Consciousness and Cognition 35 (2015) 66–77

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Tunes stuck in your brain: The frequency and affective evaluation of involuntary musical imagery correlate with cortical structure

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ARTICLE INFO

Article history:
Received 21 November 2014

Keywords:
Music
Imagery
Involuntary
Cortical thickness
Voxel-based morphometry

ABSTRACT

Recent years have seen a growing interest in the neuroscience of spontaneous cognition. One form of such cognition is involuntary musical imagery (INMI), the non-pathological and everyday experience of having music in one's head, in the absence of an external stimulus. In this study, aspects of INMI, including frequency and affective evaluation, were measured by self-report in 44 subjects and related to variation in brain structure in these individuals. Frequency of INMI was related to cortical thickness in regions of right frontal and temporal cortices as well as the anterior cingulate and left angular gyrus. Affective aspects of INMI, namely the extent to which subjects wished to suppress INMI or considered them helpful, were related to gray matter volume in right temporopolar and parahippocampal cortices respectively. These results provide the first evidence that INMI is a common internal experience recruiting brain networks involved in perception, emotions, memory and spontaneous thoughts.

1. Introduction

It is a common experience to have music looping in one's head, a phenomenon colloquially termed "earworms", as well as "stuck song syndrome", or, more formally, involuntary musical imagery (INMI, Liikkanen, 2008). INMI appears spontaneously and without conscious control. As a spontaneous cognitive phenomenon, INMI can be considered alongside other self-generated thoughts (SGT) such as mind wandering or daydreaming, which are known to occupy a substantial proportion of mental life (Killingsworth & Gilbert, 2010; Klinger & Cox, 1987).

INMI is prevalent in the general population (Liikkanen, 2008) and several diary and behavioral studies have shed light on the phenomenon. INMI is typically triggered by recent musical exposure (Bailes, 2007; Byron & Fowles, 2013; Halpern & Bartlett, 2011; Hyman et al., 2013), as well as low attention states and memory associations (Williamson et al., 2011). Individuals who are musically trained or who actively engage with music in other ways, experience INMI more frequently (Beaty et al., 2013; Liikkanen, 2011; Müllensiefen et al., 2014). INMI episodes are mostly pleasant but can also be disturbing (Beaman & Williams, 2010; Williamson, Liikkanen, Jakubowski, & Stewart, 2014), while recent data suggests that the

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http://dx.doi.org/10.1016/j.concog.2015.04.020
1053-8100/

occurrence of musical imagery (both involuntary and voluntary) is influenced by mood states (Beaty et al., 2013; Williamson et al., 2011). Personality traits such as obsessive–compulsive traits (Müllensiefen, Fry, et al., 2014), neuroticism and openness to experience (Beaty et al., 2013; Floridou, Williamson, & Müllensiefen, 2012) are associated with more frequent INMI, while individual differences in mental control and schizotypy predict difficulty in the suppression of INMI (Beaman & Williams, 2013). Finally, there is evidence that the occurrence of INMI depends on availability of cognitive resources (Hyman et al., 2013), as is the case for other forms of SGT (Forster & Lavie, 2009).

In contrast to the behavioral literature that has emerged over recent years, no study to date has focused on the neural basis of INMI. This may, in part, relate to the lack of predictability of INMI, such that episodes of INMI would likely prove elusive in a functional scanning paradigm, or unsuitable for typical neuroimaging designs. Nonetheless, it is of considerable interest to examine the cerebral basis of INMI, not least because the experience is very common, can be vivid and complex, and may have the capacity to positively influence moods and emotions, akin to instances of actual music listening (Fritz, Halfpaap, Grahl, Kirkland, & Villringer, 2013; Koelsch, 2014; Schellenberg, Nakata, Hunter, & Tamoto, 2007; Shifriss, Bodner, & Palgi, 2014).

A potentially fruitful approach to a neurological investigation of INMI is one based on individual differences, i.e., investigating whether discrete aspects of the INMI experience systematically co-vary with regional differences in brain structure. A new measure, the Involuntary Musical Imagery Scale (IMIS) (Floridou, Williamson, Stewart, & Müllensiefen, 2015) captures multiple facets of the INMI experience, including questions relating to frequency, as well as evaluative, sensorimotor and self-reflective aspects of the experience. The measure has been tested on 2315 participants, and has been demonstrated to have good validity using exploratory and confirmatory factor analysis (Cronbach's alpha for the factors ranged from 0.76 to 0.91), as well as good test–retest reliability (all significant test–retest correlations ranging from 0.65 to 0.79). This makes the IMIS a valuable tool for establishing whether variation in any of these aspects of the INMI experience is reflected in systematic differences in brain structure. In formulating our hypotheses regarding a potential relationship between INMI and brain structure, we consider three bodies of literature, pertaining to the neural bases of deliberate auditory imagery, emotional response to music, and self-generated thought.

Voluntary musical imagery, or more generally auditory imagery, has been previously described in the psychological and neuroscientific literature (Halpern, 2001; Herholz, Halpern, & Zatorre, 2012; Hubbard, 2010; Zatorre, Halpern, Perry, Meyer, & Evans, 1996) and has been shown to recruit brain areas similar to those involved in music perception and performance, including the primary and secondary auditory cortices (Halpern & Zatorre, 1999; Linke & Cusack, 2015; Zatorre & Halpern, 2005; Zatorre et al., 1996) and the supplementary motor area (SMA) (Halpern, Zatorre, Bouffard, & Johnson, 2004). Voluntary musical imagery also relies on interactions between auditory areas and the right inferior frontal gyrus (rIFG) (Herholz et al., 2012), the latter being recruited in working memory for pitch processing (Albouy et al., 2013; Hyde, Zatorre, & Peretz, 2011; Hyde et al., 2007) and both auditory perception and imagery (Herholz et al., 2012).

Recent research on the neural correlates of music-evoked emotion has shown that music can elicit widespread activity in the brain's emotional circuitry (Koelsch et al., 2004). Intense pleasure, fear and joy evoked by music activates deep regions involved in reward such as the nucleus accumbens, amygdala, striatum and hypothalamus (Blood & Zatorre, 2001; Koelsch et al., 2013; Pehrs et al., 2013; Zatorre & Salimpoor, 2013). Furthermore, a wide range of cortical areas contribute to the affective evaluation of music, such as the orbitofrontal cortex (OFC), ventromedial prefrontal cortex and anterior cingulate cortex (ACC) (Alluri et al., 2013; Blood & Zatorre, 2001; Lehne, Rohrmeier, & Koelsch, 2013), as well as the parahippocampal cortex (PHC) (Engelien et al., 2006; Koelsch, Fritz, von Cramon, Müller, & Friederici, 2006). Whether these brain networks are also implicated in the affective evaluation of musical imagery has not yet been addressed.

Brain networks involved in endogenous processes such as mind wandering may also contribute to aspects of the INMI experience, such as frequency of episodes, linking them with personal concerns, or forming an evaluative judgment. The generation of SGT may rely on spontaneous activity in the Default-Mode Network (DMN), a set of brain areas which are more active when participants are not focusing on a task (Andrews-Hanna, Reidler, Huang, & Buckner, 2010; Buckner, Andrews-Hanna, & Schacter, 2008; Callard, Smallwood, Golchert, & Margulies, 2013; Fox, Nijeboer, Solomonova, Domhoff, & Christoff, 2013; Kucyi & Davis, 2014). This network includes the medial prefrontal cortex, the posterior cingulate cortex, the PHC, and the ventral ACC. While generating undirected thoughts, the DMN may be also coupled with the executive network and decoupled from sensory areas (Christoff, 2012), while the internal train of thought could emerge from interactions between the DMN and fronto-parietal networks (Smallwood, Brown, Baird, & Schooler, 2011). It appears that the form and content of SGT are reflected in spontaneous fluctuations during resting state in perigenual cingulate cortex, primary visual cortex, the insula and the cerebellum (Gorgolewski et al., 2014), as well as the medial OFC. Accordingly, it was found that patterns of activations in the medial OFC during task and rest encode the affective content of SGT (Tusche, Smallwood, Bernhardt, & Singer, 2014). Finally, in a structural MRI study of SGT it was found that midline brain areas mediate task unrelated thoughts; the tendency to engage in SGT during low cognitive load correlates with cortical thickness in the medial prefrontal cortex, the ACC and lateral prefrontal opercular cortex (Bernhardt et al., 2013).

A recent review has emphasized the potential of structural MRI to uncover brain–behavior relationships (Kanai & Rees, 2011). Here, we use two common methods to study covariation between brain structure and behavior, namely voxel-based morphometry (VBM, Ashburner & Friston, 2000) and cortical thickness. These two measures provide different insights into brain morphology, as VBM measures local variations in gray matter volume (GMV), while cortical thickness measures the distance between the gray–white matter interface and the pial surface. Typically, cortical thickness is measured by modelling the surface of the cortical sheet. This surface model can subsequently be used to derive measurements