010; Kvavilashvili & Mandler, 2004). One type of involuntary cognition that is fairly prevalent in Western populations (Liikkanen, 2012; Williamson et al., 2012) takes the form of music and is referred to as 'involuntary musical imagery' (INMI, or an "earworm" as it is commonly known). INMI is a short section of music that comes to the mind spontaneously without effort and then goes on repeating itself without conscious control.

Despite the fact that research on INMI only begun fairly recently (Brown, 2006; Kellaris, 2001), a considerable number of studies during the past few years have produced a range of significant results which now allow the construction of a theoretical framework as well as the refinement of research methods which help to further investigate this by definition very inaccessible phenomenon. Thus, research findings to date have provided information on a range of environmental factors and psychological conditions that contribute and affect the experience of INMI. We will summarize these findings first before laying out the rationale and motivation for the current study. In this brief summary of the literature, we focus on transient momentary conditions and states rather than on personal traits and stable individual differences that have been covered elsewhere (Beaman & Williams, 2013; Müllensiefen et al., 2014).

* Corresponding author.
E-mail addresses: g.floridou@gold.ac.uk (G.A. Floridou), d.mullensiefen@gold.ac.uk (D. Müllensiefen).

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1.1. Mental and environmental phenomena related to INMI

1.1.1. Triggers

Both INMI and non-musical involuntary memories (Berntsen, 1996, 2001; Rasmussen & Berntsen, 2009) are generally assumed to be triggered by external or internal cues, with the major difference that in the case of involuntary semantic memories (ISM) the majority of the people (63% according to Kvavilashvili & Mandler, 2004) are not able to report what preceded them, whereas in the case of INMI, triggers can be identified most of the time. A study by Williamson et al. (2012) investigated cues that precede and ultimately trigger INMI. The study identified several different such triggers, which can be categorized in 4 dominant themes, namely exposure to music, memory triggers, affective states and low attention states. The first two themes (recent exposure to music and memory triggers) have also been confirmed by Hyman et al. (2013) and are supported by ISM literature (Kvavilashvili & Mandler, 2004).

1.1.2. Mind wandering

Mind wandering is one of the low-attention states that Williamson et al. (2012) found to be associated with subsequent INMI experiences. Mind wandering is characterized by a shift of attention from a main task that the individual is engaged in toward internal information such as the processing of memories (Smallwood, Baracaia, Lowe, & Obonsawin, 2003; Christoff, Ream, & Gabrieli, 2004; Smallwood, O'Connor, Sudberry, & Ballantyre, 2004; Smallwood, Obonsawin, & Heim, 2003; Smallwood and Schooler, 2006; Smallwood et al., 2004). Different terms have been used to describe this phenomenon, including task-unrelated thought (Smallwood, Davies, et al., 2004), stimulus-independent thought (Antrobus, 1968; Teasdale, Lloyd, Proctor, & Baddeley, 1993), mind pops (Kvavilashvili & Mandler, 2004), and zone outs (Schooler, 2002; Schooler, Reichle, & Halpern, 2005). There are minor differences between the exact meaning of these terms but all of them generally characterize a process of self-generated thought. The association between mind wandering and INMI reported by Williamson et al. (2012) supports findings from early INMI research, such as those of Bennett (2002) who suggested that the appearance of INMI is always associated with a lack of focus and relaxed states in which the brain is in a condition of break or distraction. This is also in line with Kellaris (2001) assertion that «earworms eat idle brains».

1.1.3. Concurrent activities

In addition to mind wandering and low-attention states, mental or physical activities that are concurrent to the appearance of INMI are assumed to be a key feature for understanding the latter's etiology. From the data of a large survey of retrospective reports, Liikkanen (2012) concluded that INMI appear most frequently when individuals are working alone, traveling or exercising. He also found that they occur least during activities requiring auditory engagement (e.g. conversing, which was mentioned by only 10.9% of the participants of his survey). However, the same study also reported that watching TV and listening to music was the fifth most common situation (42.3%) to be associated with INMI, even though they also require auditory engagement. The apparent contradiction implied by these two findings is one of the topics addressed by the current study.

In a study on both, voluntary and involuntary musical imagery, Bailes (2006) reported that socializing was the most frequent activity in the context of which musical imagery tend to appear, a result which conflicts with Liikkanen's findings (2012) described above. Other activities associated with INMI occurrence, as reported by Bailes (2006), are working and traveling as well as waiting and getting up in the morning, while INMI was reported less commonly during audio/visual activities like watching TV and listening to music.

A more recent study by Hyman et al. (2013) showed that the activities which tend to be associated with INMI can be characterized by low but also by high cognitive load ("cognitive load continuum").

Taken together, findings to date suggest that INMI tend to occur more frequently when the activity that a person is engaged in is not demanding, is associated with low cognitive load and tends to be monotonous and automatic. These conditions are generally also associated with mind wandering (Schooler, 2002; Smallwood & Schooler, 2006).

1.1.4. Time of the day

Findings about the relationship between time of the day and likelihood of INMI occurrence are mixed. Halpern and Bartlett (2011) found that mornings (34%) favor INMI appearances, followed by the afternoon (20%), evening (20%) and night (10%) On the other hand, in Bailes' study (2007) the musical imagery (voluntary and involuntary) rate was found to be almost constant throughout the day, dropping to half during the night. Byron and Fowles (2013) found no significant difference between the frequencies of INMI occurrence at different times of the day. They argued that the contradiction between these findings with those of previous studies could be due to chance or – in the case of Bailes' study – the inclusion of voluntary imagery in the observations.

1.1.5. Factors affecting subjective evaluation

Although common belief has it that INMI is mostly evaluated as a negative experience, studies so far have shown that evaluations of INMI experiences can vary greatly between individuals. Several studies show that the experience of INMI is predominantly considered as pleasant (Beaman & Williams, 2010; Halpern & Bartlett, 2011; Hyman et al., 2013) while others report negative evaluations (Floridou, Williamson, Stewart & Müllensiefen, in press; Hemming, 2009; Williamson et al., 2014). Thus it is not yet clear which are the factors that modulate the evaluation of INMI experiences and, for this

reason, one aim of this study is to identify contextual as well as psychological factors that account for differences in subjective evaluations.

1.1.6. Mood

Although the occurrence as well as the subjective evaluations of INMI may possibly also connected to the momentary concurrent mood state of the individual, the relationship of INMI with mood states has not yet been fully explored and the evidence remains sketchy at best. One relevant finding comes from Williamson et al. (2012) who found that affective states, including the current mood state, are generally associated with the onset of INMI. However no details of the particular moods involved are provided by that study. Two experience sampling method (ESM) studies (Bailes, 2007; Beaty et al., 2013) on musical imagery (voluntary and involuntary) provide some more specific information about the role of mood states. The findings presented in Bailes (2007) indicate an association between positive mood (happy and relaxed) and high arousal (alert and energetic), on one hand, and the appearance of musical imagery on the other. This is not fully congruent with the results from Beaty et al. (2013) who reported that people experienced musical imagery when they were happy or worried. However, the fact that both of these studies did not distinguish between voluntary and involuntary musical imagery means that their results can only serve to generate hypotheses regarding the impact of mood states on INMI experience that still need to be tested.

1.2. Scope of the present study

Motivated by recent findings on the environmental factors and psychological conditions that seem to cause INMI experiences and interactions with other relevant INMI factors, this paper explores the relationships and interplay between INMI and mind wandering and aims to construct a common framework which facilitates the description of the relationships between these mental phenomena.

Previous studies on INMI have made use primarily of retrospective reports via surveys (Liikkanen, 2012; Williamson et al., 2012) and, to a smaller extent, data from behavioral experiments (Byron & Fowles, 2013; Floridou, Williamson, & Müllensiefen, 2012; Hyman et al., 2013) and diary studies (Beaman & Williams, 2010; Halpern & Bartlett, 2011). In the present study we make use of the experience sampling method (ESM) approach which has been used for the exploration of everyday occurrences (Csikzentmihalyi & Larson, 1987; Kubey, Larson, & Csikszentmihalyi, 1996; Reason & Mycielska, 1984) and can provide rich data regarding the experiential nature and causes of INMI as and when they occur in everyday life as well as on situations where they do not occur. Thus, the ESM data from the present study can complement the findings of previous studies that used other data gathering methods. Data on INMI experiences can be easily collected via ESM, given that such experiences constitute a ubiquitous phenomenon experienced by more than 90% of people at least once per week and by 33.2% everyday (Liikkanen, 2012). A second novel methodological aspect of the present study is the use of Bayesian networks as a data analysis technique. This technique offers the possibility to construct network models of causative associations between relevant environmental and psychological variables around the INMI experience, which make it possible to understand the potentially complex interactions between different factors leading to the INMI experience and mind wandering.

2. Methods

2.1. Participants

A total of 40 individuals (24 females), 18–72 years of age, were recruited from the "Goldsmiths Earwormery Questionnaire" (http://earwormery.com/) database. Of these, 20 had previously declared experiencing INMI frequently (more than once a day) while the other 20 participants had claimed to experience INMI rarely (less than once per month or never). Two of the participants were discarded because the either did not complete the required forms or completed them hours later than when contacted, leaving a total of 38 participants.

2.2. Materials

Participation in the study required the use of a mobile phone, which individuals had to carry with them all the time, and an Experience Sampling Booklet (ESB). The ESB was sent to the participants along with a consent form, which they were asked to complete and return, and an information/instruction sheet about the study. This sheet also contained the definitions of INMI ("An earworm refers to the experience whereby a tune comes to your mind unbidden and repeats itself (i.e. it gets stuck in your mind) without your conscious control") and mind wandering ("Mind wandering describes the experience of the mind drifting away from a person's main activity at the time to other «internal» things such as memories, feelings, inner thoughts and fantasies. An example of mind wandering is when we are reading a book and, after a couple of pages, we realize that we cannot really say what the story is about because while we were reading we had something else on our mind") so as to help the participants to identify these phenomena when they occurred.

The ESB contained 42 Experience Sampling Forms to be completed (ESF; 6 per day, for one week). Each ESF (see Appendix A) contained slots for the following information: date, time when message was received and time when the form was

completed. Two sections followed. Section A contained information items that had to be provided at all times regardless of whether or not the participants were experiencing INMI at the time of the prompt (when they would receive the text message). If they experienced INMI they would continue to Section B, otherwise they would stop after completing Section A. Section A asked for the following information: Occurrence or not of INMI and mind wandering episodes at the time of the prompt, current activity the participant was engaged in (12 categories: housework, getting dressed, in the bath, traveling, working, studying, reading a book, shopping, exercising, socializing, listening to music, other) and rating of 6 bipolar items for the assessment of the current mood state using a 7-point rating scale (see Sloboda, O'Neill, & Ivaldi, 2001). If the participants did not experience INMI but did experience mind wandering, then they would complete the questions related to mind wandering as well as the rest of the general questions of Section A.

Section B of the ESF asked for details of the INMI experience, including the title and artist of the music piece involved in the INMI, the subjective pleasantness of the experience as rated on a 11-point rating scale 0–10 (Not at all pleasant-Love it) and the participant's suggestions of potential triggers of the INMI experience based on the trigger themes proposed by Williamson et al. (2012) (11 categories: Recent Music Exposure, Association, Person, Association, Sound, Association, Word, Recent/Upcoming event, Dreams, Current thoughts, Other). If mind wandering was experienced at the time of the prompt, then five items about the mind wandering content (taken from the mind wandering inventory by McVay, Kane, & Kwapil, 2009) had to be rated on a 7-point rating scale (1 = not at all, 4 moderately, 7 = very much): (1) I was aware my mind was wandering in the moments before the beep, (2) I allowed my thoughts to wander on purpose, (3) I was thinking about personal concerns or things I need to do, (4) I was daydreaming or fantasizing about something, (5) I was worrying about something). Two additional items were included in order to check the mind wandering content: (6) I was remembering something, (7) My mind was occupied only by the earworm.

2.3. Procedure

During the observation period (Monday–Sunday, 8 am–11 pm), participants were contacted, by text message via an online messaging service (www.fastsms.co.uk), on six occasions per day at random times. As soon as they were contacted they had to complete one ESF from the booklet. The completion of an ESF took between 3 and 5 min, depending on whether INMI was experienced and the level of detail the participant was able to convey about the musical piece and potential triggers.

2.4. Data analysis

Data was obtained for 1374 out of the total of 1596 prompts (86% compliance). We employed Bayesian networks for the analysis of the 14 variables from the ESFs. The Bayesian network approach (e.g. Korb & Nicholson, 2011) enables the identification of dependencies and influences within a potentially large set of variables. Bayesian networks combine principles from graph theory, probability theory, computer science and statistics. They are graphical models, which encode probabilistic relationships between the variables of interest using nodes and edges as graphical elements. The nodes in the graph represent random variables and the edges connecting the nodes represent probabilistic dependencies between the variables. The graph represents the qualitative (or structural) part of the model while the quantitative parameters are given by the conditional probability distribution in additional Tables that hold the local probabilities for the conditional dependencies between nodes that are connected. One important aspect of Bayesian networks is that they encode information about the dependence/independence of pairs of variables, conditional on sets of other variables. In highly multivariate datasets, where large sets of variables appear to be related to each other, identifying the conditional independence structure can greatly simplify the network of related variables and help to identify important causal relationships.

Due to the logical dependencies between questions, the data was divided into three sets for which separate networks were constructed. The first dataset included all 1374 episodes, regardless of whether or not INMI or mind wandering had occurred. The second dataset included only the 644 episodes were INMI was experienced and the third network included only the 335 episodes where mind wandering was experienced. The data was analyzed using the R software environment for statistical computing (R Core team, 2013) and the bnlearn package (Nagarajan, Lebre, & Scutari, 2013; Scutari, 2010).

The networks were constructed in three stages. In the first stage cross-validation was used to identify the optimal combination of the components of the network learning algorithm (i.e. goodness-of-fit criterion, type of learning algorithm, criterion for model selection). In the second stage the structure of the network was learned using the combination of components identified in the first stage. Finally in the third stage the parameters of the local distributions were computed from the network structure identified in the second stage. This generated the model-based contingency tables for all variables in the network.

3. Results

An initial analysis of the dependent variable 'INMI occurrence', which represented the occurrence of INMI during the ESM study, showed that those participants who had indicated on the Earwormery database that they experience INMI either *never* or *not very often* reported in the context of the current study INMI frequencies in the range of 3–35 episodes per week, a range comparable to that reported by participants who had indicated that they experience INMI *always* (range: 16–38). A chi square test was performed to determine if there was a difference between the people who frequently experience INMI

and those who do not in relation to the total number of INMI experienced during the ESM. The total number of INMI was equally distributed: $\chi^2(1, N = 3) = .33$, $p > .05$, indicating that there was not a significant difference between the two groups. This might indicate a key difference between self-report data from retrospective questionnaires and reports prompted via the ESM. Based on this finding, all participants and their INMI episodes were treated as a single group.

An independent sample *t*-test was performed to compare the subjective pleasantness associated with INMI in the high ($M = 5.6$, $SD = 2.7$) and the low INMI frequency ($M = 5.9$, $SD = 2.7$) group. The result indicated that there was no significant difference between the two groups of participants in terms of subjective pleasantness of their INMI experiences, $t(642) = 1.3$, $p = .2$.

3.1. Data pre-processing

Continuous variables were discretized into categorical variables because the particular class of Bayesian networks employed here requires the exclusive use of either categorical or continuous variables.

The 6 mood variables were transformed into one categorical variable *mood state*, with 4 discrete categories coding distinct mood states. We used model-based cluster analysis (Mclust package for R, Fraley, Raftery, Murphy, & Scrucca, 2012) to group the mood ratings into 4 discrete categories. The clustering model with the best model fit (according to the Bayesian Information Criterion, BIC, used as fit index) was identified from among models having one to 9 clusters and allowing for all ten possible covariance structures. The clustering model with the best fit comprised 4 clusters with an identical covariance structure and ellipsoidal distributions. The means and standard deviations of mood scales for the four clusters are given in Table 1. A simple characterization of these four mood states can be done by the attributes they are most strongly associated with relative to the other clusters: For Cluster 1 these are Drowsy, Lonely, Tired, Bored; Cluster 2: Relaxed, (Happy); Cluster 3: Sad, Tense; Cluster 4: Alert, Happy, Interested, Energetic, Connected.

In addition, we discretized the items INMI pleasantness and the 7 variables measuring mind wandering content on rating scales using Hartemink's Information Preserving Discretization method (Hartemink, 2001). Pleasantness resulted in three categories: 0–4, 5–7, 8–10, based on the initial 10-point Likert scale and mind wandering content in two categories for each variable (1–3, 4–7; 1–2, 3–7). The variables "activity" and "INMI trigger" were regrouped into new categories, larger than the ones provided in the booklet. This was done either because the category "Other" was used frequently or because some of the categories were listed only infrequently. As a result the variable describing the activity that participants were engaged in at the time of the prompt comprised the following nine categories: (1) working, (2) socializing, (3) grooming, (4) audio/visual, (5) traveling, (6) physical movement, (7) low cognitive load activities, (8) computer/leisure, and (9) high cognitive load activities. For INMI triggers the following categories were identified: (1) Music Exposure, (2) Association with a Person, (3) Association with a Sound, (4) Association with a Word/Image, (5) Recent/Upcoming event, (6) Thoughts/Dreams, (7) Not aware of trigger, (8) the same as the previous INMI, (9) Default INMI (an earworm that is experienced quite frequently), (10) Memory. Finally the time of the day when the ESF was completed was divided into 3 categories: 8 am-1 pm, 1:01–6 pm, 6:01–11 pm).

3.2. Descriptive statistics

3.2.1. Overall INMI rate, percentages of INMI triggers and average pleasantness

The INMI frequency rate was calculated based on the total INMI episodes divided by the total number of surveys completed and resulted in an overall rate of 47% over a week.

In terms of the INMI triggers reported by the participants, the most frequent trigger was "exposure to music" (33.1%), followed by "not aware of trigger" (18.7%). The frequencies of the other triggers can be seen in Fig. 1. The percentage frequency of all identifiable triggers (except for "not aware of the trigger", "same INMI", "default INMI") combined is 62.3%.

The average pleasantness based on the data before the discretization is $M = 5.76$ ($SD = 2.91$) on the 0–10 scale, indicating that on average INMI experiences were rated as slightly pleasant.

3.3. Bayesian network models

3.3.1. INMI and mind wandering network

The first network included the five variables that were filled out regardless of whether or not INMI and/or mind wandering had occurred: INMI occurrence, mind wandering occurrence, time of the day, activity and mood state. The network was

Table 1
Means and SDs of mood variables for the 4 different mood states.

Mood pairs	Mood state 1, (527 episodes) Mean [SD]	Mood state 2, (330 episodes) Mean [SD]	Mood state 3, (273 episodes) Mean [SD]	Mood state 4, (208 episodes) Mean [SD]
Alert-Drowsy	4.04 [1.60]	5.86 [.62]	6.04 [.66]	6.33 [.60]
Happy-Sad	4.61 [1.25]	5.76 [.68]	4.51 [1.38]	6.17 [.59]
Tense-Relaxed	3.31 [1.46]	2.16 [.73]	4.34 [1.28]	2.54 [1.20]
Interested-Bored	4.24 [1.16]	5.64 [.81]	5.58 [.91]	6.32 [.61]
Energetic-Tired	3.35 [1.39]	4.17 [1.25]	4.15 [1.45]	5.72 [.80]
Lonely-Connected	3.66 [1.07]	2.91 [1.19]	3.24 [1.22]	1.53 [.53]

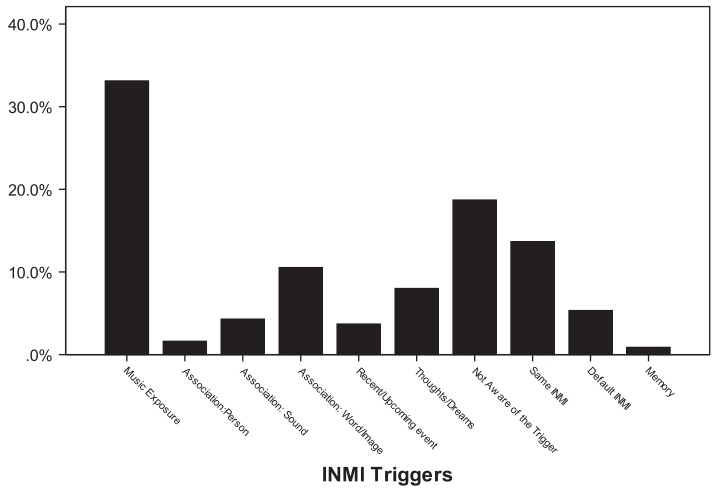

Fig. 1. INMI triggers percentages.

constructed from 1374 observations. The best network was generated by the tabu algorithm (Glover, 1986), a Bayesian fitting criterion and the Bayesian-Dirichlet equivalence (bde) score. The structure of the network is graphically depicted in Fig. 2.

The network shows that time of the day determines the activity that the person is engaged in, then the activity can cause the appearance of mind wandering and, in turn, mind wandering can cause the appearance of INMI. Mind wandering also affects the mood state but the network does not indicate a direct effect of INMI on mood. From the contingency table of mind wandering vs activity (Table 4) we can see that activities that are associated with mind wandering occurrence are those characterized by low cognitive load (conditional probability of mind wandering to occur is .46), traveling (.39) grooming (.36), and physical activities (.30), while those that prevent mind wandering are socializing (.90), activities characterized by high cognitive load (.85), audio visual activities (.85) working (.79) and computer/leisure activities (.78).

Mood is influenced by mind wandering, with mind wandering leading to a mood state characterized by high happiness, relaxation, interest, tiring and connection (.49) (see conditional probabilities in Table 2).

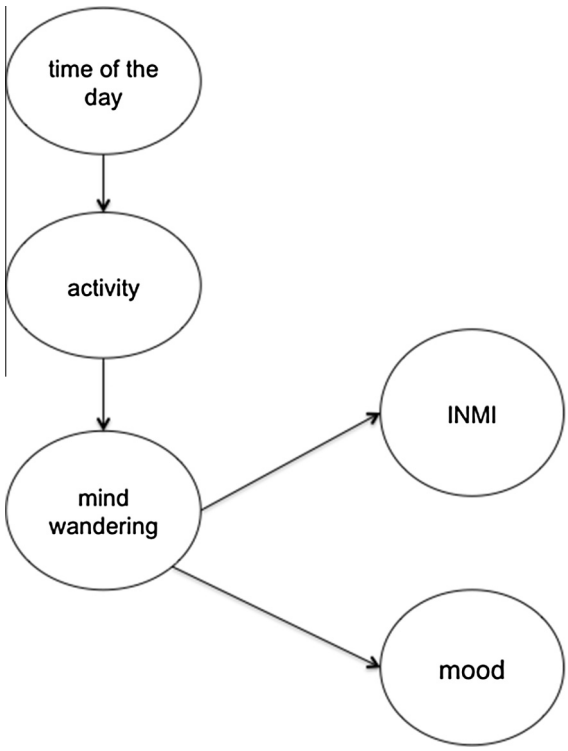

Fig. 2. General INMI/mind wandering Bayesian network.

Table 2
Conditional probabilities of mind wandering and mood.

Mood	Mind wandering	
	0 (No)	1 (Yes)
1. Drowsy, Lonely, Tired, Bored	.36	.49
2. Relaxed, (Happy)	.26	.20
3. Sad, Tense	.20	.20
4. Alert, Happy, Interested, Energetic, Connected	.17	.11

Table 3
Conditional probabilities of mind wandering and INMI.

INMI	Mind wandering	
	0 (No)	1 (Yes)
0 (No)	.56	.20
1 (Yes)	.44	.80

Table 4
Conditional probabilities of mind wandering and activity.

Activity	Mind wandering	
	1 (Yes)	0 (No)
Working	.21	.79
Socializing	.10	.90
Grooming	.36	.64
Audio/Visual	.15	.85
Traveling	.39	.61
Physical movement	.30	.70
Low cognitive load	.46	.53
Computer/Leisure	.22	.78
High cognitive load	.15	.85

The mind wandering experience plays a key role by affecting the initiation or not of the INMI experience (.80 on 278 episodes and .20 respectively on 70 episodes; Table 3).

The network also indicates that there is no direct influence of time of day on mind wandering or INMI. The remaining of the conditional probability tables can be found in the Appendix A.

3.3.2. INMI episodes network

For the second part of the analysis, observations from only the instances where the INMI occurrence was reported ($n = 644$) were included, along with mind wandering occurrence or not, time of the day, activity, INMI pleasantness and INMI triggers. We constructed the network to include the structural connections identified in the first network. After cross validation, the best network was obtained with the tabu algorithm using the bde score and the maximum likelihood fitting method and is depicted in Fig. 3.

Table 5 shows that INMI is experienced as more pleasant when it is triggered by a specific memory (.67), when it has been associated with a sound (.50), the person has been recently exposed to the music (.41) and when a recent/upcoming event is being contemplated (.38). INMI is experienced as least pleasant when the person cannot identify what triggered it (.65), when the same INMI content (i.e. song) is experienced more than once throughout the day (.61) and when the default INMI of the individual is experienced (.49).

3.3.3. Mind wandering episodes network

The third part of the analysis was constructed only on the basis of those instances were mind wandering was reported ($n = 335$). It included the variables: INMI occurrence or not, time of the day, activity, mood and the mind wandering content questions. The best resulting network was generated by a combination of the max–min hill-climbing algorithm, the bde score and the Bayesian fitting method, and is given in Fig. 4.

The network contains several new relationships: The experience of INMI can lead to the suppression of any other mind wandering contents when only INMI is experienced (.52). Awareness of a current mind wandering experience can lead to a conscious decision to allow the mind to wander (.61). Thinking about personal concerns can cause daydreaming (.21) and also start worries (.60). Mood state and the engaging with memories during mind wandering episode were found to be independent from the rest of the variables in the network.

Fig. 5 represents an attempt to depict the structural connections from all three networks in a single graph.

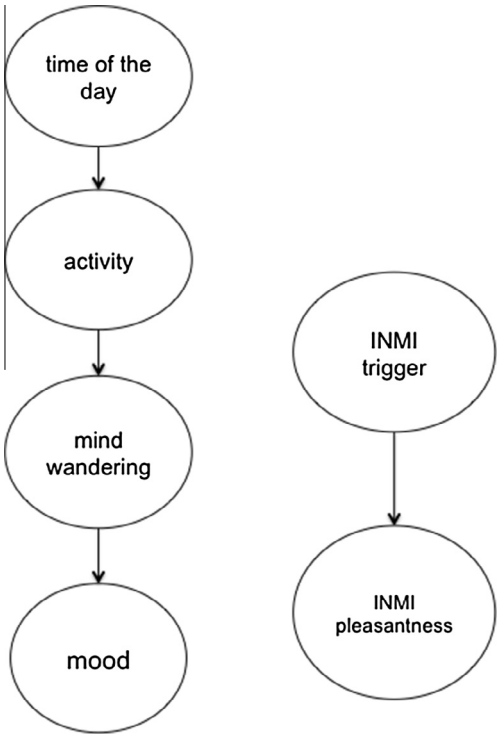

Fig. 3. INMI episodes Bayesian network.

Table 5
Conditional probabilities of INMI triggers and pleasantness.

INMI trigger	Pleasantness		
	Low (0–5)	Middle (5–7)	High (7–10)
Music exposure	.36	.23	.41
Association; Person	.49	.23	.29
Association; Sound	.40	.10	.50
Association; Word/Image	.44	.22	.33
Recent/Upcoming event	.47	.18	.35
Thoughts/Dreams	.39	.40	.22
No idea	.15	.47	.38
Same INMI	.64	.22	.13
Default INMI	.61	.26	.13
Memory	.17	.17	.67

4. Conclusions and discussion

The aim of this study was to examine the role of environmental conditions and psychological states of the individual in relation to the INMI experience. The study specifically looked at interactions and causal relationships between these conditions and also investigated the relationship between INMI experiences and mind wandering.

This study used the ESM technique to study INMI experiences in real-life situations. An important finding is the discrepancy of the frequency of INMI experiences as obtained via ESM sampling in comparison with that obtained via retrospective estimates from the same individuals. Kvavilashvili and Mandler (2004) reported a similar discrepancy between the two different measures for the same participants in relation to ISM frequency. This suggests that, at least for certain individuals, retrospective meta-memory for involuntary semantic memories may be less accurate than measures obtained from experience sampling. A tentative explanation for this discrepancy, given by Kvavilashvili and Mandler, is that some people who do experience involuntary semantic memories may not be paying attention to them and thus may tend to assume that they never experienced them (p. 73). Our finding is particularly important for future studies based on retrospective questionnaire reports for e.g. INMI frequency and other factors of interest, where poor meta-memory for INMI experience could distort empirical results.

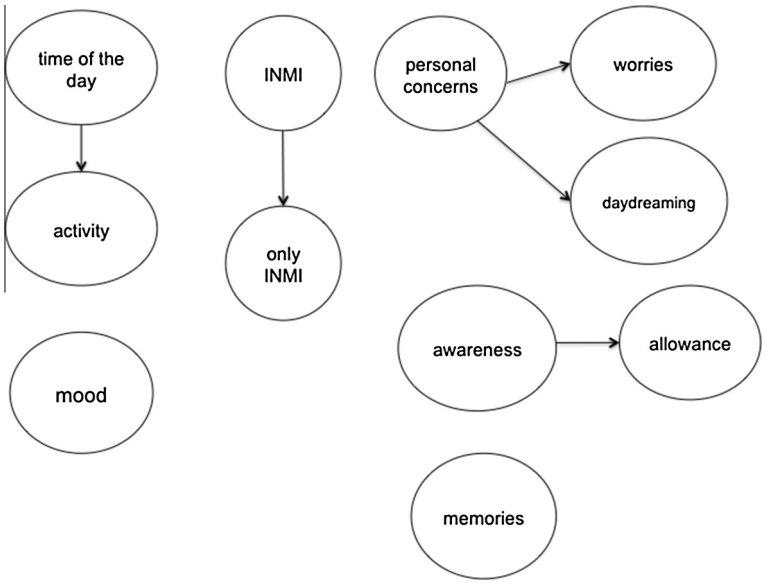

Fig. 4. Mind wandering network.

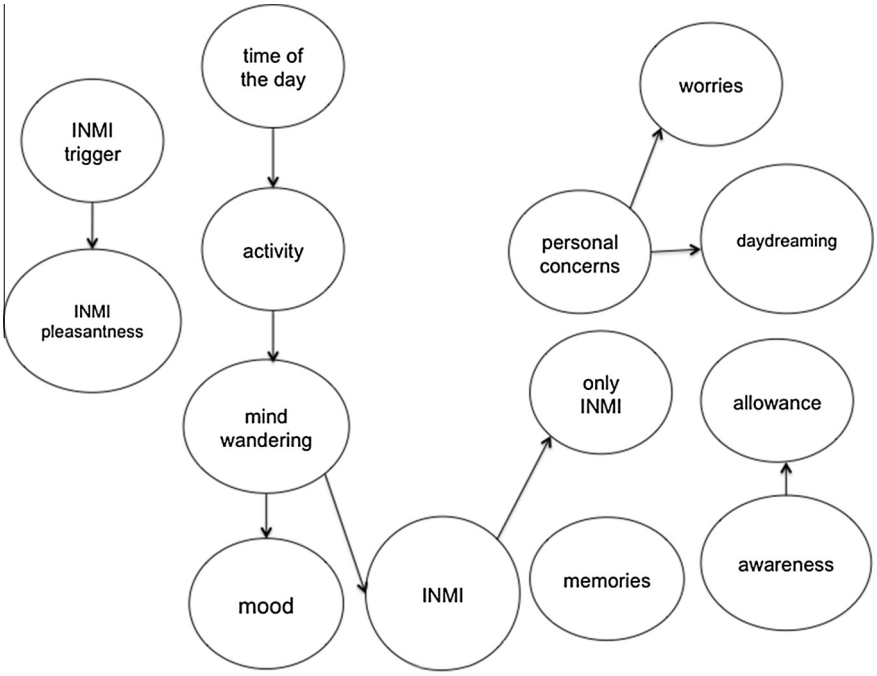

Fig. 5. All networks combined together.

The overall frequency of INMI reported in our study was 47% over the course of a week. This rate is substantially greater than that reported in previous ESM studies on musical imagery, with Bailes (2006) reporting a 32% INMI rate and Beaty et al. (2013) reporting a frequency of 17%. This difference could be the result of the selection criteria of the different studies. The higher overall frequency we observed in this sample could be due to a selection bias, as participants were recruited among people who had completed the earwormery survey and thus it is possible that our participants were more familiar, interested and maybe more aware of this phenomenon.

The results suggested by the network models indicate that the activity that a person is engaged in plays the key role for the appearance of mind wandering, which in turn enables the appearance of INMI. Conditional on the activity, INMI occurrences are independent of time of the day, a result that agrees with Byron and Fowles (2013) and resolves previous

conflicting findings in the literature (Bailes, 2007; Halpern & Bartlett, 2011). Thus, according to our results it is the activity that the person engages in that causes mind wandering and, in turn, the activity is constrained by the time of the day.

Generally, activities found to favor mind wandering, and subsequently INMI appearance, are characterized by low cognitive load (e.g. just woke up, going to sleep), traveling (confirming the findings of Liikkanen, 2012), housework and physical movement. On the other hand, activities that make the appearance of mind wandering and INMI less likely are socializing, a finding that confirms the finding of Liikkanen (2012) but is in conflict to that of Bailes (2006). However one has to bear in mind that the latter study also included voluntary musical imagery episodes in which the participants might purposely have imagined the music in their heads.

Audio/visual activities were found to reduce the likelihood of mind wandering experiences and subsequently INMI. This finding is in contrast with a result from a study (Liikkanen, 2012) which was based on retrospective reports. Both, socializing and audio/visual activities, involve auditory engagement. Neuroimaging findings (Kraemer, Macrae, Green, & Kelley, 2005; Zatorre & Halpern, 2005) show that the auditory cortex is activated in voluntary but also involuntary musical imagery activities. Taking this into consideration, it seems possible that INMI may compete for the same auditory processing resources that are engaged during socializing and audio/visual activities. This could provide an explanation for why involuntary musical imagery appearance is less likely when individuals are engaged in concurrent activities that require auditory processing.

Activities described by high cognitive load such as reading, playing Sudoku, and school homework, but also working and computer/leisure activities, seem to discourage INMI. This finding is at odds with the conclusion by Hyman et al. (2013) that appearance of INMI is favored by activities at both ends of the cognitive load continuum. To resolve these conflicting findings, more experimental studies based on the systematic manipulation of the amount of cognitive load, are required.

With regard to the influence of mood on INMI, the picture emerging from the data of this study is quite clear. The networks described above show that mood is independent of INMI but is affected by the occurrence of mind wandering, which in turn enables INMI occurrence. In other words, mind wandering is a common cause of both INMI and the affective quality of a mood state. The distribution of mood states in all the networks shows that the participants were most often in a calm and happy mood and least likely to be in an energetic mood. This result agrees with the findings by Ruby, Smallwood, Engen, and Singer (2013) that self-generated thought (mind wandering) can temporally precede positive mood. It is also in accordance with musical imagery findings by Bailes (2007) and Beaty et al. (2013) regarding the quality of mood states.

The data of this study also provide a tentative explanation for the observation that the subjective evaluation of INMI episodes can be highly variable (Beaman & Williams, 2010; Liikkanen, 2012; Halpern & Bartlett, 2011; Hemming, 2009). According to the output of the second network, the participant's opinion about what triggered their INMI seems to determine how pleasant an INMI experience is perceived to be. Memory-associated triggers and music exposure increase INMI pleasantness. This could be explained by the fact that people listen to and are more exposed to music that they like and enjoy (North & Hargreaves, 2003; North, Hargreaves, & Hargreaves, 2004). Therefore, there is a higher likelihood of INMI triggers related recent exposure to songs that are perceived as pleasant. However, when the person cannot identify the trigger, experiences an INMI more than once in a day and/or experiences his/her default INMI (i.e. INMI that reoccurs frequently), then the pleasantness of the INMI experience decreases. This could be because of the repetitive quality of INMI that can lead to negative evaluation of the experience. The individual initially enjoys the INMI but finds it unpleasant when this experience occurs and reoccurs. It could also be explained by the findings of Müllensiefen et al. (2014) that individual differences in obsessive compulsive trait – which is characterized by repetitive thought patterns – partially influence INMI valence (unpleasantness).

The relative frequencies of INMI triggers found in this study confirm findings by Williamson et al. (2012) but also allow direct comparisons with triggers of involuntary semantic memories. A key characteristic of ISMs, in comparison to IAMs, is that identification of the ISM trigger is not easily traceable. In our study INMI triggers could be identified in 62.3% of the instances. Kvavilashvili and Mandler (2004) reported ISMs triggers for 37% of the cases, which is approximately half the proportion reported by our participants. This difference might suggest that INMI triggers are more identifiable than triggers of other ISMs because of their persistence that could give more time to the person to identify them.

Finally turning to the relationship between INMI and mind wandering, all the networks derived in the present study reveal interesting relationships. Mind wandering often seems to be the cause of INMI that follows its occurrence, i.e. it appears that the mind starts to wonder and subsequently it enables the appearance of INMI. This finding is in accordance with mind wandering literature where a big portion of its content is reported as musical imagery (Delamillieure et al., 2010)

In summary, this study has demonstrated the advantages of the ESM approach for the study of conditions surrounding the occurrence of INMI and allows a comparison to data from retrospective self-reports. One interpretation of the discrepancy between the results from the two data collection methods suggests that retrospective self-reports can suffer from memory bias. Using Bayesian Networks as an analysis technique, it was found that INMI triggers determine whether INMI is experienced as pleasant or not. Also that INMI does not affect mood directly, but that mind wandering is a common cause behind the two. INMI occurrence is independent of the time of day but activity is a causal link between the two. Finally, low cognitive load activities favor mind wandering occurrence and subsequently INMI appearance.

This paper provides new insights into the contextual and psychological conditions that affect the occurrence and experiential quality of INMI. It uses a data collection method that is highly suited for observing these real-world contexts and a modeling approach that is suitable for identifying complex networks of interacting variables as well as causal mechanisms. The Bayesian network modeling approach appears to be appropriate for the analysis of this type of data because, as previous literature has shown, the conditions which govern INMI experiences are highly complex.

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Appendix A

A.1. Experience Sampling Form

Date: Time when message was received: am/pm Time when form was filled: am/pm

A. At the time of the beep (when the text message came in)

1) I was experiencing an earworm(s) YES/NO

2) My mind had wandered to something other than what I was doing. YES/NO

If NO, go to question 10; if YES, how would you rate the following statements? (1=not at all, 4 moderately, 7=very much)

3) I was aware my mind was wandering in the moments before the beep	1 2 3 4 5 6 7
4) I allowed my thoughts to wander on purpose	1 2 3 4 5 6 7
5) I was thinking about personal concerns or things I need to do	1 2 3 4 5 6 7
6) I was daydreaming or fantasizing about something	1 2 3 4 5 6 7
7) I was worrying about something	1 2 3 4 5 6 7
8) I was remembering something	1 2 3 4 5 6 7
9) My mind was occupied only by the earworm	1 2 3 4 5 6 7

10) What were you doing? (PLEASE UNDERLINE)

Housework, getting dressed, in the bath, travelling, working, studying, reading a book, shopping, exercising, socializing, listening to music, other (please specify) _____

11) How would you rate the way you were feeling (tick in the Table below)?

	Very	Quite	Somewhat	Neither	Somewhat	Quite	Very	
Alert								Drowsy
Happy								Sad
Tense								Relaxed
Interested								Bored
Energetic								Tired
Lonely								Connected

If you're not experiencing an earworm (if you replied NO to question 1) then do not answer section B.

B.

12) Can you name the title and the artist of your earworm tune? YES/NO

Title _____ Artist _____

13) How would you rate the pleasantness of the earworm? 0-10 (0=not at all pleasant, 10= love it) _____

14) Can you give a possible explanation of how the earworm was triggered?

☐ I heard it recently (Please specify by circling: private music (e.g. home/car), public music (e.g. restaurant, shop), radio, live music, ringtone, contagion, learning, other_____)

☐ I saw a person that reminded me of it ☐ I heard a sound that reminded me of it

☐ A word that I saw or heard was somehow connected with the earworm

☐ An recent or upcoming event made me think of it ☐ A dream that I had is connected with the tune

☐ It expresses my current thoughts at this moment/period

☐ Other (please specify) _____

A.2. Conditional probabilities of all the networks

1. Conditional probabilities of the First Network

INMI	Mind wandering	
	0 (No)	1 (Yes)
0 (No)	.56	.20
1 (Yes)	.44	.80

Activity	Time of the day		
	8:00 am–1:00 pm	1:01–6:00 pm	6:01–11:00 pm
1. Working	.28	.32	.04
2. Socializing	.06	.10	.16
3. Grooming	.26	.16	.20
4. Audio/Visual	.07	.09	.21
5. Traveling	.09	.10	.08
6. Physical movement	.06	.07	.05
7. Low Cognitive Load	.06	.02	.06
8. Computer/Leisure	.06	.08	.09
9. High cognitive load	.05	.05	.10

Mood	Mind wandering	
	0 (No)	1 (Yes)
1.Drowsy, Lonely, Tired, Bored	.36	.49
2. Relaxed, (Happy)	.26	.20
3. Sad, Tense	.20	.20
4. Alert, Happy, Interested, Energetic, Connected	.17	.11

2. Conditional Probabilities of the Second Network

Activity	Mind wandering	
	0 (No)	1 (Yes)
1. Working	.70	.30
2. Socializing	.75	.25
3. Grooming	.58	.42
4. Audio/Visual	.64	.36
5. Traveling	.54	.46
6. Physical Movement	.60	.40
7. Low Cognitive Load	.37	.63
8. Computer/Leisure	.68	.32
9. High Cognitive Load	.74	.26

Activity	Time of the day		
	8:00 am–1:00 pm	1:01–6:00 pm	6:01–11:00 pm
1. Working	.26	.33	.02
2. Socializing	.049	.06	.10
3. Grooming	.28	.20	.28
4. Audio/Visual	.06	.05	.10
5. Traveling	.10	.14	.12
6. Physical Movement	.06	.08	.06
7. Low Cognitive Load	.08	.03	.09
8. Computer/Leisure	.06	.06	.09
9. High Cognitive Load	.05	.05	.13

Mood	Mind wandering	
	0 (No)	1 (Yes)
1. Drowsy, Lonely, Tired, Bored	.39	.52
2. Relaxed, (Happy)	.25	.18
3. Sad, Tense	.20	.20
4. Alert, Happy, Interested, Energetic, Connected	.16	.11

INMI trigger	Pleasantness		
	0–4	5–7	8–10
Music Exposure	.36	.23	.41
Association; Person	.49	.23	.29
Association; Sound	.40	.10	.50
Association; Word/Image	.44	.22	.33
Recent/Upcoming Event	.47	.18	.35
Thoughts/Dreams	.39	.40	.22
No Idea	.15	.47	.38
Same INMI	.64	.22	.13
Default INMI	.61	.26	.13
Memory	.17	.17	.67

3. Conditional Probabilities of the Third Network

Activity	Time of the day		
	8:00 am–1:00 pm	1:01–6:00 pm	6:01–11:00 pm
1. Working	.19	.28	.03
2. Socializing	.04	.04	.05
3. Grooming	.32	.20	.36
4. Audio/Visual	.03	.08	.14
5. Traveling	.11	.21	.10
6. Physical Movement	.07	.09	.06
7. Low Cognitive Load	.13	.03	.10
8. Computer/Leisure	.06	.06	.08
9. High Cognitive Load	.03	.02	.08

Mind wandering; allowance	Mind wandering; awareness	
	1–4	5–7
1–3	.70	.39
4–7	.30	.61

Mind wandering; daydreaming	Mind wandering; personal concerns	
	1–4	5–7
1–2	.46	.79
3–7	.54	.21

Mind wandering: worries	Mind wandering: personal concerns	
	1–4	5–7
1	.62	.40
2–7	.38	.60

Mind wandering: Only INMI	INMI	
	0 (No)	1 (Yes)
1	.99	.52
2–7	.01	.48

References

Antrobus, J. S. (1968). Information theory and stimulus-independent-thought. *British Journal of Psychology, 59*, 423–430.

Bailes, F. (2006). The use of experience-sampling methods to monitor musical imagery in everyday life. *Musicae Scientiae, 10*(2), 173–190.

Bailes, F. (2007). The prevalence and nature of imagined music in the everyday lives of music students. *Psychology of Music, 35*(4), 555–570.

Beaman, C. P., & Williams, T. I. (2010). Earworms (stuck song syndrome): Towards a natural history of intrusive thoughts. *British Journal of Psychology, 101*(4), 637–653.

Beaman, C. P., & Williams, T. (2013). Individual differences in mental control predict involuntary musical imagery. *Musicae Scientiae*.

Beaty, R. E., Burgin, C. J., Nusbaum, E. C., Kwapil, T. R., Hodges, D. A., & Silvia, P. J. (2013). Music to the inner ears: Exploring individual differences in musical imagery. *Consciousness and Cognition, 22*(4), 1163–1173.

Bennett, S. (2002). Musical Imagery Repetition (MIR). Master's thesis. Cambridge University: Cambridge.

Berntsen, D. (1996). Involuntary autobiographical memories. *Applied Cognitive Psychology, 10*, 435–454.

Berntsen, D. (2001). Involuntary memories of emotional events: Do memories of traumas and extremely happy events differ? *Applied Cognitive Psychology, 15*, 135–158.

Brown, S. (2006). The perpetual music track: The phenomenon of constant musical imagery. *Journal of Consciousness Studies, 13*(6), 43–62.

Byron, T. P., & Fowles, L. C. (2013). Repetition and recency increases involuntary musical imagery of previously unfamiliar songs. *Psychology of Music*, 1–15.

Christoff, K., Ream, J. M., & Gabrieli, J. D. E. (2004). Neural basis of spontaneous thought processes. *Cortex, 40*, 1–9.

Csikzentmihalyi, M., & Larson, R. (1987). Validity and reliability of the experience-sampling method. *The Journal of Nervous and Mental Disease, 175*(9), 526–536.

Delamillieure, P., Doucet, G., Mazoyer, B., Turbelin, M.-R., Delcroix, N., Mellet, E., et al (2010). The resting state questionnaire: An introspective questionnaire for evaluation of inner experience during the conscious resting state. *Brain Research Bulletin, 81*, 565–573.

Floridou, G. A., Williamson, V. J., & Müllensiefen, D. (2012, July). Contracting earworms: The roles of personality and musicality. In E. Cambouropoulos, C. Tsougras, P. Mavromatis, & K. Pastiadis (Eds.), *Proceedings of the 12th international conference on music perception and cognition and the 8th triennial conference of the european society for the cognitive sciences of music*, Thessaloniki, Greece (pp. 516–518).

Floridou, G. A., Williamson, V. J., Stewart, L., & Müllensiefen, D. (in press). The Involuntary Musical Imagery Scale (IMIS). *Psychomusicology: Music, Mind and Brain*.

Fraley, C., Raftery, A. E., Murphy, T. B., & Scrucca, L. (2012). mclust Version 4 for R: Normal Mixture Modeling for Model-Based Clustering, Classification, and Density Estimation Technical Report No. 597, Department of Statistics, University of Washington.

Glover, F. (1986). Future paths for integer programming and links to artificial intelligence. *Computers and Operations Research, 13*(5), 533–549.

Halpern, A. R., & Bartlett, J. C. (2011). The persistence of musical memories: A descriptive study of earworms. *Music Perception, 28*, 425–443.

Hartemink, A. J. (2001). Principled Computational Methods for the Validation and Discovery of Genetic Regulatory Networks. PhD thesis, School of Electrical Engineering and Computer Science, Massachusetts Institute of Technology.

Hemming, J. (2009). Zur Phänomenologie des 'Ohrwurms' in W. Auhagen, C. Bullerjahn & H. Höge (Eds.) Musikpsychologie – Musikalisches Gedächtnis und musikalisches Lernen. Jahrbuch 20 (pp. 184–207). Göttingen: Hogrefe.
Hyman, I. E., Jr., Burland, N. K., Duskin, H. M., Cook, M. C., Roy, C. M., McGrath, J. C., et al (2013). Going Gaga: Investigating, creating, and manipulating the song stuck in my head. *Applied Cognitive Psychology, 27*, 204–215.
Kellaris, J. J (2001). Identifying properties of tunes that get 'stuck-in-your-head': Toward a theory of cognitive itch. In *Proceedings of the society for consumer psychology winter 2001 conference* (pp. 66–67). Scottsdale, AZ: American Psychological Society.
Killingsworth, M. A., & Gilbert, D. T. (2010). A wandering mind is an unhappy mind. *Science, 330*, 932.
Korb, K., & Nicholson, A. (2011). *Bayesian artificial intelligence*. Boca Raton, FL: Chapman and Hall/CRC.
Kraemer, D. J., Macrae, C. N., Green, A. E., & Kelley, W. M. (2005). Musical imagery: Sound of silence activates auditory cortex. *Nature, 434*, 158.
Kubey, R., Larson, R., & Csikszentmihalyi, M. (1996). Experience sampling method applications to communication research questions. *Journal of Communication, 46*(2), 99–120.
Kvavilashvili, L., & Mandler, G. (2004). Out of one's mind: A study of involuntary semantic memories. *Cognitive Psychology, 48*, 47–94.
Liikkanen, L. A. (2012). Musical activities predispose to involuntary musical imagery. *Psychology of Music, 40*, 236–256.
McVay, J. C., Kane, M. J., & Kwapil, T. R. (2009). Tracking the train of thought from the laboratory into everyday life: An experience-sampling study of mind wandering across controlled and ecological contexts. *Psychonomic Bulletin and Review, 16*, 857–863.
Müllensiefen, D., Fry, J., Jones, R., Jilka, S. R., Stewart, L., & Williamson, V. J. (2014). Individual differences predict patterns in spontaneous involuntary musical imagery. *Music Perception, 31*(4), 323–338.
Nagarajan, R., Lebre, S., & Scutari, M. (2013). *Bayesian Networks in R: With applications in systems biology*. NY: Springer-Verlag.
North, A. C., & Hargreaves, D. J. (2003). Is music important? *The Psychologist, 16*(8), 406–410.
North, A. C., Hargreaves, D. J., & Hargreaves, J. J. (2004). Uses of music in everyday life. *Music Perception, 22*, 41–77.
R Core Team (2013). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
Rasmussen, A. S., & Berntsen, D. (2009). The possible functions of involuntary autobiographical memories. *Applied Cognitive Psychology, 23*, 1137–1152.
Reason, J., & Mycielska, K. (1984). *Absent-minded? The psychology of mental lapses and everyday errors*. NJ Prentice Hall: Englewood Cliffs.
Ruby, F. J. M., Smallwood, J., Engen, H., & Singer, T. (2013). How self-generated thought shapes mood—the relation between mind-wandering and mood depends on the socio-temporal content of thoughts. *PLoS ONE, 8*, e77554.
Schooler, J. W. (2002). Re-representing consciousness: Dissociations between experience and meta-consciousness. *Trends in Cognitive Sciences, 6*, 339–344.
Schooler, J. W., Reichle, E. D., & Halpern, D. V. (2005). Zoning-out during reading: Evidence for dissociations between experience and meta-consciousness. In D. T. Levin (Ed.), *Thinking and seeing: Visual metacognition in adults and children* (pp. 204–226). Cambridge, MA: MIT Press.
Scutari, M. (2010). Learning Bayesian Networks with the bnlearn R Package. *Journal of Statistical Software, 35*(3), 1–22.
Sloboda, J. A., O'Neill, S. A., & Ivaldi, A. (2001). Functions of music in everyday life: An exploratory study using the experience sampling method. *Musicae Scientiae, 5*(1), 9–32.
Smallwood, J., Baracaia, S. F., Lowe, M., & Obonsawin, M. C. (2003). Task-unrelated-thought whilst encoding information. *Consciousness and Cognition, 12*, 452–484.
Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M. V., O'Connor, R. C., et al (2004). Subjective experience and the attentional lapse. Task engagement and disengagement during sustained attention. *Consciousness and Cognition, 4*, 657–690.
Smallwood, J., Obonsawin, M. C., & Heim, S. D. (2003). Task-unrelated-thought: The role of distributed processing. *Consciousness and Cognition, 12*, 169–189.
Smallwood, J., O'Connor, R. C., Sudberry, M. V., & Ballantyre, C. (2004). The consequences of encoding information on the maintenance of internally generated images and thoughts: The role of meaning complexes. *Consciousness and Cognition, 4*, 789–820.
Smallwood, J., & Schooler, J. W. (2006). The restless mind. *Psychological Bulletin, 132*, 946–958.
Teasdale, J. D., Lloyd, C. A., Proctor, L., & Baddeley, A. (1993). Working memory and stimulus-independent-thought: Effects of memory load and presentation rate. *European Journal of Psychology, 5*, 417–433.
Williamson, V. J., Jilka, S. R., Fry, J., Finkel, S., Mullensiefen, D., & Stewart, L. (2012). How do "earworms" start? Classifying the everyday circumstances of involuntary musical imagery. *Psychology of Music, 40*, 259–284.
Zatorre, R. J., & Halpern, A. R. (2005). Mental concerts: Musical imagery and the auditory cortex. *Neuron, 47*, 9–12.