# Earworms and Working Memory

## How do the inner ear, inner voice and attention keep earworms looping in memory?

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**Declaration**

"I declare that this research project is my own, unaided work. It has not been submitted before for any other degree or examination at this or any other university"

Date: 15th March 2017

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## Abstract

The report evaluates the application of established working memory (WM) theory to the emerging field of involuntary musical imagery (INMI) using an experimental, repeated-measures factorial design. First, INMI is defined and characterised by briefly overviewing the literature. Then, the WM model is applied to INMI, and the literature evaluated in light of this application. Most importantly, three mechanisms for sustaining earworms are identified: the inner ear, inner voice and attentional refreshing. The study then aims to see how induced INMI is effected by the suppression of these three mechanisms, on a sample of 29 university students. To do this, the study uses a repeated-measures 2 × 2 × 2 factorial design where participants complete the attention network test (ANT) under eight conditions, based on the combination of these manipulations: chewing gum, hearing foreign speech, easy or difficult ANT. The results found a main effect of the foreign speech, and interactions between chewing gum and attention, and hearing the foreign speech and chewing gum. This suggests that attention plays a definite role in sustaining INMI, or conversely that when distracted and under high attentional load, INMI is supressed. Hearing foreign speech also supresses INMI, which supports the role of the PL, and likely the inner ear, while chewing gum was surprisingly found to facilitate INMI. More descriptively, the study supports the literature in finding that in a South African university sample INMI is a common, positive to neutral experience, but that can be induced experimentally and can be distracting. Ultimately, in proposing and evaluating an application of WM to INMI, the study adds depth to field of INMI by highlighting mechanisms involved in facilitating and supressing INMI.


***Keywords:*** *attention network test (ANT), chewing gum, earworms, involuntary musical imagery (IMIS), involuntary musical imagery scale (IMIS), working memory (WM).*

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First and foremost, this research is to the glory of God, my source of strength, inspiration and creativity. May this be a new song sung to the Lord.

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# 1. Literature Review

The phenomenon of involuntary musical imagery (INMI) is slowly burgeoning into a field in its own right. Since the first studies at the beginning of the millennium, research has blossomed and a special issue has been published (Cohen, 2015). Although still somewhat controversial, the definition of INMI is becoming more standardized. INMI is simply defined here as the involuntary recall of musical imagery. Many exploratory studies have mapped out descriptive elements to provide insight into the nature of this phenomenon. Experimental studies have induced and manipulated aspects of INMI, to map out causal pathways, and investigated which factors may influence the occurrence of INMI.

Nonetheless, the field of INMI may be characterised as having two major gaps: there is the absence of cohesion in the field, particularly concerning the definition and measurement of INMI; moreover, the field lacks an overarching theory that explains the phenomenon. This review will highlight these extant gaps, where some research has attempted to address them and where future research, and thus the current research, should be directed. Attention will be given to how working memory (WM) theory may illuminate the workings of INMI.

## 1.1. Definitions and Characteristics

INMI is defined as *the experience of musical imagery, which is recalled involuntarily*. Earworms are considered a subtype of INMI that loop serially and repeat, and can more commonly be described as a song that is stuck in the head. Firstly, INMI is distinguished as a non-voluntary subtype of musical imagery (MI) and auditory imagery in general. Then, earworms are defined and characterised as a subtype of INMI. Finally, the atypical forms of INMI are identified and set aside.

### 1.1.1. (Voluntary) MI

Auditory imagery, while less researched than visual imagery, has been a fruitful area of study in cognitive psychology (see Hubbard, 2010 for a recent review). INMI falls within this tradition and is specifically a subset of MI (e.g. Liikkanen, 2012a; Kellaris, 2001, 2003; Müllensiefen et al., 2014; Sacks, 2007). As such, the first task is to locate INMI within MI, and thereby distinguish it from voluntary forms of MI. Musical imagery simply refers to *music experienced without an external source or sensory* *experience of music* (Bailes, 2007; Williamson, et al., 2011). Moreover, this experience of MI is auditory in nature, being 'heard' internally rather than merely being thought about.

Voluntary refers to the fact that the MI is recalled purposefully (Beaty, et al., 2013), for example, a pianist intentionally imagining a musical piece by looking at the score. The involuntary aspect of INMI simply denotes that the recall of music is not voluntary, but this does not imply spontaneity as INMI can be induced (Liikkanen, 2011; cf. Beaty et al., 2013; Williamson, Liikkanen, Jakubowski, & Stewart, 2014). However, involuntary seems qualitatively different from 'automatic' MI, that is, MI that continues when a short silent gap is inserted into a song (Janata, 2001; Kraemer, 2005) . Such an 'after image' and the methods for achieving it have yet to be linked or addressed within the INMI literature (but see Liikkanen, 2012a).

The involuntary nature of INMI places it within the tradition of involuntary memories, and some particularly suggest semantic rather than autobiographic memories, because there are not always clear triggers (Kvavivilashvili & Anthony, 2012; Kvavilashvili & Mandler, 2004). However, INMI is equally triggered by semantic and autobiographical cues (Byron & Fowles, 2013). Moreover, while auditory imagery does involve semantic components (Hubbard, 2010), it is not entirely semantic. Ultimately, INMI does not seem to neatly fit into a particular category of any memory typology.

#### 1.1.2. Earworms

Although many studies presume INMI and earworms to be synonymous, Williams (2015) presents a strong argument for earworms forming a subtype of INMI. Specifically, an earworm is *the experience of musical imagery, which is recalled involuntarily, that then loops serially and repeats* and the music is therefore familiar to the individual. A typical earworm experience might be a chorus of a song heard on the radio, which repeats continuously. Each facet in this definition links to a step in the WM model, and is discussed and supported later in the context of this model. However, it is worth noting that early research supports this distinction between earworm and INMI, where self-reported frequency showed earworms as a subtype of INMI (Geffen, 2015). Consequently, these will be differentiated in the literature where possible. The characteristics of earworms and their operationalisation are now explored.

#### *1.1.2.1. Characteristics*

Not only are earworms and INMI common, but they seem to be the most common form of involuntary cognition (Kvavivilashvili & Anthony, 2012) and MI (Bailes, 2015). A typical earworm experience could be a chorus from a song, or a riff, but normally a short section of music (Beaman & Williams, 2010; McCullough, 2014). The earworm will repeat several times in a loop, and seems to move in and out of awareness (Williams, 2015). While the experience can be frustrating or distracting at times, it is often pleasant or neutral (Halpern & Bartlett, 2011; Floridou & Müllensiefen, 2015 cf. Liikkanen, Jakubowski, & Toivanen, 2015). Often the occurrence and response to the earworm may depend on personality (Floridou, Williamson, & Müllensiefen, 2012), current activity, thoughts, mood (Williamson, et al., 2011) and the song that is stuck (Byron & Fowles, 2013).

Earworms seem to raise many questions, and current research raises more than it answers. Earworms do not seem to be like most other conscious phenomena – they creep into awareness, and often seem to escape control (Beaman & Williams, 2010). They even appear to be vastly different from other imagery, which is usually called to mind to serve some straightforward cognitive goal, rather than just repeating in the mind – repetition which seems to mirror the repetitive structure of music itself (Margulis, 2013). However, some certainties have become increasingly clear. Earworms are not primarily reported as frustrating, but often as enjoyable (Beaman & Williams, 2010; Halpern & Bartlett, 2011; cf. Kellaris, 2001; Sacks, 2007). Moreover, this is not just an obscure or pathological imagery form, but seems to be widely experienced in Western populations (Liikkanen, 2011).

#### *1.1.2.2. Operationalisation*

While there is controversy regarding the INMI working definition (dealt with subsequently in relation to WM), equal controversy surrounds its operationalisation and measurement. However, as the characteristics of earworms have become clearer, it has been increasingly necessarily to quantify these properties in standard ways. There is a vast range of operationalisations (see especially Müllensiefen et al., 2014; Wammes & Barušs, 2009), but most measure the frequency, duration and the pleasantness of INMI. One attempt to capture many relevant facets of earworms is the Involuntary Musical Imagery Scale (IMIS) developed by Floridou, Williamson, Stewart and Müllensiefen (2015), which found four underlying factors and three independent ones (from an array of potential INMI characteristics). The negative valence subscale captures the unpleasantness of earworms and a desire to stop them, while the help subscale measures how much a person believes experiencing an earworm aids them in completing or focusing on an activity. Movement measures a propensity to move in response to earworms and personal reflections show an internal emotional connection to the earworm. The three independent subscales are earworm frequency, the length of the section of music that forms the earworm, and the entire episode length (i.e. how long the earworm lasts for). While this is a step towards a universal measurement, it is only newly developed and requires further investigation to evaluate its usefulness to the field.

#### 1.1.3. Atypical

INMI also come in atypical forms, which should be distinguished from earworms. In principle, atypical INMI should be considered under INMI (Williams, 2015) and on a continuum with typical forms of INMI (Liikkanen, 2012b), based on a dimensional view. However, in practice and for the purposes of this report, apart from this discussion of atypical INMI, the paper focuses purely on the typical experience of INMI. The term atypical is preferred to imply that the common feature is a non-normative and distressing experience. It is not necessarily associated with pathology or mental disorder or an organic brain disease, although these may be related. Atypical INMI includes permanent INMI, musical obsessions, musical (pseudo)hallucinations and musical palinacousis (Liikkanen, 2012b).

Current research suggests that INMI episodes are generally intermittent (e.g. Hyman et al., 2013), but for some individuals, the imagery can be described as perpetual (Brown, 2006), long-term (Hemming & Altenmüller, 2012) or permanent (Hemming & Merrill, 2015). The experience is like an earworm, but the imagery is continuous and long-term, occurring throughout waking life (and even in dreams) for a period of years, and the individual is largely unable to stop the imagery during these long periods. This permanent INMI may be experienced as distressing and intrusive to varying degrees but the source of the music is acknowledged as internal.

This phenomenon is related to musical obsessions. The Diagnostic and Statistical Manual, Fifth Edition (DSM-5; American Psychological Association, 2013) defines obsessions (in the context of obsessive-compulsive disorder) as “recurrent or persistent thoughts, urges, or images that are experienced… as intrusive and unwanted” (p. 237) that the individual attempts to stop, take an hour or more per day or cause distress. Taylor et al. (2014) apply these criteria to MI to define musical obsessions as a pathological form of INMI, and further consider its characteristics and potential aetiology and treatment. As such, musical obsessions may not necessarily be continuous, whereas permanent INMI may not necessarily be associated with compulsions or clinically significant distress (e.g. Brown, 2006). Similarly, Liikkanen (2012b) has also proposed disturbance as a dimension for differentiation.

Insight is relevant to pathological forms of INMI, but requires careful consideration. Taylor et al. (2014) state that insight is required for musical obsessions, specifically insight into the music being a product of one’s mind and not coming from an external source, differentiated from insight into the verdicality of one’s obsessive-compulsive beliefs (i.e. the causal relationship between them) in the DSM-5 (American Psychological Association, 2013). As such, individuals with pathological musical hallucinations believe that the source of their music is external in contrast to the insight present in musical obsessions and hallucinosis (or pseudo-hallucinations), the latter being generally related to an organic brain disease, deafness or intoxication (Hemming & Merrill, 2015; Taylor, et al., 2014).

From a neurophysiological perspective, Sacks (2007) also differentiates between non-pathological earworms, or ‘brainworms’, and pathological INMI, giving rich qualitative descriptions mostly in relation to neurological disorders and hearing difficulties, such as musical epilepsy and musical (pseudo)hallucinations. Another form which may be associated with organic brain disease is musical palinacousis, where the individual experiences an echo or preservation immediately following the cessation of external musical stimulus (Taylor, et al., 2014; Williams, 2015). However, this is different from the less severe and non-pathological, briefly perceived continuation of music when a gap of silence is inserted (Kraemer, 2005).

### 1.2. WM Model

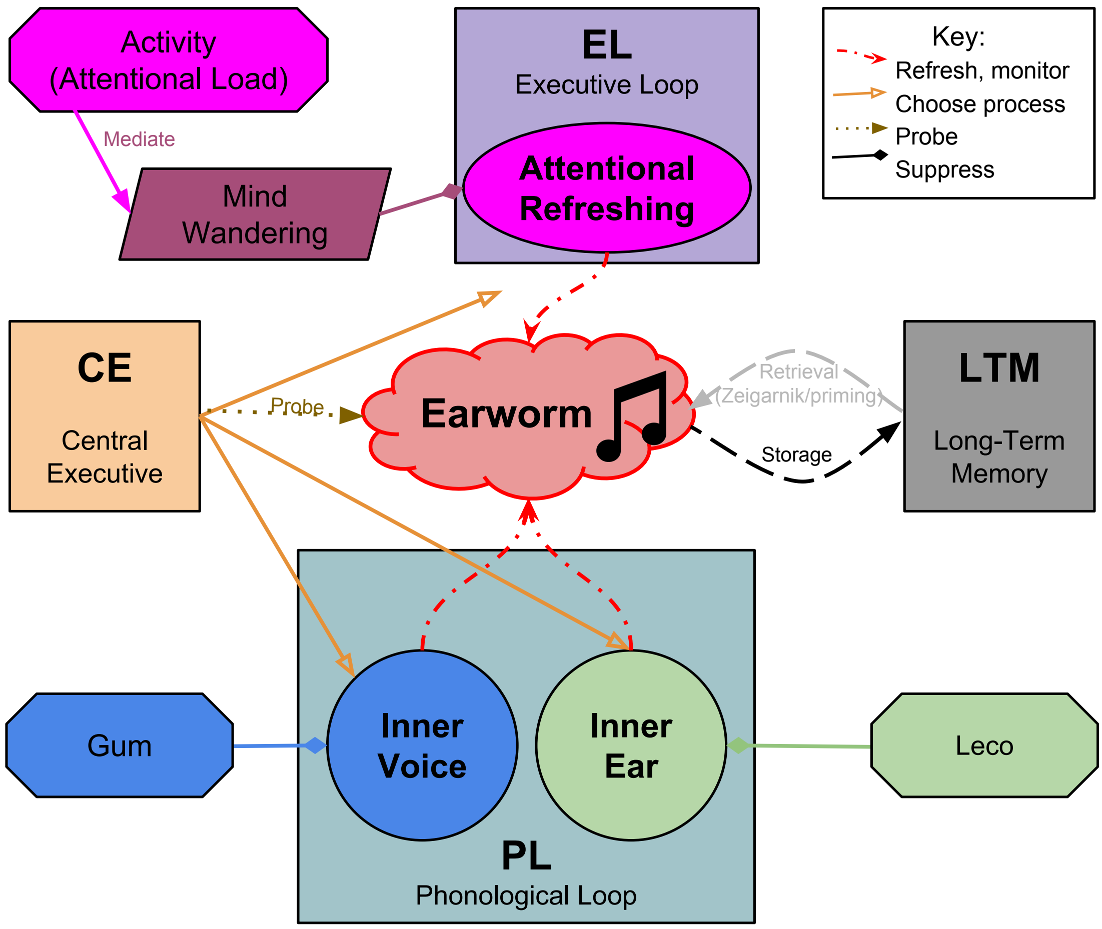
As discussed, there is a lack of theory, especially macro-theory, in the field. While this remains a gap in the literature, some studies have considered Baddeley's (2012) WM model. "Baddeley and Logie (1992) suggested that the phonological loop subsystem of working memory provides a basis for auditory imagery" (Hubbard, 2010, p. 314). Specifically, this grounds a new, emerging field in an established cognitive theory, developed, tested and growing since 1974 (Baddeley & Logie, 1974). However, the present application extends and synthesises several partial applications, connecting a range of INMI and WM facets. Such an application to INMI, and its testing, may also provide insight into WM and a method to study it; especially everyday auditory imagery.

Baddeley's (2012) WM model is a multi-component model, but the focus will be on the interplay of four specific components: the central executive (CE), phonological loop (PL), long-term memory (LTM) and the episodic buffer or executive loop (EL). LTM is defined as "more permanent crystallized skills and knowledge" (Baddeley, 2012, p. 11), and is linked to the PL and EL; specifically, it is the storage from which the PL or EL retrieves earworms. The PL has two distinct components that can work both separately or together, named the inner ear and inner voice, by Smith, Wilson and Reisberg (1995). The inner voice is involved in subvocalisation for the rehearsal and refreshing of the PL, such as mouthing the digits for a phone number. Although termed a 'voice', it may not be limited to vocal and verbal rehearsal, but has been implicated in pitch and non-vocal timbres (Smith, Reisberg, & Wilson, 2014). The inner ear is "a short-lived store that represents material in a phonological form" (Smith, Wilson & Reisberg, 1995, p. 1434), used, for example, in recalling the sound of a bell chiming. An additional method of attentional refreshing has recently been suggested by Camos (2015) as an isolable EL process. This diverts attention to domain-general material, focusing on it rather than rehearsing it. Auditory material is stored in LTM, and can be refreshed using any or all the above three mechanisms. Interestingly, even Baddeley's most recent work does not view the PL as having an inner ear and inner voice refreshing mechanism, or consider attentional refreshing directly. Lastly, the CE distributes, allocates and balances attentional and cognitive resources between tasks (Hitch, 2005). The CE chooses which mechanism should refresh, and presumably also which should suppress, an earworm.

The process of getting an earworm can be delineated into the standard steps of encoding, storage and retrieval (Rutherford, 2005). I add two additional steps, namely the looping of the earworm, and then bringing this looping earworm to attention and awareness. Encoding of music is clearly the logical first step, but the way this occurs is not focused on here. Subsequently, music is stored in LTM, a prerequisite given that all earworms are, by definition, familiar. Next, the music is retrieved from LTM and brought into the PL or EL. Thereafter the music repeats involuntarily and is potentially sustained by the PL (inner ear and/or inner voice) and/or attentional refreshing in the EL. To be clear, retrieval is the process whereby auditory material is made available to the PL or EL, while looping is the rehearsal or refreshing process whereby it is maintained in the PL or EL. Finally, given that earworms are a conscious mental event, attention and awareness are required from the CE. Each step is now discussed in detail.

Consider, an advertising jingle, which gets encoded into LTM. Some trigger then allows for the retrieval of this jingle into the PL or EL, where a person hears the jingle 'in their head'. As the jingle gets stuck, three potential mechanisms may cause it to repeat: the inner ear, inner voice or attentional refreshing. Specifically, these mechanisms may vary based on attentional load, circumstances and desirability (i.e. when the person wants the earworm). The person may become aware of this stuck jingle, through the probing of CE. Equally, a person could attempt to supress an earworm through the above three potential mechanisms, which could cause ironic effects.

*Figure 1: WM and INMI Theoretical Framework*




### 1.2.1. Storage

A component of the definition not yet justified, is that the earworm music is always familiar to the individual, and is thus stored in LTM. Indeed, in the WM tradition, empirical research has demonstrated that there is a direct and bi-directional link between the PL and LTM (Baddeley, 2012). To demonstrate this connection in the case of earworms, I will discuss three areas of empirical data in relation to confusion and inconsistency in the literature.

Firstly, it appears that the length of earworms can be well over the storage capacity of the PL (they cannot be maintained by subvocal rehearsal), so LTM must be implicated for their storage (Beaman & Williams, 2010; Hyman et al., 2013). This is supported by the fact that while the looping fragments often consist of short phrases, most commonly choruses, they are reported to include the entire song up to 28% of the time (Beaman & Williams, 2010). To be clear, the length here refers to the actual section of music that forms the earworm rather than the duration of an earworm episode, since earworms may be persistent (e.g. Brown, 2006). Still, in the case where earworms contain only a short section, they seem to become encoded into LTM, and return later to become stuck again (Hyman et al., 2013).

There is also some confusion regarding what familiar music means, leading to inconsistent self-reported results. For *a priori* definitions, Bennet (2002) defines INMI as "previously heard" (p. 2), while Liikkanen (2008) contrasts this with "familiar or novel" (p. 408). Empirically, Liikkanen (2008) found 20% of earworms were retrospectively reported as "new" music, while Beaman and Williams (2010) found that 100% of earworms could be named. In the case of Liikkanen (2008), "new" could be conflated with either recent or novel earworms. If they are recently released songs, they could also be familiar, if they are novel (e.g. a melody the participant had constructed) they could easily be very familiar to that participant. In the case of Beaman and Williams (2010) and other studies, there is an implicit bias in asking participants to list the names of songs, resulting in participants not listing novel creations. In general, the discrepancy is because "unfamiliar" is conflated with unidentifiable or novel music, and "new" with recent or novel music. Consequently, INMI must be familiar, a construct that includes any recent, novel or unidentifiable music that has been heard or imagined by the participant before.

### 1.2.2. Retrieval

While music for INMI is clearly stored and, at some point, retrieved, and some empirical evidence has converged on what triggers this, the deeper question is to provide a theoretical account for the triggers. First, two possible theories are considered: priming and the Zeigarnik effect. Following this brief overview, several triggers will be discussed in relation to these theories: recency, repetition, memory association, previous imagery and incompletion – Williamson et al. (2011) have a similar typology of triggers based on a qualitative grounded theory approach.

#### *1.2.2.1. Zeigarnik Effect and Priming*

The Zeigarnik effect essentially proposes that incomplete tasks are more easily recalled than completed tasks (Zeigarnik, 1937). A wealth of evidence has been provided by Zeigarnik (1937) and others since for the increased recall of incomplete cognitive and manual tasks (e.g. puzzles, constructing clay figures). Essentially, if an earworm is, in some sense, incomplete it may trigger (and continue to re-trigger, and thereby sustain) the earworm because the person has a 'quasi-need' to complete the tune (Zeigarnik, 1937).

In terms of earworms and WM, an earworm may be incomplete in two ways. The song may be incomplete externally, in which case the song being heard is truncated. For example, radio stations sometimes truncate a song, stopping the music before the end of the track. Alternatively, the song may be incomplete internally, in which case the person does not imagine the entirety of the song. In the case of the latter, it does not seem important whether or not the person knows the entire song, but simply that they do not imagine the entirety of the song. For example, a person may imagine a chorus, which means that the song is internally incomplete, given that they have not imagined the entire song to the end. If the song is externally or internally incomplete, as in these two examples, the Zeigarnik effect suggests it is more prone to being recalled.

Alternatively, earworms may be primed to be recalled. In relation to involuntary semantic memories, Kvavilashvili and Anthony (2012) suggest long-term priming, whereby "stimuli (words, objects, places, music, etc.) encountered in everyday life subconsciously activate corresponding and related representations [which] may result in the conscious experiences of the mind-pop" (p. 1). Many things, including repetition and semantic similarities may prime an earworm or other involuntary memories (Kvavilashvili & Mandler, 2004).

#### *1.2.2.2. Triggers*

When earworms were induced experimentally, the last song listened to was the most likely to be retrieved, indicating a recency effect (Floridou et al., 2012; Liikkanen, 2009). Similarly, the retrieval of earworms is more frequent immediately after the song is heard, but then decreases over the short-term (McCullough, 2014) and longer-term in a diary study (Byron & Fowles, 2013). Retrospective surveys (e.g. Williamson & Jilka, 2014) and diary studies (Halpern & Bartlett, 2011) are also consistent with the finding that recent exposure can trigger earworms, including mood which is commonly considered in the literature, but not addressed here. Together, this suggests a waning of the priming effect over time.

To examine repeated exposure, Byron and Fowles (2013) randomly assigned participants to hearing previously unfamiliar songs either two or six times. Over the next 72 hours, participants in the higher exposure condition experienced twice as many earworms, suggesting that repeated exposure strongly influences availability. These findings are again consistent with retrospective reports that indicate an association between repeated exposure and INMI frequency (Bennet, 2002; Byron & Fowles, 2013; Williamson et al., 2011). Liikkanen (2012a) argues that the effect of recent and repeated exposure is best explained by spreading activation in LTM. Importantly, earworms can be successfully induced in an experiment by simple recent and/or repeated exposure, as shown by the multiple studies above. This may be best explained by priming, where repeated exposure to a song can prime its recall in memory.

Recency and repetition rely on actually hearing the song, but it may be possible that imagining the song is as effective at triggering a subsequent earworm. One way to induce imagery (and a subsequent earworm), is through asking participants to complete lyrics of a song. This procedure was employed by Liikkanen (2009), where participants were given four or five lines from songs and then asked to complete the lyrics. This successfully induced an earworm in in 67.1% and 49.6% of participants respectively, depending on the song genre. Floridou, Williamson and Müllensiefen (2012) used a similar procedure, but compared playing songs and completing lyrics within participants. In comparing the 20 participants who had lyrical induction first (17 had earworms induced) and the 20 who heard the songs first (13 had earworms induced), there were no significant differences.

Clearly lyrical completion is effective at inducing INMI, but it is possible (although unlikely) that completing lyrics uses semantic LTM without requiring a person to actually imagine the song. Several studies test the effect of imaging a song more directly. Hyman et al. (2013) found that individuals who reported imagining the song after it was heard were more likely to experience a subsequent earworm. Imaging the song increased its propensity to become an earworm whether the song was heard during a university class and returned over a few days, or was experimentally induced and returned within 24 hours (Hyman et al., 2013).

INMI has been reported to be triggered by memories (Byron & Fowles, 2013, Hemming, 2008, Hyman et al., 2013), similar phrases and emotional experiences (Hyman et al., 2013). Specifically, a qualitative grounded theory analysis usefully classified these memory triggers as associations to a person, situation, word or sound, recollection of an autobiographical moment related to music or anticipation of a forthcoming event (Williamson et al., 2011). These memory triggers may be a form of semantic priming, where an association relates to a song that becomes primed for retrieval as an earworm. Interestingly, Byron and Fowles (2013) found that autobiographical-association did not increase the frequency of INMI compared to semantic-association, which suggests that semantic and autobiographical primes may trigger INMI.

While priming has support for retrieval, it does not explain why earworms continue to repeat in memory, since repetition priming in imagery does not seem a sufficient explanation for their looping nature. The looping nature of INMI may be better explained by the Zeigarnik effect.

To provide evidence for the Zeigarnik effect, two studies used external incompletion, inducing an earworm by playing participants songs that were either complete or truncated, but there was no difference in INMI frequency (Hyman, et al., 2013; McCullough Campbell & Margulis, 2015). However, Hyman et al., (2013) realised that while the song could be truncated, participants could still complete it internally, preventing the Zeigarnik effect. Equally, an internal experience of an earworm would likely be internally incomplete, given their serial looping nature (e.g. participants imagined the chorus on repeat). Indeed, Hyman et al. (2013) found that participants who had an earworm following induction (i.e. likely internal incompletion, as they repeatedly imagined a fragment of the song) were more likely to experience an earworm subsequently.

While the Zeigarnik argument plausibly explains the way in which earworms consistently return and repeat, some might suggest that priming also explains this, as when they are repeated they are imagined, and this primes the individual to experience them again. Still the Zeigarnik effect also explains several other results. Given that the Zeigarnik effect essentially relies on the individual feeling that they have not completed the song to their own satisfaction (Zeigarnik, 1937), this may also explain the link between earworms and the need for cognitive closure (Kellaris, 2003), non-clinical obsessive compulsive traits (Müllensiefen, et al., 2014; Williamson & Müllensiefen, 2012) and neuroticism (Beaty, et al., 2013). Indeed, such traits show a propensity to be dissatisfied with a recollection, thus the quasi-need to complete the earworm (or recall it perfectly) remains.

#### 1.2.3. (Phonological) Loop

The involuntary, serial looping of an earworm is at the crux of the definition, but how and why this looping occurs remains to be explored (but see Margulis, 2013 for an interesting take on their repetitive nature). As argued, the length and nature of INMI implicates the use of LTM in the storage and retrieval of earworms, and thus in the looping of an earworm. The traditional view is that the inner ear and inner voice work by refreshing auditory material from LTM in the PL (Smith et al., 1995).

A great deal of auditory imagery research has shown how the inner ear and inner voice are isolable – they work both independently and together to rehearse auditory imagery (Smith et al., 2014). For example, an actress may largely employ subvocalisation to rehearse lines thereby using the inner voice, whereas a pianist may tap his fingers and hear the piece with his inner ear.

A review by Hubbard (2010) found mixed evidence for the use of the PL in sustaining MI, so for INMI, a subtype of MI, it is not certain whether the PL is employed. Still, early evidence suggests that the internal representation of earworms can be manipulated and changed, corroborating the use of the PL which manipulates auditory material (Brown, 2006; Williamson et al., 2014). As with many studies of the PL (e.g. Smith et al., 1995), the best way to test if the PL is being used is to suppress it, namely by suppressing the inner ear and inner voice (or equally by suppressing attention). Consequently, evidence for INMI is discussed in light of the inner voice and ear, expanding on Beaman et al.'s (2015) initial application.

#### *1.2.3.1. Inner Voice*

If the inner voice is used in sustaining earworms, suppressing it should substantially diminish earworms (Smith et al., 1995). Hence, the best evidence implicating the inner voice is a series of experiments by Beaman, Powell and Rapley (2015). Participants in one experiment were played a song to induce an earworm, and then assigned, in a random order, to articulatory suppression (chewing gum) or a control condition. The chewing gum condition specifically suppressed the inner voice by inhibiting the use of subvocalisation by stopping the muscles involved in subvocalising, a method similar to irrelevant speech (e.g. repeating "the"), but with less widespread use (Kozlov, Hughes, & Jones, 2012). Their results indicated that those in the articulatory suppression condition experienced significantly fewer induced earworms than those in the control condition.

The use of the inner voice is consistent with retrospective reports, which found that INMI rarely occurs while speaking (Bennet, 2002) or having a conversation (Liikkanen, 2011) where the inner voice is suppressed. Equally, social distractions (e.g. talking to someone) is reported as a preventative strategy (Kellaris, 2003). The use of subvocal rehearsal also speculatively explains why a person experiencing an earworm may sometimes realize (to their horror) they are singing the song aloud (Liikkanen, 2012c). When the earworm is looping, the person is subvocally and unconsciously singing along, and this subvocalisation slips into actual vocalization unintentionally. In fact, in some earlier works in German, voicing the *Ohrwurm* through humming, whistling or singing was an explicit component of the definition (Williams, 2015).

#### *1.2.3.2. Inner Ear*

Although there is not yet evidence as sound as the Beaman et al. (2015) study, there are indications that the inner ear is implicated in sustaining earworms. Suppressing the inner ear is simply done through using the outer ear – that is, by playing continuous music or sounds (Smith et al., 1995). Although this has not been investigated experimentally, individuals report the use of listening to music as a means of removing an earworm (e.g. Beaman & Williams, 2010; Williamson et al., 2014). Some studies have found that people report fewer earworms when engaged in tasks that employ the outer ear (and thus override the inner ear), such as watching television or listening to music (Floridou & Müllensiefen, 2015), but others do not (Liikkanen, 2011). One possibility is that talking or listening to a different song prevents an earworm, but when hearing a song, one can also 'sing along' in one's head to it, and thus experience INMI. Still, further research is required to determine whether directly suppressing the inner ear affects INMI.

#### 1.2.4. Executive Loop

Attentional load is often proposed as a key to understanding the occurrence of INMI, and, thus the executive loop (EL) is the WM component related to this. Specifically, it is hypothesised that mind-wandering mediates the link between attentional load and the executive loop (EL), which in turn refreshes INMI through a process of attentional refreshing. To simplify, where there is mind wandering there seems to be earworms. This theoretical model is considered first considering attentional refreshing, mind-wandering and attention-demanding activities, and then evidence is provided for this model.

##### *1.2.4.1. Theoretical Model*

In Baddeley's (2012) classic model of WM, the rehearsal of auditory imagery in the PL is the primary mechanism for maintaining auditory material in awareness and storing it in LTM. While there is strong evidence for this process to be split into the inner voice and ear, an independent, domain-general process of attentional refreshing has been proposed by Camos (Camos, 2015; Camos & Barrouillet, 2014). To fulfil this function, an executive loop (EL) is proposed, defined as a cognitive system that maintains domain-general (i.e. visuo-spatial, auditory and other) information (Camos & Barrouillet, 2014). Specifically, the EL is procedural in the same sense that the PL is, because it refreshes domain-general information, rather than providing a binding space or buffer for it, as in Baddeley's (2012) newly added episodic buffer. Still, these two are seen as highly related and form an integrated unit of domain-general processing, buffering and refreshing. However, unlike Camos' model, the CE is still seen as a separate system, which does not process or store, but rather allocates attentional resources and determines which refreshing process is most adaptive for a task. Specifically, attentional refreshing may be effective in some instances but requires high levels of attention, whereas rehearsal in the PL does not (Camos &

Barrouillet, 2014), but does require that the inner ear and voice are not suppressed (Smith et al., 1995).

In this theoretical model, the effect of attention-demanding activities on the EL, is mediated by mind wandering. Mind-wandering can be understood as “a shift of attention from a main task that the individual is engaged in toward internal information such as the processing of memories” (Floridou & Müllensiefen, 2015, p. 473). During low attentional load mind-wandering occurs due to boredom, but equally during high attentional load when the individuals’ mind is overwhelmed and they may lose focus and become distracted. However, in the ‘cognitive sweet spot’, the individual becomes fully engaged and does not experience mind-wandering. In other words, there is a quadrative, inverted-U effect of attentional load on INMI.

Although little mention is made of the cognitive mechanisms by which attention affects INMI, attentional refreshing is proposed here as the likeliest mechanism. Specifically, mind-wandering frees attentional resources for the attentional refreshing process, but also allows the mind to focus on internal events, such as earworms, rather than external, attention-demanding tasks.

##### *1.2.4.2. Evidence*

Preliminary evidence from self-report data suggests that INMI may be prone to occurring during low attentional load, such as travelling and physical activity (Hemming, 2008; Liikkanen, 2011), dreams and mind-wandering (Williamson, et al., 2011). It does not seem to occur during completing engaging mental activity but after taking a break from it (Bennet, 2002). Across these many reported activities, the common thread seems to be mind-wandering.

Furthermore, earworms reportedly disappear when there is a cognitive distraction, and this has even been used as a response strategy to remove an earworm, although the exact operationalisation of this strategy differs between studies. Kellaris (2003) found that participants reported using a broad distraction strategy 48.7% of the time, while Bennet (2002) found that concentrating on other tasks was mentioned 8% of the time as an effective strategy. Relatedly, a generalised displacement strategy (e.g. thinking of something else) was used 26% of the time, although this decreased to 12% when measured with diary entries (Beaman & Williams, 2010). However, earworms may also disappear on their own, which occurred in 22% of diary entries (Halpern & Bartlett, 2011). Theoretically, a wholly engaging task should prevent an earworm because it stops mind-wandering and shuts off the attention resources used by attentional refreshing for maintaining an earworm. However, ironic effects (as discussed later) can occur, because trying to block the distracting earworm may result in ironically increasingly one's thoughts about the very earworm one hopes to remove.

Three studies (Beaman, Powell & Rapley, 2015; Floridou, Williamson & Stewart, 2016; Hyman, et al., 2013) directly manipulated attentional load to measure its effect on INMI. Firstly, participants were played a variety of songs to induce an earworm and then they were randomly assigned to tasks of varying difficulties where INMI was measured. For Hyman et al.'s (2013) experiment, participants completed a Sudoku or an anagram task and were randomly assigned to either the easy or difficult condition. For both the anagram and Sudoku tasks, participants in the high attentional load condition experienced more earworms. In contrast, in Floridou, Williamson and Stewart's (2016) experiment, participants who closed their eyes (baseline) had more INMI occurrence, frequency and duration than those who did a dot task at varying levels of difficulty (the three levels of dot task difficulty were not significantly different). Beaman et al., (2015) compared participants tapping their fingers to a control, and found no significant difference.

While the results may initially seem conflicting, they become more aligned with consideration to mind-wandering. Specifically, they highlight the quadratic effect: mind-wandering would occur during easier tasks (tapping, closing eyes) and difficult tasks (difficult Sudoku and anagram puzzles) but not during completely engaging tasks (dot tasks, easy Sudoku and anagram puzzles). Indeed, this follows the pattern of increased INMI frequency, bolstering the positioning of mind-wandering as a mediator between attentional load and INMI. Moreover, in the Floridou et al. (2016) experiment consistent attention was required for the dot task which may have ensured that participants were in the 'cognitive sweet spot' of full immersion, whereas moving from one puzzle to the next in Hyman et al.'s (2013) experiment may have led to mind-wandering, especially during difficult puzzles.

Using data from an experience sampling study, Floridou and Müllensiefen (2015) employed Bayesian probability networks and considered the conditional probabilities of mind-wandering and INMI. They concluded that "the mind wandering experience plays a key role by affecting the initiation or not of the INMI experience". Specifically, if a participant experienced mind-wandering, the conditional probability of experiencing an earworm was 0.8, but only 0.44 when not mind-wandering (Floridou & Müllensiefen, 2015). This is not proof of mediation, but does support the model. Finally, Bailes (2015) suggests that the above link with mind-wandering may also explain the correlation between earworms and transliminality. Transliminality measures the degree to which thoughts pass between conscious and unconscious, and has been associated with INMI (Wammes & Barušs, 2009) and MI (Bailes, 2015).

#### 1.2.5. Interactions

To summarise, a person experiencing an earworm might be sustaining it in WM in three non-exclusive, potentially interactional ways: by subvocalizing, by internally perceiving it in their inner ear or by giving the song attention and refreshing it. Arguments have been made for the independent use of these three processes in refreshing INMI, but it is worth considering their interactions.

Currently, the literature has examined the interaction of the inner voice and attention on INMI. Beaman et al. (2015) found that participants had more INMI when chewing gum (suppressing the inner voice) than when tapping their fingers (a generalised cognitive distraction). However, as this was a direct comparison, there was no measurement of the interaction between attention and the inner voice. Hyman et al. (2013) compared a task that suppressed the inner voice (anagram, where participants might subvocalise) compared to a more generalised task (Sudoku), and a control in the former study. Both main effects and an interaction on INMI frequency was found, suggesting that attentional refreshing and the inner voice may be isolable processes. Similarly, in Floridou et al.'s experiment (2016), participants counting dots in the medium and difficult condition would likely have used subvocalisation to count, whereas in the easy condition they simply marked dots (which would presumably not require subvocalisation). However, there were no significant differences for INMI frequency between counting dots and marking dots. It is worth noting that Floridou et al. (2016) did not consider the possible interference of subvocalisation (and also did not design the experiment to assess an interaction between subvocalisation and task difficulty). Moreover, these experiments have not completely isolated the effect of attention and the inner voice on INMI, so further research is required (especially in relating the inner ear).

Using a complex span paradigm, Camos (2015) found that depending on the instructions and nature of the task, individuals might favour either attentional refreshing or articulatory rehearsal in maintaining verbal material in WM. Still, this experiment used verbal memory and voluntary recall, so it might not apply to MI, particularly INMI. At present, there has been no consideration of the interaction of all three refreshing mechanisms on INMI, although there is evidence for each individual. As these three mechanisms are closely linked, they need to be carefully isolated in order to separate out how each might affect INMI independently and interact with each other, to provide support for the theoretical model.

#### 1.2.6. Central Executive

In the WM model, attention is considered a limited resource which is allocated to cognitive tasks. Baddeley (2012) proposes the CE as the master controller, thereby performing three tasks: focusing attention, allocating attention and switching between tasks. In the context of an earworm (auditory information) being refreshed, the CE adaptively chooses the inner ear, inner voice or attentional refreshing as the mechanism for sustaining the earworm (Figure 1). In the proposed model, the EL (attentional refreshing) requires attentional resources, whereas the PL does not. Thus, when attention demanding activities are being undertaken, the CE chooses the least attention intensive process, which would be the PL, rather than attentional refreshing. Conversely, when the PL is supressed, the EL might be employed. Equally, the CE may choose to block the three refreshing processes to prevent an earworm when it becomes distracting (which can lead to ironic effects). Lastly, the CE is also the component which controls awareness of earworms. While the three mechanisms that the CE may use to sustain an earworm have been discussed, this section will focus on the role of the CE in the awareness and control of earworms.

#### *1.2.6.1. Awareness*

Since there is no external, objective measure of INMI, an individual must report experiencing INMI. This means that INMI is widely defined as a conscious experience (e.g. Liikkanen, 2012b); but given that INMI may occur during dreaming (e.g. Brown, 2006; Williamson, et al., 2011), altered consciousness may also allow for INMI – thus awareness, rather than waking consciousness, may be required. Still, people retrospectively report experiencing INMI (Liikkanen, 2011), so it may be that recall rather than current awareness is the minimal requirement. Moreover, earworms seem to move in and out of awareness (Hyman et al., 2013), so one might not be currently aware of an earworm, but aware when probed. Similarly, if not probed one might have no earworm experience or just no record of the experience.

Consequently, studying task-unrelated cognitions, such as INMI or relatedly mind-wandering, is also methodologically problematic because these thoughts are often not focused on, so people do not retrospectively recall instances of INMI or mind-wandering (Kvavilashvili & Mandler, 2004). To avoid this, experience sampling can be used, such as a study by Floridou and Müllensiefen (2015) where participants were sent text messages to notify them to immediately complete a questionnaire form. This technique allows the 'live capturing' of INMI as it occurs, by jolting participants into awareness of their current mental contents. On the other hand, it could be argued that some participants were not experiencing INMI prior to being asked, but when probed found that a song was stuck in their head simply because they were asked (so the probing ironically creates earworms). Still, by comparing retrospective and experience sampling studies, the problems inherent in each may be counteracted. However, in experimental studies retrospective reports may be inaccurate, but probing may interfere with the experiment, and any measurement may create hyper-sensitivity.

An alternative view of the above discussion might find fault with the way in which INMI is construed, and see this as emblematic of the broader problems of understanding consciousness. Some like Dennett (1991) would argue that there is no 'singular' version of conscious events that a homunculus sees in a Cartesian theatre, (i.e. observing whether INMI was present), but instead a continuous rewriting of consciousness in the form of multiple drafts. Therefore, probing as to the occurrence of INMI at different points is not only bound to affect the results, but also create contradictions depending on which draft is being ‘read’. In the case of earworms, the awareness of the CE is less of a conscious homunculus and more of a probe.

#### *1.2.6.2. Control*

In the WM model, the CE is generally assumed to be in a position of control allocating attentional resources to tasks, with the PL as slave. However, the PL can also act as master, controlling WM through subvocal self-instruction, especially useful when switching between tasks (Baddeley, 2012). However, when individuals find an earworm intrusive or annoying they may attempt to remove it by using mental control, often causing ironic effects. This seems to further implicate the use of the CE, as it can ironically sustain earworms. First, I will outline Wegner’s ironic process of mental control; second, I will apply it to INMI and finally I will provide evidence for this effect, and in doing so reconcile potentially conflicting results.

Three things require defining at the outset, as termed by Wegner (1994). First, the person has a desired state, which is a mental state that they consciously aim to achieve. Two processes are used: the operating process “searches for mental contents that will yield the desired state” (p. 35), while the monitoring process “searches for mental contents that signal the failure to achieve the desired state” (p. 35). The monitoring process is unconscious and autonomous, and activated by the intention to control (i.e., the CE); the operating process is effortful, and activated by the monitoring process. Together, these two attempt to achieve mental control, given limited cognitive resources. Normally both the operating and monitoring processes are used, but when there are cognitive demands, only the more efficient monitoring process is used. However, by enhancing sensitivity to unwanted thoughts, the monitoring process brings unwanted thoughts into awareness – this ironically creates the state opposite to what was desired. (Wenzlaff & Wegner, 2000).

This model was initially applied to earworms by Kellaris (2008), where under attentional load, the person would turn to the monitoring process to search for inconsistent mental states (i.e. search for the stuck earworm) and ironically bring the earworm into awareness.

Preliminary evidence for ironic control exists within the literature. Beaman and Williams (2013) measured individuals' scores on the White Bear Suppression Inventory (WBSI). The WBSI indicates a person's ability to dismiss intrusive thoughts; high WBSI scores indicate an inability to dismiss intrusive thoughts stemming from ironic control (Wegner & Zanakos, 1994). High WBSI scores were associated with longer INMI episode duration and greater earworm interference, demonstrating that attempting to suppress an earworm ironically makes it more intrusive (Beaman & Williams, 2013). In other words, those who lack the ability to control unwanted thoughts, try suppressing them more, but ironically fail and thus suffer the most from earworms. Ironic effects also inform the finding that those with greater non-clinical obsessive compulsive traits report being more prone to earworms (Williamson & Müllensiefen, 2012). Such individuals have a greater desire for mental control, and so eagerly suppress earworms, only to ironically reinforce them. Similarly, ironic control provides a perspective on why active attempts to suppress earworms are generally counterproductive (Beaman & Williams, 2010; Bennet, 2002).

Wegner's (1994) theory and the evidence underpinning the theory, demonstrate that the operating system suffers most under attentional load; so ironic effects (and thus earworms) are increased during cognitively demanding tasks. This seems to contradict the aforementioned findings that earworms are most prominent during mind-wandering (Floridou & Müllensiefen, 2015). However, the contradiction may be resolved as follows. It is necessary to differentiate between the desired state of concentration during attentional load, and the desired state of being earworm-free when attempting to suppress an earworm. When an individual is optimally engaged with a task, their awareness and attention are entirely devoted to the task; their desired state is one of concentration so their monitoring process keeps the individual focused on the task.

However, once their mind wanders away from the task, their awareness may be drawn to an earworm that they were previously unaware of. If the person were to then try to suppress the earworm, they would use the monitoring and operating process as above to suppress the earworm and attempt to create the desired earworm-free state. If they returned to their cognitive task whilst suppressing the earworm, they would have a much more difficult time, and experience greater ironic effects – as Wegner's theory predicts. However, the studies that associate INMI with mind-wandering, do not associate INMI with mind-wandering during suppression. As such, this model would hypothesize that the suppression of INMI would be most effective under low attentional load, when the operating process has greater cognitive resources.

Apart from a direct instruction to suppression (as in the WBSI), suppression may occur naturally in two ways. Firstly, if the person does not desire the mental state (e.g. the earworm is annoying) then they may attempt to supress it. Secondly, if a person is engaged in a cognitive task, they may attempt to remove distraction through suppression (e.g. trying to block the distracting earworm).

In the current application of ironic control, it is not yet clear as to what the nature of monitoring process is, in terms of WM terminology. The CE seems to determine whether the operating process (intentional control) or monitoring process (ironic control) searches for earworm-related content. The CE may be impinged upon by attentional load, and thereby switch-off the operating process and use the monitoring process. Potentially, the monitoring process may be domain-general, but it specifically uses minimal attentional resources, so is not an attention-intensive process like attentional refreshing. Alternatively, it may be an auditory-specific search, and thus use the PL. The inner ear might be given the instruction to 'listen' for the earworm tune, or the inner voice might be instructed to search for it by subvocalizing it and finding a match. Using either the inner ear or inner voice, the ironic effect is more direct, because as soon as searching begins it creates the earworm. The domain-general search may have the traditional ironic effect, because if the earworm tune is found, by notifying the mind of this, it brings it ironically into awareness. Potentially, the CE may adaptively select the best method for the monitoring process, as above, where it selects the best method for refreshing an earworm.

## 2. Research Questions

The overarching aim of the study would be to examine variation in the experience of induced INMI under different experimental conditions that manipulate components of the WM model (inner ear and inner voice of the PL, as well as attentional load). Specific research questions are:

1. How do individuals experience earworms and INMI?
    a. Is the IMIS a valid and reliable measure of earworms?
    b. What is the frequency and length of earworms?
    c. What is the subjective experience of earworms?
    d. How do these earworm properties relate to general musicality?
2. How do WM components affect the frequency of INMI?
    a. Does supressing the inner ear affect INMI frequency?
    b. Does supressing the inner voice affect INMI frequency?
    c. Does varying attentional load affect INMI frequency?
    d. Do the inner ear, inner voice and/or attentional load interact in their effects on INMI frequency?

# 3. Method

## 3.1. Sample

### 3.1.1. Collection Procedure

The sample was drawn from students of the University of the Witwatersrand, largely from the Psychology Department. Participants were recruited with an online announcement, emails and by word of mouth. The online announcement contained a link to an online survey (Appendix A) where participants were provided with information about the study and could give their email address(es) and available time slots. Following this the researcher contacted the respondents via email to arrange a lab session based on the time slots they chose.

The notice also included information about compensation, to encourage participation and compensate students for their time. Participants from the first year psychology class could earn a 1% course credit under the Student Research Participation Programme, and all participants could enter a raffle to win a set of headphones.

### 3.1.2. Exclusion

34 participants completed the experiment, but 5 participants' responses were excluded from the data analysis. One participant performed very poorly on all the attention tasks (they were an outlier and their error rate was far above 2 standard deviations from the mean). Three did not follow instructions correctly and did not open all the experiments, so there was extreme missing data. Apart from these exclusions, there were 5 missing values in total for INMI frequency for 4 participants due to a minor software error. The one participant with two missing values was excluded, but the other 3 were included in the analysis as each had only a single missing value out of 8 values (and the software error was fixed). Hearing difficulty, which was assessed via self-report, was also considered as a possibility for exclusion, but only minor difficulties were reported so no respondents were excluded on this basis.

### 3.1.3. Description

The final sample consisted of 29 participants who were students at the University of the Witwatersrand between ages 18-30, with a mean age of 22.14 (Figure 2). As frequently occurs in studies with psychology students, the sample's gender distribution was highly skewed, with just two males participating. Although 17 participants spoke English as their home language, there was a reasonable diversity in home language (Figure 3) as well as language proficiency (Figure 4), with all participants having reasonable English fluency.

***Figure 2: Sample age***

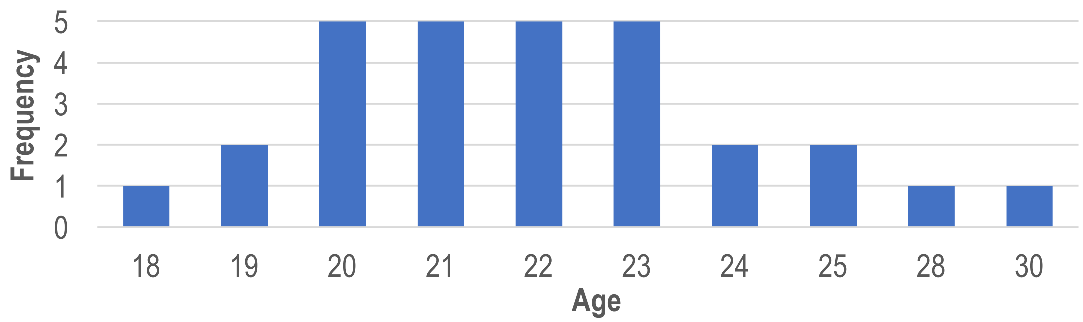



***Figure 3: Home language***

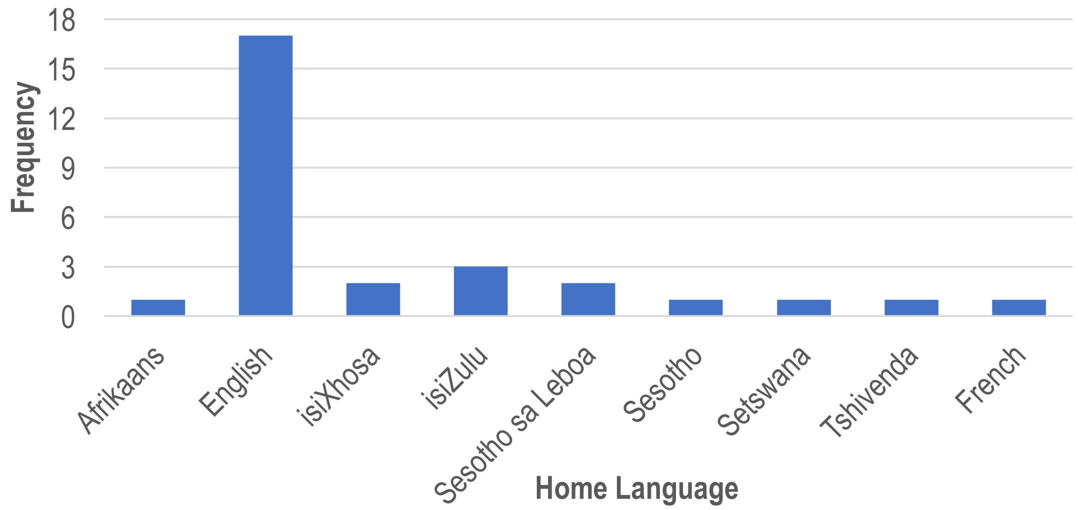
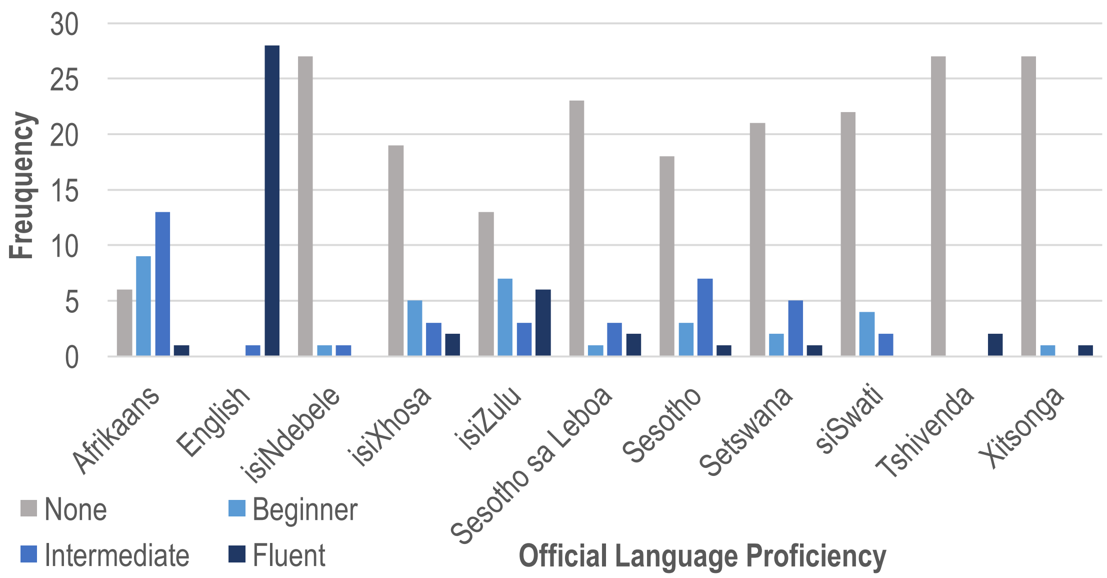



***Figure 4: Proficiency in official languages***



#### 3.1.4. Considerations

Given that the study uses a within-groups design, the small sample size allows for reasonable power and effect sizes (Charness, Geezy, & Kuhn, 2012); moreover, since not all 72 690 orders are possible given the quasi-randomisation of order (Table 3), a smaller sample still allows for a spread of potential orders (Vogt, Gardner, & Haeffele, 2012). A university student sample has several advantages in this context. The sample was easily accessible, and had easy access to the computer laboratories used at the University. Moreover, since the sample comprised university students, they were English literate (Figure 4) and test-wise. Most importantly, they appeared computer literate, and thus able to adequately participate in a computer-based study, thereby limiting bias inherent in a computer-based experiment (Tourangeau, Conrad, & Couper, 2013). There are no obvious disadvantages to such a sample. Although they may differ from the population in terms of income, age and education, it is not clear how such factors would systematically influence earworms.

Given ethical constraints, the sample is also a volunteer sample, so there is the definite possibility of self-selection bias, with participants that are interested in music and INMI, and possibly more prone to experiencing earworms volunteering to participate. However, this may be to the study's advantage, as participants who experience more INMI should be likelier to have INMI effectively induced experimentally. Indeed, all participants experienced INMI a minimum of once a month (Figure 7), and so did not need to be excluded on these grounds.

### 3.2. Instruments, Tasks and Materials

#### 3.2.1. Demographics and Musicality Form

All instruments, task and materials were created on two computer-based platforms, SurveyMonkey and Paradigm. The demographics and musicality SurveyMonkey form (Appendix D) included a basic questionnaire requesting the following information: age, gender, home language, proficiency in official South African languages and self-affixed cultural labels. Moreover, participants were asked to specify any hearing difficulties, a potential exclusionary criterion. Musicality was assessed by two questions on 4-point Likert-type scales, regarding frequency of listening to music and interest in music. This was partly for demographic information but also because many previous studies have linked measures of musicality to INMI (e.g. Beaman &

Williams, 2013). In addition, participants were asked to construct a unique identifying code to link their SurveyMonkey results to the Paradigm experiments (where the same code was requested) and potentially to future research.

#### 3.2.2. IMIS

The IMIS is an 18-item questionnaire developed by Floridou et al., (2015) with four subscales, and three independent items (these item numbers are given in brackets, as per Appendix E). The independent items are Earworm Frequency (11), earworm Section Length (13) and earworm Episode Length (14). The four subscales (12) use a Likert-type response format and were presented in a randomised order in the online questionnaire. They are divided into Negative Valence (a-g), Movement (h-j), Personal Reflections (k-m) and Help (n-q). The scoring of these subscales is the summation of the score for each item; inverse-scoring is used throughout, so low scores indicate a high level of the subscales (e.g. low Negative Valence means earworms are experienced as highly negative). The original study used an exploratory factor analysis to identify the subscales and independent items (Floridou, Williamson, Stewart & Müllensiefen, 2015). This structure was confirmed using a factor analysis on a similar sample of first year Psychology students from the University of the Witwatersrand (Geffen, 2015). Also, good to excellent reliability of the subscales was found in the original study using several indicators (Floridou et al., 2015), and two subsequent studies (Cotter et al., 2016; Geffen, 2015) as reported in Table 1. Moreover, there is adequate to strong test-retest reliability for each subscale (Floridou et al., 2015).

*Table 1: Cronbach's Alphas for the IMIS subscales from previous studies*

| | Negative valence | Movement | Personal reflections | Help |
|---|---|---|---|---|
| **Floridou et al., 2015** | 0.91 | 0.88 | 0.76 | 0.84 |
| **Geffen, 2015** | 0.934 | 0.858 | 0.861 | 0.886 |
| **Cotter et al., 2016** | 0.88 | 0.85 | 0.72 | 0.79 |

Correlations between the IMIS and other scales provide measures of convergent validity. The original IMIS study compared the scale to a range of other scales related to overall musicality, voluntary auditory imagery, and thinking style, particularly task-unrelated thoughts (Floridou et al., 2015). Furthermore, the IMIS was also recently linked to facets of personality by Cotter et al. (2016). These related the IMIS subscales and independent items to the HEXACO, the brief Wisconsin Schizotypy

Scales and openness to experience scale on the NEO-PI-3, finding a variety of expected and interesting correlations (Cotter et al., 2016). Moreover, Earworm Frequency and other IMIS subscales correlate with cortical thickness and grey matter volume in various brain areas, suggesting neurological differences based on INMI as measured by the IMIS (Farrugia, Jakubowski, Cusack, & Stewart, 2015).

#### 3.2.3. Earworm Induction

The researcher created the induction procedure using Paradigm (Bruno Mars experiment – Appendix F). The researcher added the music video, cut and added the song snippets, and coded and created the induction tasks. Furthermore, the researcher created the SurveyMonkey form, which, along with Paradigm, randomised the order of conditions as per Table 3. Participants watched the music video for the song *Just the Way You Are* by Bruno Mars, and heard several snippets of the song. This song was chosen because it was considered catchy, likeable and well-known.

Although previous induction paradigms have shown almost all pop songs have an equal propensity to induce an earworm (Floridou et al., 2012, Hyman et al., 2013. McCullough, 2014), others have argued otherwise. Familiarity has been shown to be important (Halpern & Bartlett, 2011; Hyman et al., 2012; Liikkanen 2008). Participants rated their familiarity with the song on a four-point Likert-type scale (never heard it, slightly familiar, moderately familiar or very familiar), and also became familiar with it during the induction. Furthermore, the literature suggests that the chorus is most likely to become stuck (Bailes, 2007; Beaman & Williams, 2010; Hyman et al, 2012; McCullough, 2014), so this was emphasised in the induction.

However, while catchiness is provided as a reason for getting an earworm (Byron & Fowles, 2013; Hemming, 2008), others have proposed that there might be some formula for catchy music (Cunningham, Downie & Bainbridge, 2005; Kellaris, 2001; Finkel & Müllensiefen, 2010; Jakubowski, Finkel, Stewart, & Müllensiefen, 2016; Williamson & Müllensiefen, 2012). Kellaris (2001) proposed repetition (similar to Margulis', 2013, theory), simplicity and incongruity as hypothetical features. *Just the Way You Are* can be said to be repetitive and have musical simplicity. More recently and following the present data collection Jakubowski, Finkel, Stewart & Müllensiefen (2016) published a complex empirical analysis by matching reported earworms songs to non-earworms songs. While the current song was not chosen in relation to these results they are discussed briefly and retrospectively. The song and especially the chorus might be described as having a melodic arch without many steep jumps or turns (consistent with earworm songs mentioned) but has a slower tempo (109 beats per minute) more consistent with non-earworm songs (Jakubowski et al., 2016).

Participants also completed several induction tasks aimed at increasing the propensity for experiencing a subsequent earworm (Appendix F). There were three pitch differentiation tasks, where participants were required to judge the relative pitches of words from chorus lines. There was also a line completion task, where participants had to type the two lines following an extract of the song that they heard. Lastly, a counting lines tasks, in which they heard a different chorus extract and were then asked to count how many lines were in this snippet.

Several reflections are required to explain the above process. Essentially it attempted to use all possible methods of earworm retrieval outlined earlier. A primary determinant of inducing INMI is repetition, so the song and especially the chorus were repeated several times. Recency is also key, so the song was played within 3 minutes of the first condition, leaving minimal space for decay or interference. Another theory discussed in the literature review is the Zeigarnik effect, where unfinished songs may remain in memory for longer, and hence arise as earworms. As such, in the last two snippets, (following which participants had to complete and count lines) the chorus was truncated, making it externally incomplete.

A final justification for the above procedure is the proposition that imagining the song predisposes it to becoming stuck. All three tasks required that the participants had to imagine the song in their mind. The pitch differentiation tasks required participants to produce the notes internally, something that has been used in previous studies to induce MI (Hubbard, 2010). Equally, counting and completing lines meant that they had to imagine the subsequent (and possibly even preceding) lyrics, a procedure known to induce earworms (Liikkanen, 2012a).

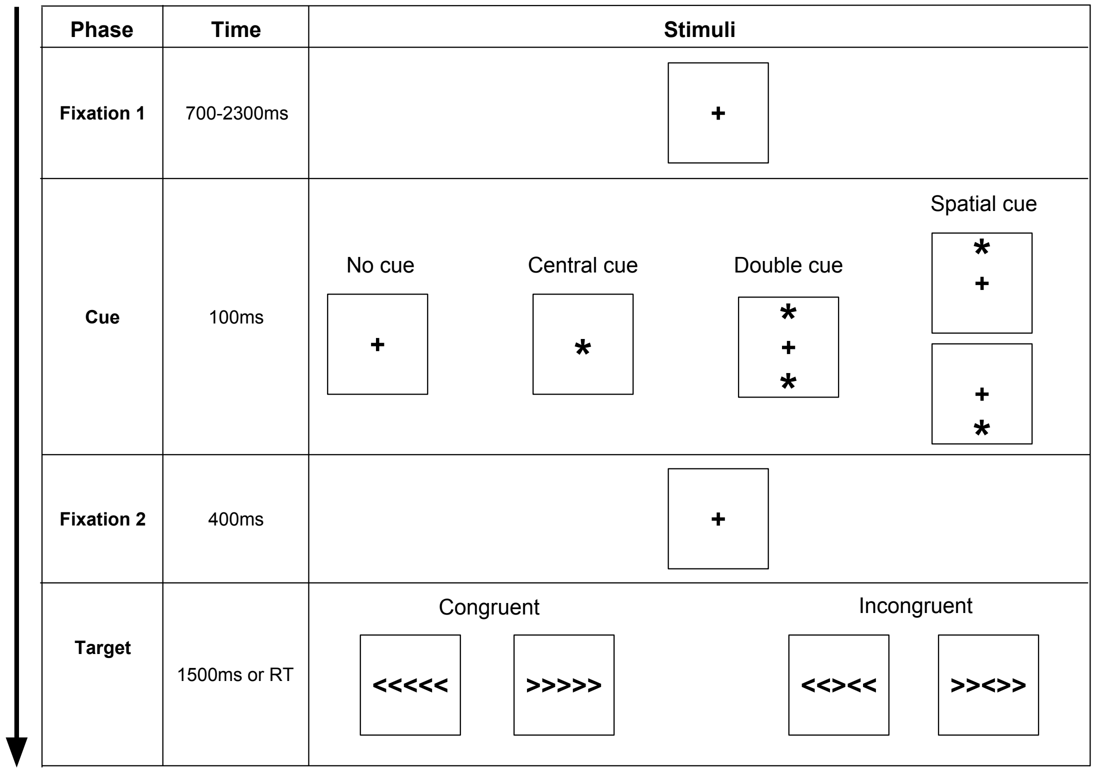
### 3.2.4. ANT

The Attention Network Test (ANT) is a task developed by Fan, McCandliss, Sommer, Raz and Posner (2002) that is designed to measure attention. The test is a computer-based reaction-time task, where participants must decide which direction a central arrow is pointing, by pressing the left or right arrow keys on the keyboard. The present study largely approximated a shortened version of the ANT (Weaver, Bédard, & McAuliffe, 2013), and the discussion largely describes the ANT as used in the present study, referencing the standard or shortened version where necessary.

#### *3.2.4.1. Process and Timing*

A single ANT trial (see Figure 5) proceeded as follows. First a fixation point (+) appeared on the screen. Then a cue (*) was shown, which could be spatial (above/below, always predicting the upcoming figure), central (superimposed on the fixation point), double (above and below) or absent, followed by just the fixation point (+). Next, respondents saw the target either above or below the fixation point (its location was predicted if there was a spatial cue). The target consisted of 5 arrows: a central arrow and flanking arrows which were either congruent (**>>>>>** or **<<<<<**) or incongruent (**<<><<** or **>><>>**). Respondents had to choose the direction of the central arrow by pressing the correct arrow on the keyboard.

*Figure 5: ANT timing and stimuli*




Regarding timing, there were some limitations imposed by the software used, so although it was close to the standard administration (Weaver et al., 2013), there were some minor differences in timing (Figure 5). Before each set, the fixation point was shown for 2000ms to allow participants to get ready to respond and move their fingers to the keyboard arrow keys. The fixation length was randomised to be 700, 900, 1100, 1300, 1500, 1700, 1900, 2100 or 2300ms. The cue (if present) was displayed for 100ms followed by the fixation again for 400ms. The target was displayed for a maximum of 1500ms or the participant's reaction time (RT). As such, each ANT trial took a maximum of 3500ms. Essentially this timing created a comparable experience to the standard ANT. Importantly, the randomness to the timing ensured that participants could not be certain when the next target would appear on the No Cue trials (Weaver et al., 2013).

#### *3.2.4.2. Measurements*

As is standard, both the accuracy and speed of response was recorded. The error rate (ER) quantifies accuracy by providing the percentage of incorrect trials (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The reaction time (RT) measures reaction speed in milliseconds and is averaged across correct trials to give the mean reaction time (MRT; Fan et al., 2002). Generally, these measures are not normally distributed, so they may undergo various transformations (e.g. logarithmic), and sometimes the median RT is used instead (Weaver et al., 2013).

#### *3.2.4.3. Type Manipulation*

Three standard subscales exist for this task, based on the above variations in the cue and flankers: orienting, alerting and executive attention (see Figure 5 and Table 2). Alerting compares when the participant is not alerted (no cue) to when they are alerted but not oriented (double cue). Orienting compares when the participant is aware of the position of the forthcoming target (spatial cue) to when they are not (central cue). Executive attention compares whether the respondent must inhibit their response (incongruent flankers) or not (congruent flankers).

Measures for these three subscales are calculated by subtracting both the MRTs and ERs for each comparison above. Reliability and independence of these subscales has been demonstrated for the standard ANT (MacLeod, et al., 2010) and the shorter version (Weaver et al., 2013). However, the present study used the variations in the ANT (based on these subscales) to manipulate attentional load. Depending on whether a participant is alerted and oriented and whether the flankers are congruent or not, there is a range of possible ANT trial types based on these combinations (Table 2). However, the ANT is clearly easiest when the respondent is oriented and/or alerted and/or the flanker arrows are congruent.

Difficult and easy trails can be differentiated in this way and were used to manipulate attention. The Easy version contained only those trials where at least two of the three poles were easy (green cells in Table 2), while the Difficult version contained trials where at least two of the three poles were difficult (red cells in Table 2). While this change and reduction in trial types per set might affect the reliability of the ANT, performance on the ANT subscales is not of concern, it is simply a proxy for manipulating attentional load. Moreover, when the Easy and Difficult ANT sets are combined, they essentially form a standard ANT, with no changes except for the order of trial types. Specifically, each Difficult and Easy ANT set had 24 trials each.

*Table 2: Possible ANT types based on alerting, orientating and cue combinations*

| | | Flankers | |
|---|---|---|---|
| | | **Congruent** | **Incongruent** |
| **Cue** | **No cue** (not alerted) | Difficult | Difficult |
| | **Central** (alerted) | Easy | Difficult |
| | **Double** (alerted, not oriented) | Easy | Difficult |
| | **Spatial** (alerted and oriented) | Easy | Easy |

Based on this differentiation, the researcher radically changed a basic version of the ANT on Paradigm to create an Easy and Difficult version each with 24 trials. Each set was altered to ensure the correct presentation and somewhat randomised timing (Figure 5). Within this single Paradigm experiment, the order of the Easy and Difficult ANT sets was counterbalanced, and followed by reported INMI frequency (Appendix G). Four versions of the Paradigm experiment with the Easy and Difficult ANT sets were created by adding to the given conditions the Leco track in the background of the experiment and the reminder that participants would hear this, and the reminder to be chewing or not chewing gum. Finally, a separate practice version of the ANT (Experiment P), with feedback, but not separated Easy and Difficult sets was created.

#### 3.2.5. Leco and Gum

During the ANT sets, participants heard foreign speech and/or chewed gum. The foreign speech, aiming to suppress the inner ear, was a recording of a male speaking Leco (downloaded from http://files.globalrecordings.net/audio/language/mp3/sample-12825.mp3), a language spoken in Bolivia. This language was chosen because of its obscurity. It is currently only known to be spoken by 20 elderly people (Moore, 2007), and while previously thought to be extinct, it was recently reinvestigated (van de Kerke, 2000). Most importantly, it is a language isolate, meaning that it has no demonstrated common predecessor or genealogical relationship with another language (Moore, 2007; van de Kerke, 2000). As such, there was an absolute guarantee that no participant would be vaguely familiar with the language, ensuring that it should not engage semantic memory but simply supress the inner ear. Similar arguments have also informed the use of foreign speech (shown to have a stable suppressive effect over time) in similar experimental paradigms (Hellbrück, Kuwano, & Namba, 1996). Chewing gum was used to supress the inner voice, as it has known efficacy (Beaman et al., 2015; Kozlov et al., 2012), and participants could choose from a range of gum flavours provided.

### 3.2.6. Self-Reported INMI

The primary dependent measurement was self-reported INMI as experienced under each of the trail conditions (see Appendix G). Participants reported "the degree to which [they] experienced a song in their head" on a four-point Likert-type scale, with the following points: not at all, somewhat, most of the time, all the time. This single item rating scale was integrated into the ANT task on Paradigm, and was reported following each of the 8 ANT sets.

Two induction studies which contained tasks of varying attentional load, used similar measures, where participants reported the percentage of time that they experienced INMI during the task (Floridou, et al., 2016; Hyman, et al., 2013). Other studies used a dichotomous yes or no response to having an earworm (Liikkanen, 2012a; McCullough Campbell & Margulis, 2015), which was not sufficient for a repeated-measures ANOVA design. A more detailed measure, which ensured the data was at least interval, was Beaman et al.'s (2015) where participants pressed a key on the keyboard whenever they experienced INMI. While this may seem to more closely approximate an accurate frequency measure, it does not deal with the complexities of INMI as it makes a continuous experience discrete. For example, someone might press a key every time they hear the chorus, but if this chorus loops, the discrete key press does not indicate that there was a continuous earworm. Moreover, given the nature of the ANT task, it was not practical for participants to complete the task and report each earworm instance, and constant monitoring of INMI (as opposed to retrospective reporting) could also distract from the task and therefore prevent it manipulating attention.

As INMI is a first-person phenomenological experience, it requires a self-report measurement. Given the repeated-measures design, INMI needed to be measured 8 times (once for each condition). This in turn implied that the self-report scale would need to be brief and straightforward, so that the experiment would not become tedious. For example, hiding this item in a longer questionnaire (Floridou et al., 2016) repeated 8 times would make the experiment impossibly long and tedious. Equally, it was not possible to hide the purpose of the experiment, given the repeated measures. The possibility that participants, knowing the upcoming question on INMI frequency, would be primed to experience INMI was considered. If this was the case, the priming should occur equally across all conditions, irrespective of order. Still, this once-off measurement at the end would be less likely to heighten self-consciousness of INMI and reactivity effects, as with a continuous measurement throughout each condition (e.g. pressing a keyboard key). Moreover, the nature of the ANT was such that it seemed to occupy participants' focus, and participants probably thought their accuracy was the primary dependent variable, not INMI. There were also software limitations, which meant adhering to a basic rating scale was most practical and feasible.

### 3.3. Procedure

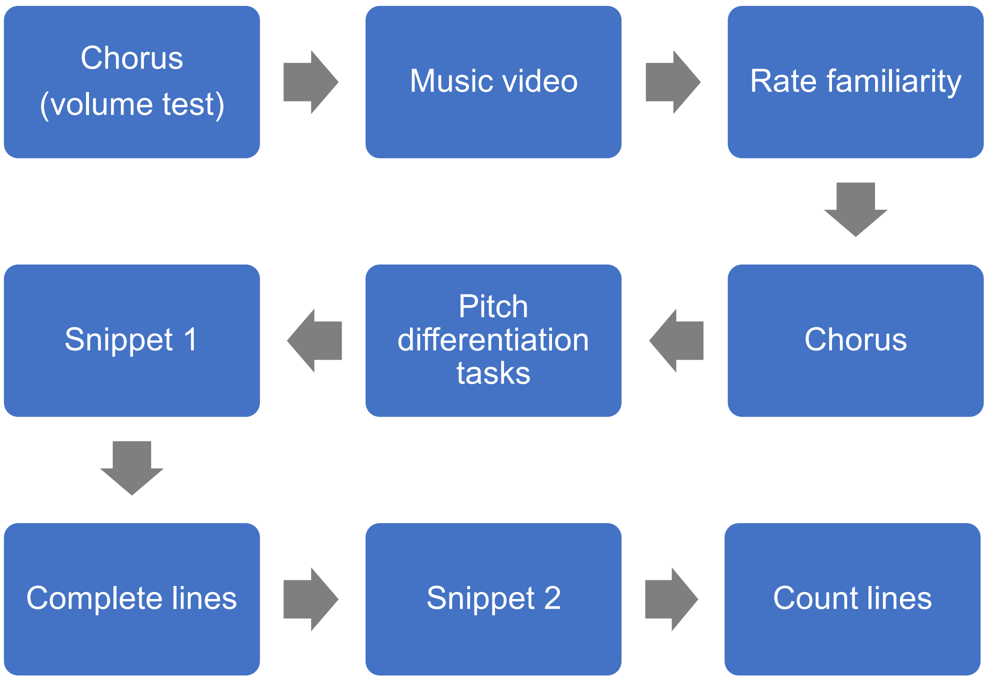
The research was in the form of an experiment set in a computer laboratory. Participants used a dual-monitor computer with a set of over-ear headphones. On the left-hand screen was a SurveyMonkey form where participants answered a range of questions and followed instructions to open experiments on the right-hand screen. On the right-hand screen participants opened and completed these experiments, which ran using Paradigm software. Together, the two screens formed an integrated unit. The experiment consisted of two primary phases: the first was descriptive and second was experimental, segmented into earworm induction and ANT trials. The experiment concluded with a follow-up section.

Prior to commencing, participants were briefly told what the experiment consisted of, and the researcher ensured this information was comprehended and that participants felt free to clarify instructions. The logistics of the dual-monitor set-up was explained and the instruction to chew any flavour of gum, and later stop chewing gum were emphasised. Additionally, a brief explanation of the ANT task was given and then participants were asked to put on their headphones and begin on the left screen.

In the first phase, participants signed informed consent (Appendix C) and completed the demographics and musicality form on the left-hand screen (Appendix D). These included age, gender, home language, language proficiency, and cultural background, and questions around music interest and hearing difficulties. Lastly, they completed the IMIS (Appendix E; Floridou et al., 2015).

The first stage of the experimental phase involved an earworm induction procedure where participants opened the "Bruno Mars" experiment on the right-hand screen. They first entered their unique identifying code to link their results. Then the earworm induction began (Figure 6), where participants listened to the song, watched the music video and completed three tasks, as described earlier. Firstly, participants heard the chorus of the song (*Just the Way You Are)*, which formed a volume test that allowed them to adjust the volume to a comfortable level using keyboard buttons. Secondly, participants watched the music video for the song and then rated their familiarity with the song. Then, participants heard the chorus again. Following this were the three pitch differentiation tasks, completing the lines and counting the lines (Appendix F).

***Figure 6: Flow chart of induction procedure***




Following the induction procedure, participants completed a practice ANT set (each set had 24 trials). Participants opened "Experiment P" on the right screen, and read instructions for the ANT. Feedback was given for each ANT trial in the practice set, so that participants gained familiarity and minimal proficiency. For each correct trial "Well Done" appeared on the screen in green, and for each incorrect trial "Try Again" appeared in red. In the rare case where participants did not follow instructions correctly and were making a consistent error (e.g. using the mouse, not the keyboard arrows), the researcher re-explained the instructions to ensure the participant achieved proficiency. Participants then returned to the left-hand screen and were told that they would complete several ANT sets without feedback and would have to rate how frequently they experienced an earworm or song 'in their head' during the set. 8 ANT sets were completed in a quasi-randomised order as per Table 3.

The instructions prior to each ANT set consisted of the following elements. Participants were either requested to chew gum (GS, GL) or there was no instruction (CS, CL). Then, they were requested to open Experiment, CS, CL, GS, or GL randomised as per Table 3. At the beginning of each experiment it was reiterated that they should be chewing gum (GS, GL) or should not be chewing gum (CS, CL). Furthermore, they were told that they should be hearing Leco (CL, GL), or there was no information about this (CS, GS). For each of the four experiments they were exposed to one Easy and one Difficult ANT set in randomised order. Following each set, they reported their INMI frequency during the set (Appendix G). After the four sets while chewing gum (GS, GL), they were asked how distracting it was to chew gum, and at the end of all eight sets, they were asked how distracting hearing Leco was (Appendix G). Then, they were asked if they would like to participate in future research and lastly, for personal details (in a separate linked survey – Appendix I) for compensation purposes.

*Table 3: All 8 conditions showing randomised order*

| **Inner voice suppression** | Control (C) | | | | Gum (G) | | | |
|---|---|---|---|---|---|---|---|---|
| **Inner ear suppression** | Silence (S) | | Leco (L) | | Silence (S) | | Leco (L) | |
| **ANT Difficulty** | Easy(1) | Hard(2) | Easy(1) | Hard(2) | Easy(1) | Hard(2) | Easy(1) | Hard(2) |
| **Code** | CS1 | CS2 | CL1 | CL2 | GS1 | GS2 | GL1 | GL2 |

The manipulation labels are given in brackets and condition codes in the last row. The double-headed arrows represent the order randomisation between conditions. In total, there are 128 potential orders.

The experiment was designed in this quasi-randomised fashion for important logistical reasons. To minimise participants constantly starting and stopping chewing gum (up to 4 times), participants either chewed gum in the first half or the second half (in randomised order). Similarly, within each half, they heard Leco in the first or second and third or fourth quarter in a random order. Again, within each quarter, the difficulty of the ANT was in a random order. While this does not allow for all possible orders, it presents a significant number of possibilities (summarised in Table 3). Given the complexity of the randomisation, the research randomised the Gum and Leco conditions using SurveyMonkey, while the Paradigm experiments randomised the order of attentional load.

Still, it is important to highlight the need for counter-balancing and the practice set. Learning effects have been found with executive attention, where reaction time increased when practice participants received more incongruent flankers (Ishigami & Klein, 2010). Furthermore, fatigue occurs across ANT sets for executive attention (Holtzer, Shuman, Mahoney, Lipton, & Verghese, 2011), meaning that attention may waver, making individuals more susceptible to mind-wandering and experiencing earworms. Finally, in earworm induction paradigms, there is some decay and recency effects (Floridou et al., 2016), meaning there might be a decrease in frequency over time irrespective of condition.

### 3.4. Research Design

Several research designs are employed in the research, but the overall method is quantitative, interpreting statistical analyses to answer the research questions. The first stage of the experiment is purely descriptive and non-experimental. There was no manipulation, only the measurement of a range of reported information regarding the participants' demographics, musicality and earworms experiences. These measurements are cross-sectional, rather than compared over time.

The second phase of the research is a repeated-measures factorial experimental design. The design is factorial given that there are multiple independent variables each having two levels: inner ear suppression, inner voice suppression and attentional load (Table 3). The suppression of the inner ear and inner voice were manipulated and compared with a control condition. The attention task did not have a control condition, but instead had two contrast conditions: Easy and Difficult. As such, this experiment may be classified as a combination of pre-experimental and true experimental within-subjects design elements.

Furthermore, the factorial design is a within-groups comparison; each participant was assigned to all 8 conditions, and then compared to themselves under each different condition (Huck, 2012). The order of these conditions was quasi-randomised, since it is random, but with only some possible order combinations (Table 3). There is a single dependent variable, INMI frequency measured on a Likert-type scale. Although this technically forms an ordinal scale, the data was considered as interval given that there is no non-parametric alternative to a three-way repeated measures ANOVA – the consequences of this violation are addressed alongside the analysis. Although there were multiple measurements of the dependent variable across time for different participants, these measurements were in a randomised order with the purpose of counterbalancing condition order – there were no strictly longitudinal comparisons. As such, the design is not longitudinal (which would measure the impact over time), but should be considered cross-sectional (Babbie, 2010).

Informal piloting of this procedure occurred during the development, which allowed the prevention of certain problems. Firstly, it became clear that the instructions on the left SurveyMonkey screen to start and stopping chewing gum were being missed. So, in addition to emphasising these, instructions were added on the right Paradigm screen as to whether participants should be chewing gum or not. Similarly, they were told whether they should be hearing the Leco voice or not. Secondly, participants in the pilot initially struggled to understand the ANT task and verbally confirmed that they understood the written instructions, so verbal instructions were also provided prior to the experiment. Apart from these major changes, a few minor changes were created to ensure that the experiment was more user-friendly.

## 3.5. Data Analysis

### 3.5.1. Cleaning

The data was generated from two distinct sources: SurveyMonkey and Paradigm. The Paradigm data was outputted in the form of a single Excel spreadsheet for each participant for each experiment (i.e. 6 spreadsheets per participant). The relevant Paradigm data was collated for all participants into a single spreadsheet, and some of this data required calculation using Excel. The data was then cleaned and participants' results excluded as detailed above. Several variables were also constructed in the collated spreadsheet, collapsing across conditions given the research design. Post-hoc bins/categories were created to classify the degree of accuracy in counting lines (Figure 14), and the responses to the lines were categorised based on the researcher's judgement, which fell into three categories (Figure 13).

It was also necessary to match these Paradigm results to those from SurveyMonkey, which directly generated an SPSS file. Although there were occasional minor inconsistencies in participants' reconstructions of their identifying codes, each participant's results could be clearly matched. Given that SurveyMonkey is an online platform, occasional breaks in internet connectivity meant that the page had to be refreshed which appeared as a new survey entry. In these cases, the data was collated into a single entry for each participant and it was ensured that no duplicates occurred. The end result was matched data with no duplicates.

#### 3.5.2. Reliability and Validity

At the outset, the validity of the IMIS was considered using a confirmatory factor analysis for the four IMIS factors. Following this, the internal consistency was checked for each factor using Cronbach's alpha, and ascertained the changes to Cronbach's alpha if factor items were to be removed.

#### 3.5.3. Descriptive Statistics

Descriptive statistics (frequencies and central tendencies – Table 6) are subsequently provided for the IMIS and musicality questions from the non-experimental phase. Spearman's rho correlations are also provided (Table 7), but merely for exploratory purposes, not further analysis. Importantly, descriptive statistics were also calculated for INMI frequency per condition and are given (frequencies – Figure 17, means – Table 11).

#### 3.5.4. Manipulation Checks

For the experimental phase, certain checks are performed secondary to answering the research questions. Firstly, it is necessary to confirm that the performance on the Easy ANT sets was better (i.e. lower scores) than on the Difficult sets, and whether this difference was consistent across the Leco and Gum conditions. A repeated-measures ANOVA compared the MRTs in each condition (Table 8), and relevant post-hoc paired-sample *t*-tests compared specific cells. Moreover, the degree to which chewing gum and hearing Leco (Figure 16) were reported as distracting also informs whether they used attentional resources (rather than purely affecting the PL), and they were also compared directly with a paired-sample *t*-test.

#### 3.5.5. ANOVA

The primary analysis that addresses the second research question is the 2 x 2 x 2 repeated measures ANOVA. The second-order interaction, the first-order interactions and the main effects, as well as any relevant post-hoc tests, were analysed. Given that this is a factorial design with three categorical independent variables, one dependent variable that is treated as interval, and each participant experienced all conditions, a repeated measures ANOVA is a viable analysis (Field, 2009). Performing a repeated measures ANOVA requires that several assumptions need to be tested and met: random sampling, subjects are independent of each other, at least interval dependent variables and categorical independent variables, multivariate normality, homogeneity of covariance matrices, no multicollinearity and linear relationships between the dependent variables (Field, 2009; Huck, 2012).

### 3.6. Ethical Considerations

Internal ethical clearance for the study was granted from the University of the Witwatersrand (Appendix B). Informed consent is crucial in any research (Vogt et al., 2012), and this was requested at the beginning of the experiment (Appendix C). All participants provided informed consent and could thus continue the experiment. An explicitly separate survey (Appendix I) recorded the students' email and student number to provide compensation (course credit and entry into a raffle for Philips SHP2000 headphones). This ensured that participation was entirely voluntary – participants could still receive compensation without participating in the experiment. Therefore, they were not coerced into participation with compensation. Furthermore, anonymity was guaranteed as the identifying information was captured in a separate survey so it could not be linked to any of their answers (as was explicitly stated). In addition, students were required to construct a unique identifying code based on their surname and student number to link their answers from the separate parts of the experiment on each screen, and to future studies they might participate in. They were clearly informed that while this uniquely identifies them, it is not possible to *trace* their identity from this (Appendix D).

The research will be published online via the University, and may also be published in journal articles or presented at conferences. Participants were informed of this, and provided with platforms to receive feedback in a summarised form that reports on grouped, not individual, results. The data is stored electronically on a password secured database and password secured computers, and will be deleted after a maximum of 6 years.

# 4. Results

## 4.1. Reliability and Validity

A confirmatory factor analysis was conducted on the four IMIS factors using varimax rotation (Table 4). The data was factorisable per Bartlett's test of sphericity ($\chi^2_{105} = 340.017$, $p < 0.001$) and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (KMO = 0.562). A four-factor structure was confirmed given that it explained 77.97% of the variance and only four components had Eigenvalues greater than 1 (Kaiser's criterion).

*Table 4: IMIS confirmatory factor analysis*

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| I try hard to get rid of my earworms | **.455** | .368 | .056 | **-.648** |
| It worries me when I have an earworm stuck in my head | **.548** | -.081 | .356 | -.058 |
| I find my earworms irritating | **.789** | .086 | .136 | -.310 |
| My earworms agitate me | **.870** | .006 | -.056 | .052 |
| The experience of my earworms is unpleasant | **.894** | .040 | .011 | .059 |
| I wish I could stop my earworms | **.834** | .209 | -.086 | -.333 |
| When I get an earworm I try to block it | **.428** | .047 | **.457** | -.311 |
| The rhythms of my earworms match my movements | .068 | **.927** | .117 | -.176 |
| The way I move is in sync with my earworms | -.004 | **.915** | .100 | -.021 |
| When I get an earworm I move to the beat of the imagined music | .115 | **.905** | .207 | .066 |
| My earworms result from unresolved matters | .082 | .087 | **.779** | .229 |
| Personal issues trigger my earworms | -.127 | .264 | **.889** | .106 |
| The content of my earworms mirrors my state of worry or concern | .101 | .130 | **.892** | .057 |
| I find my earworms help me focus on the task that I'm doing | -.063 | .011 | .284 | **.888** |
| Earworms help me when I'm trying to get things done | -.079 | .006 | .069 | **.962** |

The Movement, Personal Reflection and Help items loaded positively on the expected factor, with no cross-loadings. Moreover, using Cronbach's Alpha the internal consistency for each factor was excellent (Table 5). For the Movement and Personal Reflection factors, removing any items would not significantly increase the internal reliability, suggesting that all items are necessary. All items except the first one loaded correctly on the Negative Valence factor (Table 4). The first item loaded positively on the expected Negative Valence factor but also loaded negatively on the Help factor (something that is not too surprising given that attempting to remove earworms might correlate with earworms being unhelpful). The last Negative Valence factor also loaded on the Personal Reflection subscale, understandably, given that a person blocking an earworm might do because it relates to an unpleasant personal issue.

*Table 5: Cronbach Alpha internal reliability for four IMIS factors*

| Negative Valence | Movement | Personal Reflection | Help |
|---|---|---|---|
| 0.87 | 0.93 | 0.88 | 0.94 |

Nevertheless, both items included as per the original for two reasons. Firstly, the internal reliability of the Negative Valence factor is still excellent, and removing the either item (or indeed any item) would not significantly increase the Cronbach Alpha value. Secondly, the present sample is very small for a valid factor analysis, and three other studies with larger samples have verified this scale (Cotter et al., 2016; Floridou et al., 2015; Geffen, 2015 – Table 1).

### 4.2. Descriptive Statistics

#### *4.2.1.1. IMIS and Musicality*

*Table 6: IMIS central tendency measures*

| | *M* | Median | Mode | Range |
|---|---|---|---|---|
| **Music interest** | | Very much | Very much | |
| **Music listening** | | 2-3 hours a day | > 3 hours a day | |
| **Earworm Frequency** | | Several times a week | | |
| **Section length** | | 10-30 seconds | 5-10 seconds | |
| **Episode length** | | 10-30 minutes | < 10 minutes | |
| **Negative valence (35)** | 26 | 25 | 25 | 14-35 |
| **Movement (15)** | 8.17 | 8 | 6 | 3-15 |
| **Personal reflections (15)** | 11.34 | 11 | 15 | 3-15 |
| **Help (10)** | 7.59 | 8 | 8 | 3-10 |

The highest possible scores for the IMIS subscales are given in brackets, with low scores indicating high levels of the scale (i.e. inverse scoring).

On average, participants experienced earworms several times a week (Figure 7), lasting between 10 and 30 minutes (Figure 9), with a section of music 10-30 seconds long (Figure 8). In general, this appeared to be a moderately positive experience but not very helpful. Participants sometimes moved in response to their earworms but mostly did not feel they were related to personal reflections.

*Figure 7: Average earworm frequency*

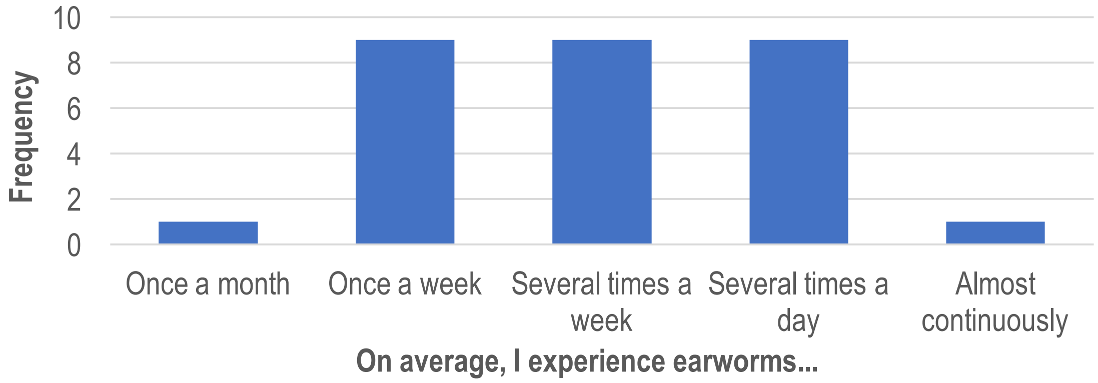



*Figure 8: Earworm section length*

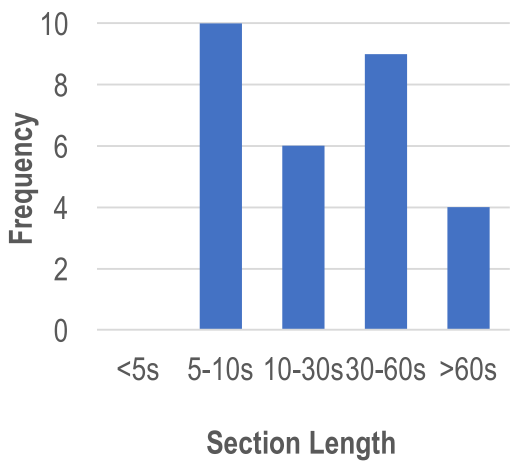
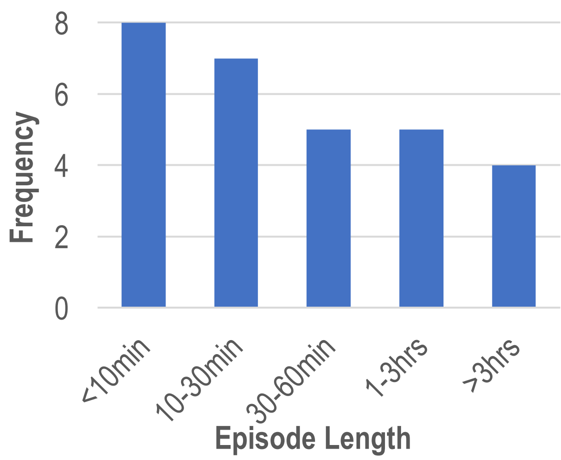



*Figure 9: Earworm episode length*




Most participants listened to music regularly (Figure 10) and were very interested in music (Figure 11). This musical predilection is expected (and welcomed) in a sample volunteering for a music-related experiment. These two musicality measures also correlated with several IMIS components (Table 7). Specifically, Music Listening was positively correlated with Music Interest, Earworm Frequency and negatively correlated with the Movement, Personal Reflection and Help IMIS subscales.

*Figure 10: Music Listening Frequency*

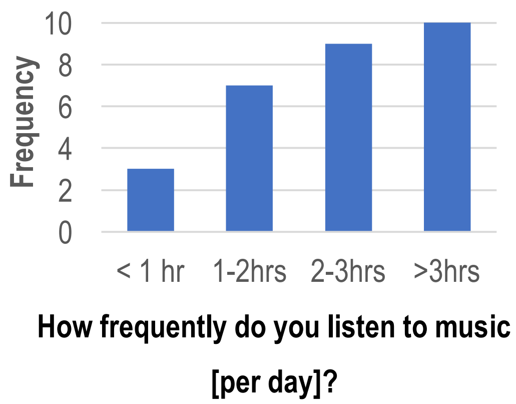



*Figure 11: Music interest frequency*

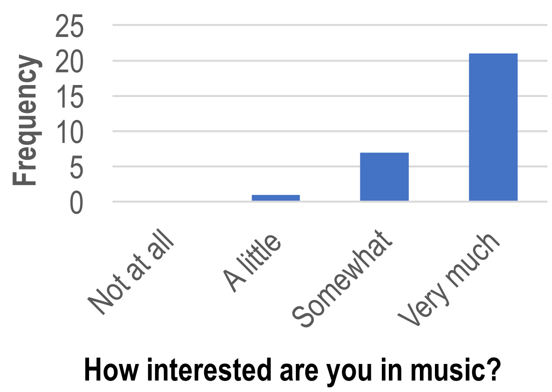


*Table 7: Spearman's rho correlations of IMIS and musicality*

| | Music Listening Frequency | Music Interest | Earworm Frequency | Section Length | Episode Length | Negative Valence | Movement | Personal Reflection |
|---|---|---|---|---|---|---|---|---|
| **Music interest** | ***0.530*** | | | | | | | |
| **Earworm frequency** | **0.427** | **0.380** | | | | | | |
| **Section Length** | -0.015 | 0.106 | 0.259 | | | | | |
| **Episode Length** | 0.151 | 0.161 | 0.213 | 0.065 | | | | |
| **Negative Valence** | 0.011 | -0.023 | 0.178 | -0.051 | -0.154 | | | |
| **Movement** | ***-0.512*** | -0.300 | -0.207 | -0.029 | ***-0.502*** | 0.316 | | |
| **Personal Reflection** | **-0.459** | **-0.368** | -0.037 | 0.013 | -0.185 | 0.119 | 0.312 | |
| **Help** | -0.351 | -0.270 | -0.144 | 0.068 | 0.048 | -0.358 | -0.054 | 0.139 |

Significant correlations are shown in **bold** for $p < 0.05$ and ***bold italics*** for $p < 0.001$

### 4.2.2. Induction

*Figure 12: Familiarity with song*

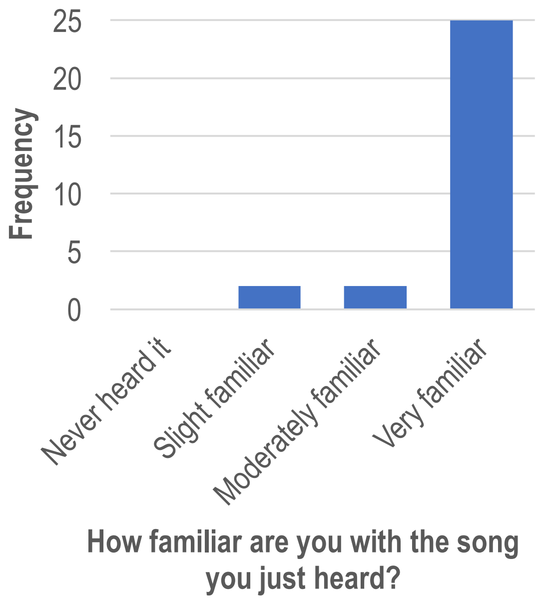
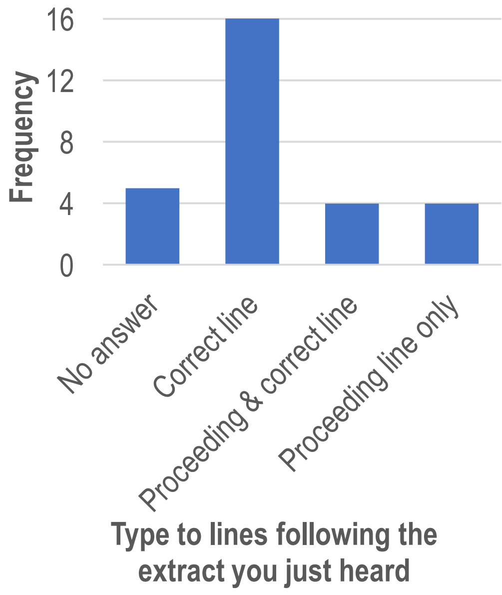



*Figure 13: Typing lines accuracy*




Some descriptive statistics for the induction phase are necessary to consider its usefulness. All participants had some familiarity with the song, and almost all were very familiar with it (Figure 12). In general, participants were not highly successful at getting the three pitch differentiation tasks correct ($M$ = 0.833 out of a maximum of 3; see Figure 15), with moderate success for typing lines (Figure 13) and counting words (Figure 14).

*Figure 14: Counting words accuracy*

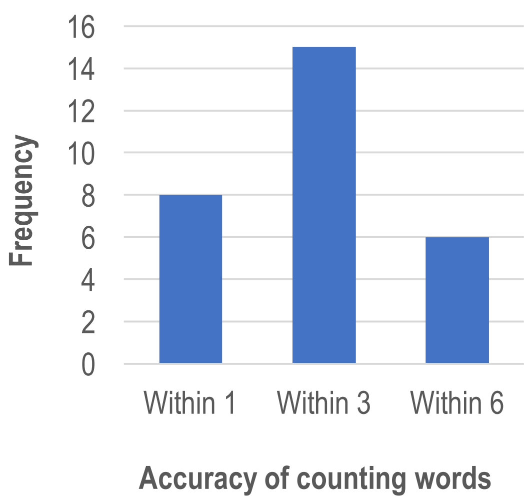
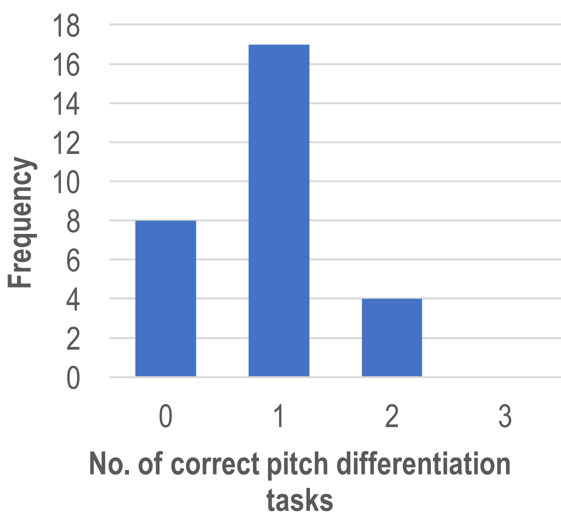



*Figure 15: Pitch differentiation accuracy*



### 4.3. Manipulation Checks

Although ANT performance is not a dependent variable or the primary concern of the study, it is necessary to analyse ANT performance to see if it manipulated attention and to confirm whether performance wavered across chewing Gum and hearing Leco. Using the Shapiro-Wilk test, the MRTs were normally distributed, but the ERs were not because there was a floor effect (as expected). As such, only the MRTs were used as is often the case in other studies (e.g. Holtzer et al., 2011), and the means are provided (Table 8).

***Table 8: ANOVA means for MRTs***

| | | ANT | Gum | | |
|---|---|---|---|---|---|
| | | | **No** | **Yes** | **TOTAL** |
| **Leco** | **No** | **Easy** | CS1 = 524.73 | GS1 = 516.12 | *S1 = 520.43* |
| | | **Difficult** | CS2 = 627.95 | GS2 = 647.65 | *S2 = 637.80* |
| | | **TOTAL** | *CS = 576.34* | *GS = 581.89* | **S = 579.11** |
| | **Yes** | **Easy** | CL1 = 507.63 | GL1 = 516.35 | *L1 = 511.99* |
| | | **Difficult** | CL2 = 628.13 | GL2 = 586.09 | *L2 = 607.11* |
| | | **TOTAL** | *CL= 567.88* | *GL = 551.22* | **L = 559.55** |
| | **TOTAL** | **Easy** | *C1 = 516.18* | *G1 = 616.87* | **1 = 516.20** |
| | | **Difficult** | *C2 = 628.04* | *G2 = 616.87* | **2 = 622.46** |
| | | **TOTAL** | **C = 572.11** | **G = 566.55** | ***T = 569.33*** |

MRTs are measured in milliseconds – lower scores represent faster and better ANT performance.

The MRTs were compared across conditions using a 2 × 2 × 2 repeated-measures ANOVA (Table 9). Both the main effect of ANT ($F_{1, 28}$ = 102.50, $p$ < 0.001, $\eta^2_{\text{partial}}$ = 0.79) and Leco ($F_{1, 28}$ = 6.24, $p$ = 0.019, $\eta^2_{\text{partial}}$ = 0.18) were significant, as well as the Gum × Leco × ANT interaction ($F_{1, 28}$ = 4.62, $p$ = 0.04, $\eta^2_{\text{partial}}$ = 0.14). MRT for Easy ANT sets was lower than MRT for Difficult ANT sets within each condition (CS1 < CS2, $t_{28}$ = -9.521, $p$ < 0.001, $D$ = 0.3; GS1 < GS2, $t_{28}$ = -9.225, $p$ < 0.001, $D$ = 0.37; CL1 < CL2, $t_{28}$ = -12.168, $p$ < 0.001, $D$ = 0.43; GL1 < GL2, $t_{28}$ = -2.322, $p$ = 0.028, $D$ = 0.17) and equally regardless of condition (1 > 2, $t_{28}$ = -10.102, $p$ < 0.001, $D$ = 0.39). Surprisingly, hearing Leco increased ANT performance regardless of condition (L < S, $t_{28}$ = -2.497, $p$ = 0.019, $D$ = 0.08). Specifically, when participants were chewing Gum and completing Difficult ANT sets, they performed significantly better on the ANT when hearing Leco versus not hearing Leco (GL2 < GS2, $t_{28}$ = 2.216, $p$ = 0.035, $D$ = 0.14).

*Table 9: ANOVA summary for MRTs*

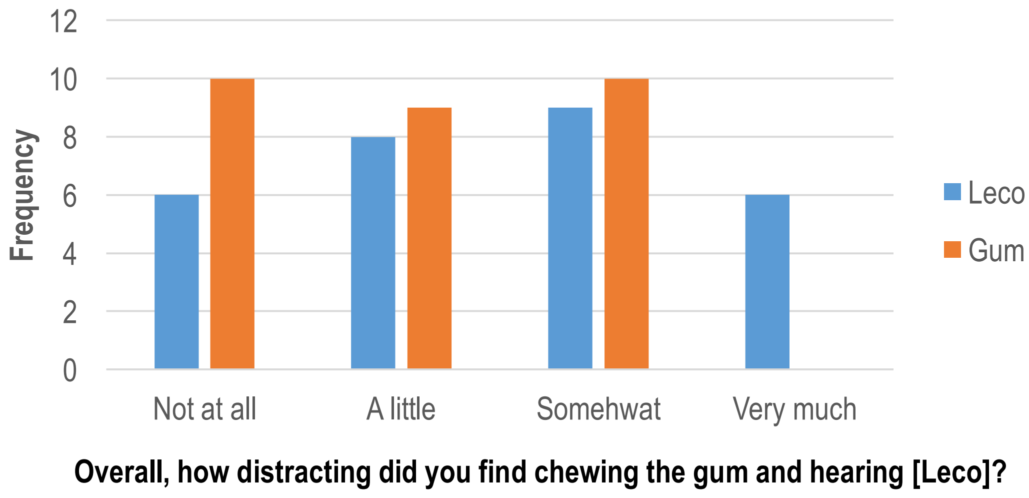
| Source | *SS* | *df* | *MS* | *F* | *p* | $\eta^2_{\text{partial}}$ |
|---|---|---|---|---|---|---|
| Gum | 1789 | 1 | 1789 | 0.370 | 0.548 | |
| *Error (Gum)* | *135592* | *28* | *4842* | | | |
| Leco | 22196 | 1 | 22196 | 6.236 | **0.019** | 0.18 |
| *Error (Leco)* | *99671* | *28* | *3559* | | | |
| ANT | 654726 | 1 | 654726 | 102.501 | ***0.000*** | 0.79 |
| *Error (ANT)* | *178850* | *28* | *6387* | | | |
| Gum × Leco | 7147 | 1 | 7147 | 1.434 | 0.241 | |
| *Error (Gum × Leco)* | *139557* | *28* | *4984* | | | |
| Gum × ANT | 1826 | 1 | 1826 | 0.391 | 0.537 | |
| *Error (Gum × ANT)* | *130751* | *28* | *4669* | | | |
| Leco × ANT | 7185 | 1 | 7185 | 2.257 | 0.144 | |
| *Error (Leco × ANT)* | *89145* | *28* | *3183* | | | |
| Gum × Leco × ANT | 22657 | 1 | 22657 | 4.615 | **0.040** | 0.14 |
| *Error (Gum × Leco × ANT)* | *137456* | *28* | *4909* | | | |

*p*-values in **bold** are significant at the 0.05 level, *p*-values in ***bold italics*** are significant at the 0.01 level.

The self-report responses (Appendix H) also check the 'pureness' of the Gum or Leco manipulation (i.e. whether participants' felt they used attentional resources). These frequencies are presented in Figure 16. The results for the self-reported distraction of Leco ($M = 2.52$) and Gum ($M = 2.00$) were found to be normally distributed and were compared. A two-tailed paired-sample *t*-test showed that the Gum was perceived as significantly less distracting than Leco ($t_{28} = -2.353$, $p = 0.026$, $D = 0.14$).

There is evidence that attentional load was successfully manipulated by the ANT. However, this was not uniform across all conditions. Indeed, while Leco was perceived as distracting, it seemed to facilitate performance when the task was most difficult. Equally, while Gum was also seen as distracting (albeit less so than Leco), it did not impede ANT performance. These patterns have great significance for the effectiveness and specificity of the manipulations, as explored later.

*Figure 16: Frequencies of self-reported distraction of Gum and Leco*




### 4.4. ANOVA

#### 4.4.1. Assumptions

It is crucial to first check whether the data violated any assumptions before running the ANOVA. Firstly, INMI Frequency (the dependent variable) is measured on a single Likert-type scale, but is treated as at least interval. While this does follow a trend of many studies and it is also subject to the same pitfalls (Jamieson, 2004). The three within-subject independent variables all have two categorical levels, each of which was experienced by all participants. Furthermore, each subject's data was independent of every other subject's data. Sphericity is not a required assumption because there are only two levels for each independent variable.

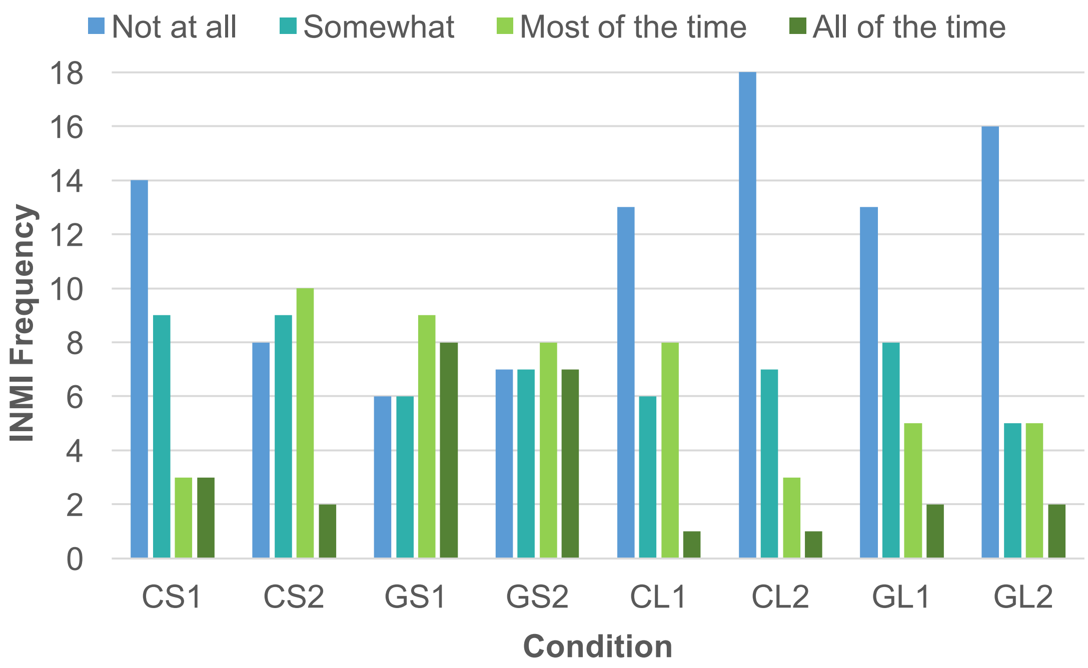
An assumption requiring further testing is that of multivariate normality. Univariate normality was considered using the Shapiro-Wilk test, and was considered for all variables used in all the ANOVAs. Almost all variables were non-normally distributed (Table 10), violating this assumption. Fortunately, repeated measures ANOVAs are robust for violations of this assumption, and it is advised the cells with at least 20 entries (each has 27) make this analysis feasible (Tabachnick & Fidell, 2007). Still, given these violations it is useful to confirm the results by running a non-parametric equivalent tests. While there is no non-parametric equivalent for a three-way repeated-measures ANOVA, Wilcoxon signed rank tests corroborated the results (see Footnote 1).

*Table 10: Shapiro-Wilk tests of normality*

| Condition | | Statistic | *df* | *p* |
|---|---|---|---|---|
| Gum × Leco × ANT | CS1 | 0.788 | 26 | 0.000 |
| | CS2 | 0.858 | 26 | 0.002 |
| | GS1 | 0.866 | 26 | 0.003 |
| | GS2 | 0.859 | 26 | 0.002 |
| | GL1 | 0.813 | 26 | 0.000 |
| | GL2 | 0.697 | 26 | 0.000 |
| | CL1 | 0.807 | 26 | 0.000 |
| | CL2 | 0.764 | 26 | 0.000 |
| Leco × ANT | S1 | 0.941 | 26 | 0.139 |
| | S2 | 0.933 | 26 | 0.091 |
| | L1 | 0.868 | 26 | 0.003 |
| | L2 | 0.804 | 26 | 0.000 |
| Gum × ANT | C1 | 0.886 | 26 | 0.008 |
| | C2 | 0.907 | 26 | 0.023 |
| | G1 | 0.883 | 26 | 0.007 |
| | G2 | 0.915 | 26 | 0.034 |
| Leco × Gum | CS | 0.906 | 26 | 0.021 |
| | GS | 0.928 | 26 | 0.069 |
| | GL | 0.876 | 26 | 0.005 |
| | CL | 0.816 | 26 | 0.000 |

#### 4.4.2. Gum × Leco × ANT

*Figure 17: Distribution of reported INMI frequency per condition*




A brief consideration of Figure 17, Table 11 and the subsequent inferential results suggests several trends. Overall, participants reported significantly less INMI in the Leco conditions than in the Silence conditions. Specifically, hearing the Leco voice decreased INMI when also chewing Gum. Chewing Gum moderated the effect of both Leco and the ANT. Regardless of Leco, chewing Gum facilitated INMI for the Easy ANT conditions. Moreover, chewing Gum increased INMI when there was Silence.

*Table 11: ANOVA means for self-reported INMI*

| | | ANT | Gum | | |
|---|---|---|---|---|---|
| | | | **Control** | **Gum** | **TOTAL** |
| **Leco** | **Silence** | **Easy** | CS1 = 1.828 | GS1 = 2.655 | *S1 = 2.241* |
| | | **Difficult** | CS2 = 2.207 | GS2 = 2.517 | *S2 = 2.362* |
| | | **TOTAL** | *CS = 2.017* | *GS = 2.586* | **S = 2.302** |
| | **Leco** | **Easy** | CL1 = 1.793 | GL1 = 1.828 | *L1 = 1.845* |
| | | **Difficult** | CL2 = 1.690 | GL2 = 1.552 | *L2 = 1.638* |
| | | **TOTAL** | *CL = 1.793* | *GL = 1.759* | **L = 1.750** |
| | **TOTAL** | **Easy** | *C1 = 1.828* | *G1 = 2.310* | **1 = 2.060** |
| | | **Difficult** | *C2 = 2.000* | *G2 = 2.034* | **2 = 2.009** |
| | | **TOTAL** | **C = 1.914** | **G = 2.172** | ***T = 2.033*** |

Second-order interaction means in normal font, first-order interaction means in *italics,* main effects in **bold**, grand mean in ***bold italics***.

All interactions and main effects were considered across conditions (Table 12)[1]. The analysis showed a significant main effect for Leco ($F_{1, 25}$ = 15.854, $p$ = 0.001, $\eta^2_{\text{partial}}$ = 0.41) but neither Gum ($F_{1, 25}$ = 2.457, $p$ = 0.130) nor ANT ($F_{1, 25}$ = 0.889, $p$ = 0.355). More importantly, the second-order Gum × Leco × ANT interaction was non-significant ($F_{1, 25}$ = 0.155, $p$ = 0.697). As such, the three first-order interactions were considered by collapsing each level, rather than the simple effects at the second-order level. Firstly, the Leco × ANT interaction was not significant ($F_{1, 25}$ = 3.960, $p$ = 0.058), so no further comparisons were conducted for this.

[1] Wilcoxon signed rank non-parametric comparisons found the same pattern as the parametric paired sample *t*-tests for the significant main effect and post-hoc comparisons. Moreover, for the significant main effect and all post-comparisons, there was no difference whether the averages for the missing values remained missing values, or were estimated by using the corresponding value of the pair averaged. As such, all reported results give only the estimated averages and paired sample *t*-tests.

*Table 12: ANOVA summary*

| *Source* | *SS* | *df* | *MS* | *F* | *p* | $\eta^2_{\text{partial}}$ |
|---|---|---|---|---|---|---|
| Gum | 2.327 | 1 | 2.327 | 2.457 | 0.130 | |
| Error (Gum) | *23.673* | 25 | 0.947 | | | |
| Leco | 13.000 | 1 | 13.000 | 15.854 | ***0.001*** | 0.41 |
| *Error (Leco)* | *20.500* | 25 | 0.820 | | | |
| ANT | 0.481 | 1 | 0.481 | 0.889 | 0.355 | |
| *Error (ANT)* | *13.519* | 25 | 0.541 | | | |
| Gum × Leco | 4.923 | 1 | 4.923 | 6.452 | **0.018** | 0.22 |
| *Error (Gum × Leco)* | *19.077* | *25* | *0.763* | | | |
| Gum × ANT | 2.327 | 1 | 2.327 | 7.118 | **0.013** | 0.26 |
| *Error (Gum × ANT)* | *8.173* | *25* | *0.327* | | | |
| Leco × ANT | 1.231 | 1 | 1.231 | 3.960 | 0.058 | |
| *Error (Leco × ANT)* | *7.769* | *25* | *0.311* | | | |
| Gum × Leco × ANT | 0.077 | 1 | 0.077 | 0.155 | 0.697 | |
| *Error (Gum × Leco × ANT)* | 12.423 | 25 | 0.497 | | | |

*p*-values in **bold** are significant at the 0.05 level, *p*-values in ***bold italics*** are significant at the 0.01 level.

#### 4.4.3. Leco × Gum

Secondly, both the Leco × Gum interaction ($F_{1,25} = 6.452$, $p = 0.018$, $\eta^2_{\text{partial}} = 0.22$), and the main effect of Leco were significant, but not the main effect of Gum. INMI frequency was collapsed across the ANT conditions (Table 13) and the first-order simple effects were compared used two-tailed paired-sample *t*-tests. Comparing within the Silence conditions, participants chewing Gum had more frequent earworms than those in the Control (GS > CS, $t_{28} = -2.786$, $p = 0.009$, $D = 0.06$), but this did not hold over the Leco conditions (GL ≈ CL, $t_{28} = 0.346$, $p = 0.732$). Comparing within the Gum conditions, participants hearing Leco experienced more frequent earworms than those in Silence (GL > GS, $t_{28} = 5.310$, $p < 0.001$, $D = 0.24$), but this did not hold over the Control conditions (CL ≈ CS, $t_{28} = 1.384$, $p = 0.177$).

*Table 13: Collapsed means for Leco × Gum interaction*

| | | Gum | | |
|---|---|---|---|---|
| | | Control | Gum | TOTAL |
| Leco | Silence | *CS = 2.017* | *GS = 2.586* | **S = 2.302** |
| | Leco | *CL = 1.793* | *GL = 1.759* | **L = 1.750** |
| | TOTAL | **C = 1.914** | **G = 2.171** | ***T = 2.033*** |

### 4.4.4. Gum × ANT

Thirdly, the Gum × ANT was significant ($F_{26}$ = 9.173, $p$ = 0.005, $\eta^2_{\text{partial}}$ = 0.26), but neither main effect was. The means were collapsed across the Leco conditions and compared using two-tailed paired-samples $t$-tests (Table 14). Comparing Easy and Difficult, neither the Control (C1 ≈ C2, $t_{28}$ = -1.625, $p$ = 0.115) nor the Gum conditions (G1 ≈ G2, $t_{28}$ = 1.010, $p$ = 0.054) were significantly different. However, comparing across the Gum conditions gave a significant difference for the Easy (C1 < G1, $t_{28}$ = -2.950, $p$ = 0.006, $D$ = 0.05) but not Difficult (C2 ≈ G2, $t_{28}$ = -0.210, $p$ = 0.835) ANT condition.

*Table 14: Collapsed means for Gum × ANT interaction*

| | | ANT | | |
|---|---|---|---|---|
| | | Easy | Difficult | TOTAL |
| Gum | Control | *C1 = 1.828* | *C2 = 2.000* | **C = 1.914** |
| | Gum | *G1 = 2.310* | *G2 = 2.034* | **G = 2.171** |
| | TOTAL | **1 = 2.060** | **2 = 2.009** | ***T = 2.033*** |

# 5. Discussion

### 5.1.1. INMI Experience

The opening research question pertained to describing the experience of INMI, and is addressed by considering the descriptive data, particularly the IMIS. It appears, in conjunction with previous research using the IMIS, that the IMIS is a valid and valuable scale. Even though the present sample was very small for a factor analysis, the structure of the IMIS was largely supported. Moreover, internal consistency in the present study (Table 5) is comparable to previous studies (Table 1; Cotter et al., 2016; Floridou et al., 2015; Geffen, 2015). In describing participants' experience of INMI, it is useful to briefly compare this data to similar data from other research. This comparison not only also provides insight into the current sample (and potentially population), but also evaluates the convergent validity of the IMIS.

Average INMI frequency (Figure 7) was very similar to Liikkanen's (2011) data, with 33.2% every day and 26.2% several times a day (although slightly different categories were used). Moreover, it was similar to Geffen's (2015) results with 36.5% several times a week and 20.1% several times a day. However, the participants gave fewer extreme results as expected with a small sample.

The IMIS has the advantage of differentiating between the section and episode length of an earworm, finding that the section of repetitive music is normally between 5 and 30 seconds (Figure 8), while the earworm episode generally lasts up to 30 minutes (Figure 9). While most studies have not differentiated section and episode length, the results for these two measures are highly comparable to a previous study using the IMIS (Geffen, 2015). Moreover, Hyman et al. (2015) recently reported similar responses to a survey based on participants' most recent earworm, although different bins/categories were used. Earworms are sometimes linked to a person's movement, but less so to personal issues (Table 6). Lastly, earworms tended to be reported as a moderately positively experience, as found in previous studies (Beaty et al., 2013; Beaman & Williams, 2013; Halpern & Bartlett, 2011; Hyman et al., 2015; Floridou & Müllensiefen, 2015), but are not generally helpful for focusing.

Correlations were found between both measures of musicality and several IMIS subscales (Table 7). Given the immense range of measures of musicality in the literature, the results most closely resembling the two questions asked in this study are considered. More frequent earworms were associated with more interest in music, as in most of the literature (Beaman & Williams, 2010; Beaty et al., 2013 Floridou et al., 2012; Hemming 2009, as cited in Beaman & Williams, 2013; Liikkanen, 2008; cf. Beaman & Williams, 2013). Similarly, the positive relationship between earworm frequency and music listening is confirmed, as often reported in the literature (Bennet, 2002; Kellaris, 2003; Liikkanen, 2008, 2011; McCullough, 2014; Müllensiefen et al., 2014), but strangely not confirmed by Geffen (2015), with almost identical measurements in a larger sample. Indeed, Geffen (2015) found several correlations that were not present in this study.

More engagement with music increases familiarity and may be associated with recent and repeated exposure – all of which increase the propensity for INMI. In relation to WM, this is consistent with a priming hypothesis, where music engagement may prime an individual to subsequently have an earworm (Kvavilashvili & Mandler, 2004). On the other hand, listening to music can also be used to block an earworm (Williamson et al., 2014), but Music Listening was not associated with attempts to block earworms. Alternatively, given that both musicality questions were associated with Personal Reflection on the IMIS (and other subscales), musicality may say something more about personality and the subjective experience of music, which could, in turn, be linked to the subjective experience of earworms.

### 5.1.2. Checks

#### *5.1.2.1. Induction*

One unchecked presumption is that the induction procedure was relatively effective. Except for three, all participants experienced some INMI during the experiment, indicating a reasonable degree of success for the induction, although at times there was low INMI (Figure 17). Still, this lends empirical support to the theoretical foundations of the induction procedure. This is not diminished by the poor performance of individuals in certain induction tasks (Figure 15), because their participation, not their performance, was important. However, it may be of some concern that certain participants did not type an answer to the lines completion question (Figure 13). This raises the possibility that some participants may not have seriously engaged in other tasks, therefore not experiencing MI which may have decreased the effectiveness of the induction procedure for certain individuals.

##### *5.1.2.2. Manipulations*

It is important to consider how successful the ANT task was at manipulating attention, and whether chewing Gum or hearing Leco also used attentional resources. Considering the results for the ANOVA for the ANT MRTs (Table 9) and the self-reported distraction (Figure 16), it is proposed that both the ANT and hearing the foreign language manipulated attention, whereas chewing Gum did not.

The Easy/Difficult manipulation of the ANT is a novel manipulation, and while it is founded on established theory and empirical results, it needs to be directly validated. Analysis of the main effect of the ANT for MRTs (Table 9), showed that participants were significantly slower to respond on the Difficult ANT sets, across and within all conditions with mostly moderate effect sizes. This was expected given that the Difficult sets had fewer alerting and orienting cues and required inhibition given a greater proportion of incongruent flankers (Table 2). This suggests the theoretical validity of the attentional load manipulation of the ANT bore out in practice.

This manipulation of attention has several advantages. Firstly, the ANT engages visual senses, limiting its impact on auditory imagery. Furthermore, given that it requires orienting, alerting and executive control, it is a comprehensive manipulation of attention. Most importantly, the progression from easy to challenging ANT sets appears seamless to participants. As such, the manipulation is very subtle as participants could not readily distinguish the Easy and Difficult ANT sets, meaning that their self-reports would not be biased by this.

Preliminary self-report evidence suggests that hearing Leco and to a lesser extent chewing Gum were perceived as distracting, but this was not consistent with the analysis of ANT performance. Certainly, there was no corroborating evidence that chewing Gum used attentional resources. As such, it seems the chewing Gum was not a significant enough use of attentional resources. However, hearing the foreign language improved ANT performance regardless of other conditions (Table 9), and closer consideration revealed that this was particularly the case when chewing Gum and completing the Difficult ANT set (GL2 < GS2 – Table 8). While this may seem counter-intuitive, Hockey's (1995) supervisory loop model may explain these results.

The theoretical model (Figure 1) simply proposed that the CE chooses the INMI refreshing process (attentional refreshing, inner ear or inner voice) based on the relative demands to each of those components. In contrast, Hockey (1995) suggests that the supervisory controller engages the supervisory loop as a more effortful method of maintaining task goals when they are not being met. Specifically, participants maybe have used subsidiary task failure, a strategy which narrows attentional focus, ignoring less important tasks. This mode would then increase ANT performance at the expense of other tasks, even while perceived distraction increased (and likely stress too). This is consistent with the results, as during the condition where the task was difficult and the condition highly distracting (GL2), the supervisory loop may have been used to increase performance. In this condition, the activation of the supervisory loop would maximise WM for the ANT task, so it would not only ignore the Leco speech, but also any INMI (and as discussed later, INMI seems inversely related to distraction).

However, Hockey's (1995) model specifically requires a differentiation of primary and secondary goals/tasks. Here, it was suggested that participants may have viewed the ANT as the primary task and INMI as a distraction (informal conversations with participants following the experiment did suggest this). Indeed, this is also consistent with the descriptive result that INMI is generally not helpful when focusing on tasks (Table 6). As such, the primary goal of ANT performance was maintained despite costs to INMI and even hearing the foreign language (both seen as distractions). In fact, a study which used the ANT under three conditions of music (silence, simple music and complex/atonal music) found that ANT performance was best in the complex music condition, followed by the simple music and then silence condition (Chettiar, 2014). To explain these similarly counter-intuitive results, Chettiar (2014) applied Hockey's (1995) model to suggest that as the distraction increased (with music of increasing complexity), so the supervisory loop was used to limit the effect of the distraction. Fundamentally, the use of Hockey's model suggests a non-linear relationship between ANT performance and distraction suggesting that hearing Leco was highly distracting despite improved ANT performance.

### 5.2. Working Memory Interactions on INMI

The primary research questions considered the independent and interactional effects of attention, the inner voice and the inner ear on INMI frequency. This discussion highlights that the manipulations may have been imprecise or impure, making it difficult to distinguish WM components. To summarise, Leco largely decreased INMI, but this effect was qualified by an interaction with Gum. Unexpectedly, Gum appeared to facilitate INMI, except when this was modified by the effect of Leco or attentional load. Interestingly, the ANT did not have a straightforward effect, but only interacted with the other two variables, but overall the EL played a significant role. Ultimately, this provides evidence for the inner ear and attentional refreshing as mechanisms for refreshing INMI, while suggesting that chewing gum can be facilitative. Each of these three refreshing processes will now be considered in relation to the descriptive and inferential statistics.

#### 5.2.1. Inner Voice

While there was not a main effect of Gum, a broad consideration of Table 11 and Figure 17 shows that Gum facilitated INMI, depending on hearing Leco and task difficulty. Specifically, chewing gum did not have an effect during the Difficult ANT set (Figure 18) and when participants heard Leco (Figure 19). This suggests that while chewing Gum may have supressed the inner voice, its facilitative effect counteracted the suppression of INMI via the inner voice.

First it is necessary to explain why chewing Gum did not decrease INMI (as hypothesised), before accounting for its amplifying effect. One possibility is that chewing Gum did supress the inner voice, but the inner voice is not involved in sustaining INMI. Given the evidence presented for the role of the inner voice, especially experimental results (Beaman et al., 2015), this seems unlikely. Alternatively, chewing Gum may have been an ineffectual manipulation, not supressing the inner voice. This seems even less conceivable as there is evidence outside of the INMI field showing the suppresive effect of gum on the inner voice (Kozlov et al., 2012). A final, and more plausible conjecture, is that while chewing

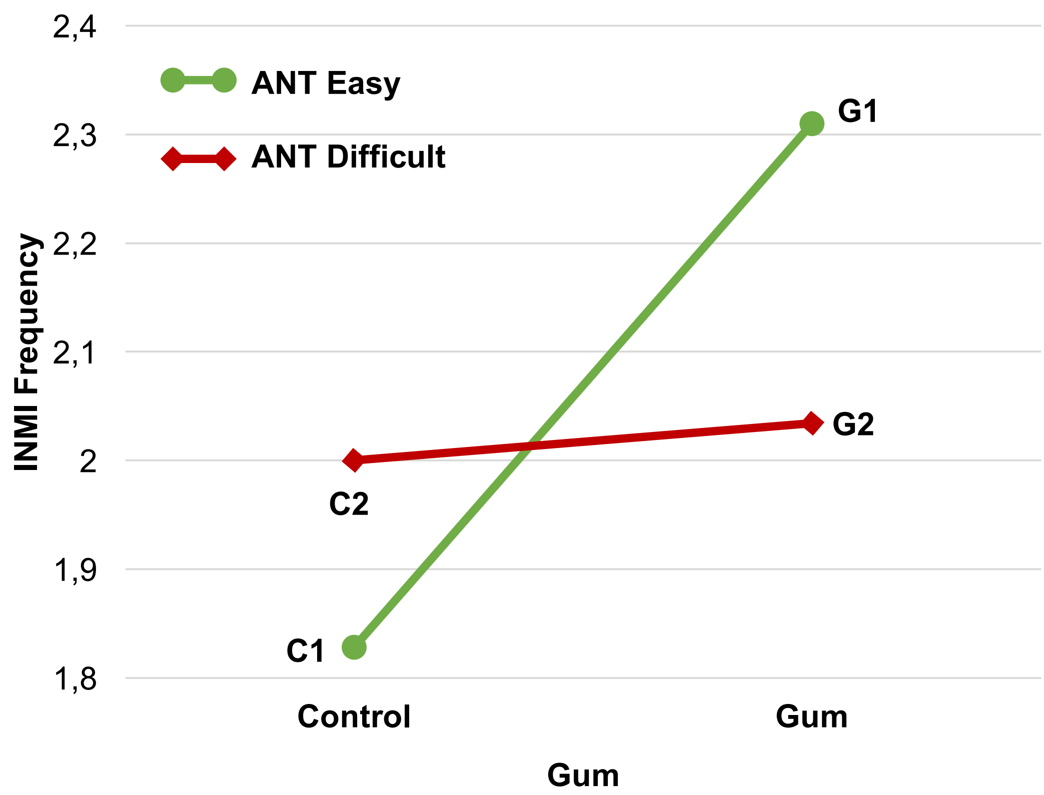
Gum did supress the inner voice, its facilitative effect counteracted this suppression, and was especially strong under certain conditions.

A potential explanation of the counteractive facilitative effect of Gum is that participants were chewing Gum to the rhythm of the song in the same manner one would tap one's foot, thus sustaining rather than supressing an earworm. One participant even commented that the arrows in the ANT seemed to be in time to their earworm, suggesting that rhythmic overlap or cadence (which was random, as per Figure 6) can reinforce INMI. This explanation also explains the pattern of the facilitative effect in Figure 18 and Figure 19. Most obviously, if there is no INMI (Figure 17), there can be no rhythmic Gum chewing to enhance it. However, even if there is minimal INMI, chewing in time to the song's rhythm could be difficult when hearing Leco, where one might instead chew randomly or in time to the cadence of the speech. Alternatively, hearing a foreign voice could also suppress the inner voice more strongly (e.g. participants subvocalising foreign words to make sense of them), which could block the counteractive effect of Gum. Equally, it is possible that during attention demanding tasks (or even hearing Leco, which appeared to use attentional resources), participants could not focus on the rhythm of the song, or there was simply no INMI to chew in time with because it was entirely blocked.

Additionally, this explanation may clarify why Beaman et al. (2015) did not find the same result, especially in light of the distinctions between the studies. The Beaman et al. (2015) study did not include any attention-based task or foreign language, but participants were instructed to supress the song from memory and then could think freely about it. While chewing gum effectively decreased INMI in both the suppression and expression conditions, the nature of the task was clearly different. Moreover, the measurement of INMI by pressing a key each time was very different to this study's aggregate measurement. Another difference is that participants were requested to chew gum vigorously, whereas there was no instruction in the present study, and participants chewed the gum normally. As such, chewing gum may have been in time to the INMI in the present study, as the tapping could also have been in time in Beaman et al.'s (2015) study, where the tapping condition was not significantly different from the control condition. While previous research has shown no difference in chewing gum vigorously or naturally in serial recall tasks (Kozlov et al., 2012), this may be specific to INMI and musical imagery, given its rhythmic nature.

Alternative accounts for the facilitation of chewing Gum are reviewed by Kozlov, Hughes and Jones (2012) in the context of recognition and recall, suggesting that the mastication involved in chewing gum increases blood flow to the brain, and that the gum flavour could also enhance memory. While this explanation is worth consideration, it does not account for the specificity of the facilitative effect when participants had Silence and completed Easy ANT sets. Still, if the rhythmic chewing of Gum is responsible for amplifying INMI it is unclear how this fits in with a more general WM model. Indeed, as most research on auditory imagery has not considered music, rhythm has not been a fundamental area of exploration. However, it has been found that during an earworm episode the tempo of the song is recalled accurately (Jakubowski, Farrugia, Halpern, Sankarpandi, & Stewart, 2015), suggesting that in WM, there may be a cognitive representation of rhythm and tempo that is key to INMI.

*Figure 18: Graph of Gum × ANT interaction*



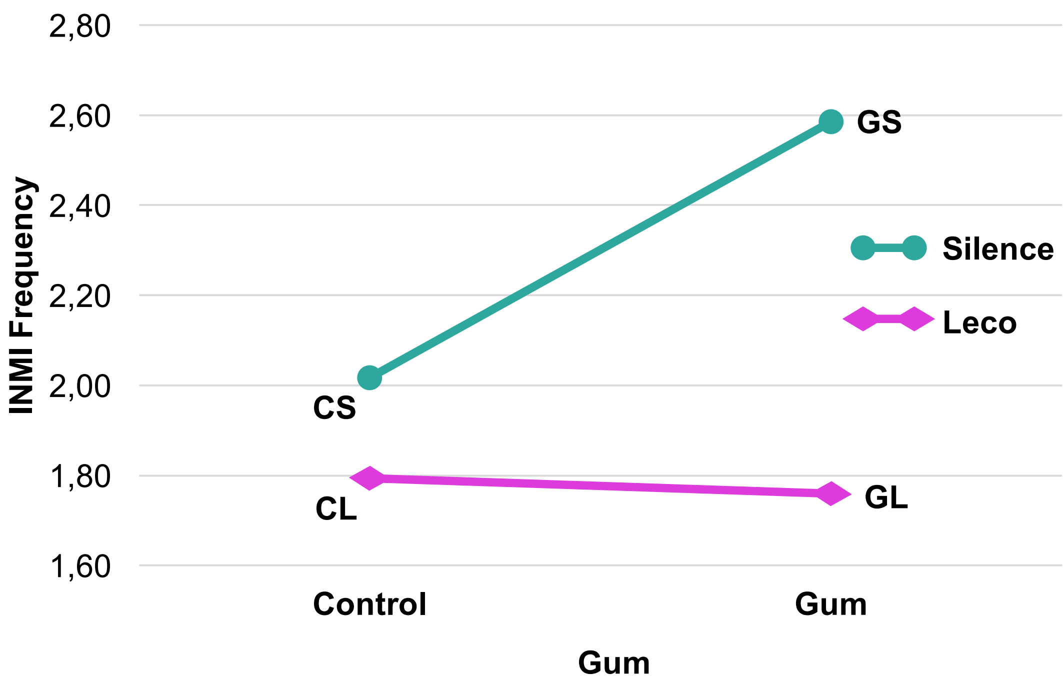
### 5.2.2. Inner Ear

In the present study, a cautious consideration of the main effect of Leco is worth exploring. Specifically, Leco seemed to be the greatest suppressor of INMI (given the significant main effect); this suppression interacted with chewing Gum (Figure 19) but not the ANT. However, it seems possible that hearing the foreign language did more than supress the inner ear, as it was a major distraction (Figure 16 and Table 9). Nonetheless, as hearing Leco seemed to also supress the inner ear, it does support the use of this mechanism in refreshing INMI in WM.

There is the strong possibility that hearing Leco interfered with a variety of WM processes, especially attention and the EL. The lack of a Leco × ANT interaction suggests that Leco may have supressed the same mechanism as the ANT task. Indeed, the Leco × Gum interaction (Figure 19) bears similarities to the Leco × ANT interaction (Figure 19), suggesting a similarity between the effect of Leco and the ANT. While great care was taken to choose an obscure language to minimise distraction, it is possible that hearing Leco was simply too distracting and therefore used attentional resources rather than purely suppressing the inner ear. Hypothetically, participants may have attempted to decode or make sense of this uninterpretable language, or had their attention drawn to its strangeness. Also, if Leco presented a distraction to participants and the supervisory loop was used, then this would lead to increased suppression of INMI (seen as a distractor alongside hearing Leco).

Nevertheless, the question remains as to the role of the inner ear in sustaining INMI. In other words, whether the effect of Leco on INMI was purely due to its effect on the EL or as a distractor in relation to the supervisory loop, or whether the inner ear also played a role. Making the same argument made for Gum, there is support for hearing irrelevant speech supressing the inner ear (Smith et al., 1995), and the inner ear being involved in INMI. Considering the present results, Leco seemed to decrease INMI beyond the effect of the ANT, (as the ANT did not have a significant main effect, and even comparing conditions L2 and 2 in Table 11). It could be suggested that Leco was simply highly distracting, more so than the ANT, but the WM theory would advocate that the inner ear was implicated too. Still, certain theorists (e.g. Baddeley, 2012) could challenge the theoretical foundation for this, and not see the PL as separated into the inner ear and voice. Consequently, given that Leco was a nonspecific manipulation, it is not entirely certain to what extent its effect was due to suppressing the inner ear or attention. Thus, future research might supress the inner ear through a different operationalisation that does not also use attentional resources, possibly in conjunction with an attention task.

*Figure 19: Graph of Leco × Gum interaction*




### 5.2.3. Attentional Refreshing

It has been suggested that hearing Leco suppressed the EL, and thus attentional refreshing, so both the Leco and ANT manipulations are considered here. Moreover, it is also worth incorporating Hockey's supervisory loop as a model for understanding how increased distraction and attentional demand may have blocked INMI as a distractor. Ultimately, the effect of attentional load is mediated by mind wandering under normal circumstances, but as distraction increases, the supervisory loop is used to block distractors (including INMI) while increasing performance.

The review of the evidence advanced that there was a non-linear, quadratic effect of attentional load on INMI as mediated by mind wandering (Figure 1), where INMI occurs at low and high levels of attentional load, given the presence of mind wandering. Considering attentional load in each condition, increased attentional load does decrease INMI frequency (CL1 > CL2, GS1 > GS2, GL1 > GL2). This supports attentional load directly suppressing the attentional refreshing of INMI. One exception is the Silence and Control condition, where CS1 < CS2. This could be consistent with a mind-wandering account, where in the easier task (CS1) participants were fully engaged, but struggled more in the difficult task (CS2) thus experiencing mind-wandering and more INMI.

In contrast, several results advocate that in high levels of attentional load and when distracted, the supervisory loop ensures performance on the primary task by ignoring distractors (including INMI) and increasing stress. Indeed, considering Table 11 and Figure 17, there is a trend that as attentional load and distractors increase, INMI decreases. This appears inconsistent with a quadratic, inverted-U effect of attentional load, as at very high levels of distraction and attentional load there is no mind wandering, and very little INMI.

To synthesise this, when the regular loop is being used, mind wandering can occur (and may be more likely to occur given a lack of sensitivity to distractions), and in this case, there is a quadratic effect of attentional load as it is mediated by mind wandering. The increase in INMI (CS1 < CS2) that corresponded to a presumed increase in mind wandering is consistent with the argument made in the literature review, and particularly Hyman et al.'s (2013) study. Conversely, when there are increased distractions (chewing Gum, hearing Leco and INMI) from a primary goal, the supervisory loop is employed which blocks distractions (especially INMI). This could also explain Floridou et al.'s (2016) results where increased attentional load decreases INMI.

However, if this explanation is valid, it is not yet clear why participants in Floridou et al.'s (2016) study would have used the supervisory loop, whereas participants in Hyman et al.'s (2013) study did not. Future research might explore possible explanations for the use of the supervisory loop in the context of INMI, such as task type, levels of motivation and distractions. Indeed, the intense effort involved in using the supervisory loop results in increased stress and fatigue which could also be research, suggesting possible downsides of continued blocking of an earworm. In addition, it would be fruitful for future research to test the relationship between distraction and mind wandering, considering whether this hypothesis remains valid under more direct testing (especially with a generalised distractor task that does not interfere with the PL, such as tapping in the Beaman et al., 2015 study) with a concurrent attention-based task.

## 5.3. Strengths, Limitations and Future Considerations

### 5.3.1. Design and Validity

Traditionally, research decisions are conceived as trade-offs, such as the choice of this study's strong experimental design possibly being at the expense of ecological validity. Instead, a more nuanced view considers that even though there are always trade-offs, careful consideration can minimise these trade-offs, maximising both ethical and effective procedures, internal and external validity, considering the effect of the context while also controlling for it.

The within-participants design of this study bolsters internal validity and allows for strong causal claims as it controls for any inter-participant differences, which might provide alternative explanations for the results beyond the manipulations of WM components. This is particularly relevant for WM where different tasks and activities could have differential suppression effects on the WM components of different individuals. What may be a moderately difficult task for one person could be exceptionally difficult for another. Equally, it is possible that chewing gum and hearing Leco may suppress individuals' inner voice and ear to different degrees. Moreover, this design is congruent with the theory, which suggests that it is about the same individual who would employ some combination of three refreshing mechanisms depending on the given condition, rather than different individuals assigned to different conditions (as in a between-participants design). Furthermore, even with small samples within-participants design largely boost statistical power and have greater sensitivity to small effects which between-participants designs may not discover (Charness, Geezy, & Kuhn, 2012).

Still, a key danger of a within-participants design is the effect of order (i.e. how the previous conditions influence subsequent conditions), which was avoided through employing counter-balancing. Counter-balancing limited systematic effects of fatigue, which is known to occur across ANT sets (Holtzer et al., 2011), where attention could waver making individuals more susceptible to mind-wandering and experiencing earworms. Equally, practice effects occur in the ANT (Ishigami & Klein, 2010), which was addressed through using a standard practice set as well as counter-balancing. Moreover, in earworm induction paradigms, both decay and recency effects have been observed (Floridou, Williamson, & Stewart, 2016), so the counter-balanced design avoided any systematic decay across conditions. As discussed, the shift between Easy and Difficult ANT sets is subtle, which is useful in minimizing carry-over effects in a within-participants design (Greenwald, 1976).

However, given the unusual manipulations, using all order combinations was not practical as participants would, for example, be stopping and starting chewing gum throughout the experiment. As such, a limited range of orders were allowed, which made it practical, thereby increasing ecological validity but still allowing a range of possible orders for counter-balancing (summarised in Table 3). More difficult to control are "demand effects", where participants guess what is being hypothesised and act accordingly – found to be more common in within-participants designs (Charness, Geezy, & Kuhn, 2012). For example, participants may have reported lower INMI on the more distracting tasks to fulfil their assumption of the research hypotheses.

Apart from the inherent limitations that computer laboratory experiments have for external validity and the attempts to make this research less contrived, it is necessary to consider the ecological validity, by evaluating the sample. Given ethical constraints, the sample consists of volunteers, so there is the definite possibility of self-selection bias. Indeed, the participants were interested in music (Figure 10 and Figure 11) and INMI, and thus may have been more prone to experiencing earworms (Figure 7). However, this may be to the study's advantage, as participants who experience more INMI are more suitable when INMI frequency is being induced.

Internationally, computer-based experimental research is increasingly popular, as it allows the experimenter a fine degree of control, recording accurate measurements, allowing complex within-participants random ordering and ensuring the delivery of multimedia stimuli remains fixed across conditions and participants (Stangor, 2011). As with any technology, there are certain requirements, that participants are not only English literate and test-wise but also computer literature. The university sample ensured this and thus limited the inherent bias in a computer-based experiments (Tourangeau et al., 2013), but this advantage limits the ecological validity of applying the results across the South African population. One of the benefits of computer-based research is that the researcher is not involved in data recording, which guarantees that participants' data remains anonymous and secure (Stangor, 2011).

Apart from the methodology and data collection method, the core measurement of INMI (a single 4-point Likert-type scale) is crucial to validity. While this scale is practical and its benefits were motivated in relation to previous measures, it also has limitations for statistical analyses. Firstly, the scale is not truly interval, although with repeated measurement (as in the pair comparisons), the scale approximates interval data. Secondly, the data was not normal, despite a reasonable sample size. The limited 4-point scale may also have influenced some of the smaller effect sizes that were found. Ultimately, this restricts the statistical validity, highlighting the difference between statistical and real-world significance.

Effective research relies on harmony of theory, design and measurement. Cognitive psychology has traditionally employed a modular approach to the mind, and the WM model exemplifies this in its segmentation of memory into distinctive, yet interrelated parts. As such, an ANOVA is the perfect design for considering these interactional relationships, and has common use in the non-INMI literature, especially for the inner ear and voice. Specifically, this makes the research unique in the consideration of these factors, whilst using WM as an integrative theoretical framework for INMI. However, the results also demonstrate that while a modular approach provides a neat theory, the reality can be messier, and manipulations are not always pure.

#### 5.3.2. Opening the 'Black Box' of INMI

Cognitive psychology, furthermore, seeks to quantify the internal, pulling objective measures out of the 'black box', and the internal event of INMI demonstrates this. Indeed, it brings INMI into the realm of experimental psychology by making this internal event measurable and inducing an involuntary phenomenon. The research demonstrates the use of the IMIS as a valid and reliability measure of INMI. Moreover, it contributes to the growing experimental research showing that INMI can be induced and manipulated in a laboratory. Given the prevalence of INMI and that it can be induced easily, it might be used experimentally in the field of musical and auditory imagery.

Apart from the INMI measurement's aforementioned implications for statistical validity, repeatedly measuring this first-person phenomenon is challenging. The INMI measurement does not act as a probe in that there is a level of predictability to the measurement, where many (e.g. Floridou et al., 2016) have argued that unexpected or hidden probing is required to capture instances of INMI and other forms of so-called mind-pops. The knowledge of the upcoming measurement automatically primes the mind and may increase sensitivity to INMI experiences. Still, while retrospective reports lack the accuracy of other reporting methods as they are biased to the effects of recall (Floridou & Müllensiefen, 2015), immediately retrospective reports should not suffer from this bias.

Previous experimental research has employed both brief and more intensive measurements, retrospective and concurrent measurement, but each has advantages and disadvantages. More generally, any measurement of INMI relies of a subjective report as it is a first-person experience. Asking a person to act as both observer and subject of INMI (or indeed any mental state) is challenging. Observing sensitises the individual to find what they are looking for, or disrupts the phenomenon in some way (e.g. by inducing unusually high levels of self-consciousness). This is especially true of a phenomenon that appears transient, moving in and out of awareness, and potentially subject to ironic effects. This places the experimenter in a double-bind, where participants may not be aware of INMI unless asked, but yet asking may disrupt the INMI, or create expectations that make it more likely. As such, future research might find creative ways to improve on the measurement of INMI in repeated-measures experiments, without the measurement activity becoming overly cumbersome, demanding or intrusive.

#### 5.3.3. Practical Implications

Apart from increasing theoretical understanding, real-world psychological applications can be extracted from this research and the field in general. Firstly, the results qualify Beaman et al.'s (2015) assertion of chewing gum as an earworm remedy, suggesting it may sometimes be ineffectual or even increase INMI. However, it does suggest tasks greatly engaging both the PL and EL may prevent earworms. These findings may be useful for those who suffer from more chronic forms of INMI (see Brown, 2006). Moreover, it suggests that even when a task is demanding, if the supervisory loop is employed, mind wandering and thus INMI, may be prevented from distracting the individual from the task. This could imply that with the right motivation, attention can be narrowed so that distractors are ignored, something that could be applied to the field of background music and more general distractors.

#### 5.3.4. Context

A unique strength of the research is that it is the first experimental INMI study on an African, or even non-Western sample. Although the present university sample is not entirely representation of South Africa, it provides initial insight into how INMI theory and measurements hold up in different populations. Still, the research is founded on literature from a new field that has not yet been applied in a South African context, so there is the possibility of cultural bias given the cross-cultural application. For example, the quantitative approach does not consider how earworms are viewed in South Africa (in particular, using the items of the IMIS presuppose a level of universality in the experience of earworms), or what cultural implications may be present in using a supposedly neutral song. Indeed, this may even be a critique of cognitive research in South Africa, which may tend to rely on untested assumptions about the nature of the mind. Specifically, the present theoretical framework drew on the WM model, predominantly formulated and tested in a Western context, and the distinction in WM components may not hold entirely in the South African population. Still, there is a small but growing field of literature on WM in the South African context (e.g. Cockcroft, 2015).

#### 5.3.5. Future Research

The present study has made use of a variety of instruments and procedures (some novel, some existing, and others adapted) that may be fruitfully used in future research on INMI. The study adds to the growing reports on the reliability and validity of the IMIS as a comprehensive measure of INMI, so future studies would benefit from using it. The earworm induction procedure was largely successful in inducing earworms (at least overall), and combined many theoretical principles and previously employed procedures. The study contributes to growing INMI induction experiments, offering and expanding methodologies and instruments that may be employed in future research. Specifically, the ANT was effectively used for manipulating attention. As the ANT uses visual material, it is a suitable tool for manipulating attention in the context of auditory imagery, as it should not interfere with the PL. The ANT is also computer-based, making it easy to administer and score.

A major finding was that chewing gum can actually facilitate an earworm during low attentional load and in silence. This is in opposition to Beaman et al.'s (2015) finding with participants also chewing gum. It further contrasts the indirect inner voice suppression by Hyman et al., (2013) which also decreased INMI and without inner voice interacting with attentional load, unlike the present study. There are obvious differences in the range of operationalisation and manipulations of WM components, but Beaman et al. (2015) also had participants supress INMI, which makes experimental conditions difficult to compare. While the facilitative effect of gum has support in the cognitive literature (Kozlov et al., 2012), the present result and speculative hypothesis about the rhythmic chewing of gum (counteractive to its suppressive effect on the inner voice) still requires further consideration. Specifically, the effect of rhythmic interference that does not affect the PL (e.g. tapping at an alternate tempo to the song) on INMI could be tested.

Although the present study did not find that all three mechanisms interacted (i.e. there was no 3-way interaction), there was at least support that the EL and the PL play a role in INMI. Still, this is limited by uncertainty that the manipulations were 'pure', so it is not certain how the EL and PL interact and if both or only one account for INMI. Therefore, future research should confirm the present study's results by using alternative methods for suppressing the inner ear and voice, which do not facilitate INMI or use attentional resources, to assess the role of the PL and EL in sustaining earworms.

The one aspect of WM which the study did not directly address was the issue of ironic control and the suppression of INMI. Although the three refreshing mechanisms were supressed externally (i.e. by the attentional demands, Leco speech and chewing gum), there was no instruction for participants to intentionally supress INMI, as in Beaman et al.'s (2015) experiments. As such, it would be interesting to see whether the present study's results held when there was a suppression instruction. This is particularly interesting given the application of Hockey's (1995) model, to suggest that the supervisory loop effectively blocks distractors and allows the individual to focus on the task. Ironic control suggests that there may be instances where attempting to do this creates ironic effects and increases earworms. It would be fruitful to assess what mechanism Hockey's supervisory loop might employ in preventing INMI being a distraction that is not susceptible to ironic effects of the monitoring process, and how attention demanding this mechanism is.

Lastly, auditory and musical imagery has increasingly become an area of neurological study (e.g. Herholtz, Lappe, Knief & Pantev, 2008; Zatorre & Halpern, 2005) and this has extended to studying what happens in the brain when gaps of silence are inserted into a song but continue playing in the mind (Janata, 2001; Kraemer, 2005). Currently, only a single study has looked at the neural correlates of INMI using the IMIS (Farrugia, Jakubowski, Cusack, & Stewart, 2015). Given the subjective nature of INMI and the difficulty in ascertaining whether WM components are supressed, neurological research (e.g. functional magnetic resonance imaging) could find neural patterns or structures that correspond to the inner voice, inner ear and attentional refreshing, the supervisory loop or even to the experience of INMI.

### 5.4. Conclusion

The present report and findings have augmented the field of INMI in several ways. Firstly, the literature review presented the author's integrative theoretical model, which used various facets of WM as an underlying framework to synthesise a range of results from the extant literature. This theoretical framework provided potential cognitive mechanisms to explain many findings while also holistically describing how an earworm occurs and is sustained. Moreover, the theoretical framework proposed several isolable mechanisms which could act independently or in interaction. The current research has attempted to address three of these mechanisms, but the literature review suggests further research should test the theoretical assumptions.

Methodologically, the report demonstrates many of the difficulties of inducing and measuring an internal experience such as INMI, but also potential methods for overcoming these challenges. The study advocates for the use of the IMIS scale and induction procedure, while highlighting the difficulty in finding ‘pure’ manipulations of WM components and also in determining the extent to which they are pure. In its design, the study adds to the experimental literature, but is the first in the INMI field to use a repeated-measures and factorial experimental format, and further research using similar designs with strong internal validity is recommended.

The findings discussed provide prima facie evidence for the use of the PL and EL in sustaining INMI, but it is less clear to what extent they are isolable. Indeed, the lack of a second-order interaction suggests a more complex picture, where all three mechanisms interact, but not with each and every other mechanism (i.e. only two out of three potential interactions). While the importance of attention and the EL was highlighted, the results point towards consideration of Hockey’s (1995) theory of the supervisory loop, in conjunction with mind wandering as a mediator. A greater dissimilarity was that chewing gum was found to facilitate INMI when there is decreased attentional load and no foreign speech, possibly due to the rhythmic chewing of gum. Overall, this suggests that under attentional load and with distractors, the use of the supervisory loop decreases INMI, yet it increases during difficult tasks but without distractors during mind wandering and is equally facilitated by chewing gum.

Ultimately, this research raises as many questions as it answers, adding complexity to a field by focusing on multiple interacting variables within an integrative framework, rather than a single mechanism manipulated experimentally or a purely descriptive and explorative non-experimental approach. While many of the findings support growing trends in the field, other results give alternative perspectives that future research should address. Moreover, this report demonstrates the usefulness of new experimental research that contributes to a growing field by applying and testing cognitive theory. Finally, in the application of established WM theory to the newly emerging field of INMI, this report supports the role of the EL and PL, while also suggesting a more complex picture of both WM and INMI.

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# Appendices

*Table of Appendices*

## **Appendix A** : Participant Recruitment Survey

Hello, my name is Thomas Geffen, a Psychology Masters student, being supervised by Michael Pitman. This survey serves to gain information from you as a potential participant, in order to email to arrange a time to participate in the study, which will take place at Wits Main Campus. This survey does constitute the survey itself. The information below details the study:

We are conducting a study looking at musical imagery – experiences of music 'in your head' that do not come from an external source in your current environment – and, in particular, some of the circumstances that might give rise to experiences of musical imagery. Participation in this study will involve completing a small number of computer-based tasks. The tasks involve music, lyrics, and your experiences of musical imagery. During various points of the task, you will hear a song as well as a recording of someone speaking in a foreign language, and be asked to chew gum. Completing this laboratory session should take a maximum of 25-35 minutes. Participation is entirely voluntary, and no one will be advantaged or disadvantaged for choosing to participate or not. First year Psychology students will be able to claim course credit for research participation and all participants, as token of thanks for the time taken to attend and complete the lab tasks, will be able to enter a draw for a prize (over-ear Philips SHP2000 headphones, or similar).

* 1. Please enter your email address below (your email address will only be used for communication about the experiment):

☐

2. Add an optional alternative email address below:

☐

You will now be asked to list times that you are generally available during each week. If you are not able to give times, the researcher will email you to discuss available times to come - in this case please skip the next section and click 'Done" at the end. Alternatively, if you give available times the researcher will contact you to confirm a time.

3. What times are you generally available?

| | 8-9 | 9-10 | 10-11 | 11-12 | 12:15-1:15 | 1:15-2:15 | 2:15-3:15 | 3:15-4:15 |
|---|---|---|---|---|---|---|---|---|
| Monday | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Tuesday | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Wednesday | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Thursday | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Friday | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

**Appendix B :** Proposal Approval Letter

**University of the Witwatersrand, Johannesburg**

**Faculty of Humanities – Postgraduate Office**

Private Bag 3, Wits 2050, South Africa • **Tel:** +27 11 717 4002• **Fax:** +27 11 717 4037• **Email:** Sarah.Mfupa@wits.ac.za

Student Number: 601640

Mr Thomas Geffen
7 Ash Street
Houghton
Johannesburg 2198
Gauteng South Africa

18 August 2016

Dear Mr Geffen

**APPROVAL OF PROPOSAL FOR THE DEGREE OF MASTER OF ARTS IN COMMUNITY-BASED COUNSELLING PSYCHOLOGY**

I am pleased to be able to advise you that the readers of the Graduate Studies Committee have approved your proposal entitled "*Earworms and working memory".* I confirm that Dr Michael Pitman has been appointed as your supervisor in the School of Human and Community Development.

The research report is normally submitted to the Faculty Office by 15 February, if you have started the beginning of the year, and for mid-year the deadline is 31 July. All students are required to RE-REGISTER at the beginning of each year.

You are required to submit 2 bound copies and one unbound copy plus 1 CD in pdf (Adobe) format of your research report to the Faculty Office. The 2 bound copies go to the examiners and are retained by them and the unbound copy is retained by the Faculty Office as back up.

Please note that should you miss the deadline of 15 February or 31 July you will be required to submit an application for extension of time and register for the research report extension. Any candidate who misses the deadline of 15 February will be charged fees for the research report extension.

Kindly keep us informed of any changes of address during the year.

**Note**: All MA and PhD candidates who intend graduating shortly must meet your ETD requirements at least 6 weeks after your supervisor has received the examiners reports. **A student must remain registered at the Faculty Office until graduation.**

Yours Sincerely

*SD Mfupa*

Sarah Mfupa
Postgraduate Division
Faculty of Humanities
Private Bag X 3
Wits, 2050

**Appendix C** : Informed Consent

Hello,

My name is Thomas Geffen, a Psychology Masters student, being supervised by Michael Pitman from the Psychology Department at the University of the Witwatersrand. We are conducting a study looking at musical imagery – experiences of music ‘ in your head’ that do not come from an external source in your current environment – and, in particular, some of the circumstances that might give rise to experiences of musical imagery. Participation in this study will involve completing a small number of computer-based tasks. The tasks involve music, lyrics, and your experiences of musical imagery. During various points of the task, you will hear a song (“Just the Way You Are” by Bruno Mars) as well as a recording of someone speaking in a foreign language, and be asked to chew gum. Should you not feel comfortable or safe completing any of these activities, or are concerned about any allergic reaction to the gum, please do not complete the experiment. Completing this laboratory session should take a maximum of 25-35 minutes.

Participation is entirely voluntary, and no one will be advantaged or disadvantaged for choosing to participate or not. First year Psychology students will be able to claim course credit for research participation and all participants, as token of thanks for the time taken to attend and complete the lab tasks, will be able to enter a draw for a prize (over-ear Philips SHP2000 headphones, or similar). This will be done by completing an entirely separate survey form at the conclusion of the lab task. There are no other direct benefits or risks to participants anticipated from participation in this part of the study.

In this study, you will be interacting with one or more of us during lab session itself. As such, your participation is not entirely anonymous. We will ask you to construct a participant code (using your initials and part of your student number) in order to connect responses to previous survey responses, but this participant code is insufficient to uniquely identify you, and no effort of any kind will be made to use it to identify you. As such, all data that you submit for the study will be and will remain anonymous. However, none of the tasks involve identifying information, and at no point will your responses to these tasks be linked to your name or any other identifying information about you. Your responses to the lab tasks will not be seen by anyone other than us (the researchers) and your responses will be saved in a neutral and secure database which is password protected, or a computer than is password protected. The data will be deleted after a maximum of 6 years. Thus, your confidentiality is guaranteed.

Your responses will only be looked at in relation to all other responses, which means that feedback and publications resulting from this project will be in the form of group trends and not individual responses. A summary of the results will be made available to you on request (via email – see contact details below), and on the research blogsite set up for this purpose (http://mmpresearch.blogspot.com). The research may also be published online, in journals or presented at conferences.

Your response to the question below, along with the completion of the tasks and submission of your responses will be taken as your consent to participate in this study. You may withdraw from the lab session at any point before pressing the "Done" button on the final page of the online instrument – all incomplete task responses will be excluded from the study.

Thank you for considering this invitation. Your participation in this study would be greatly appreciated. Best regards, Thomas Geffen– Masters in Psychology (thomas.geffen@students.wits.ac.za) Dr Michael Pitman – Senior Lecturer, Psychology (michael.pitman@wits.ac.za)

1. I have read the information about this study and consent to take part in this research.

◯ Yes

◯ No

## **Appendix D** : Demographics and Musicality Form

2. In order to connect your information with other responses in this experiment, we would ask you to please construct a unique identifying code that we can use to link your responses without providing us with any information that could be used to identify you.

In the box provided below, please use the following information to construct your identification code (as in the example we have provided):
1. The first letter of your NAME
2. The first letter of your SURNAME
3. The last FOUR numbers of your student number

Example:
Name - Grace
Surname - Nkomo
Student Number - 546897
Unique Identifying Code - GN6897

Your Unique Identifying Code: ______

3. What is your age (in years)?

______

4. What is your gender?

- ◯ Female
- ◯ Male
- ◯ Prefer not to answer

Other (self identification - please specify)

______

5. What is your home language? (please choose only one)

- ◯ Afrikaans
- ◯ English
- ◯ isiNdebele
- ◯ isiXhosa
- ◯ isiZulu
- ◯ Sesotho sa Leboa
- ◯ Sesotho
- ◯ Setswana
- ◯ siSwati
- ◯ Tshivenda
- ◯ Xitsonga

Other (please specify)

[ ]

6. Please indicate your level of proficiency in the South African official languages:

| | None | Beginner | Intermediate | Fluent |
|---|---|---|---|---|
| Afrikaans | ◯ | ◯ | ◯ | ◯ |
| English | ◯ | ◯ | ◯ | ◯ |
| isiNdebele | ◯ | ◯ | ◯ | ◯ |
| isiXhosa | ◯ | ◯ | ◯ | ◯ |
| isiZulu | ◯ | ◯ | ◯ | ◯ |
| Sesotho sa Leboa | ◯ | ◯ | ◯ | ◯ |
| Sesotho | ◯ | ◯ | ◯ | ◯ |
| Setswana | ◯ | ◯ | ◯ | ◯ |
| siSwati | ◯ | ◯ | ◯ | ◯ |
| Tshivenda | ◯ | ◯ | ◯ | ◯ |
| Xitsonga | ◯ | ◯ | ◯ | ◯ |

7. What terms (e.g. labels, groups, associations/affiliations, heritage) would you use to describe your cultural background? (please enter only one term per box)

1 [ ]

2 [ ]

3 [ ]

4 [ ]

8. How frequently do you listen to music?

- ○ Less than an hour a day
- ○ 1-2 hours a day
- ○ 2-3 hours a day
- ○ More than three hours a day

9. How interested are you in music?

- ○ Not at all
- ○ A little
- ○ Somewhat
- ○ Very much

10. Do you experience any hearing difficulties?

- ○ Yes
- ○ No

If Yes, please specify

| |
|---|
| |

# **Appendix E** : IMIS

**Sometimes having a tune stuck in your head is referred to as "having an earworm".**

**An earworm is a short section of music that comes into your mind without effort (it is involuntary; i.e. it comes even though you did not have any intention to retrieve or remember the music) and then repeats by itself spontaneously (i.e. without you consciously trying to replay the music) at least once, on a loop. It may have words or it may just be a melody or a rhythm.**

**The items that follow are used to study this experience of having an earworm. The scale consists of 18 items. You may find that there is some overlap with questions you have already answered about involuntary musical imagery. Please try to focus your answers in this section on your experience of earworms, as just defined. If useful, please refer back to the definition of an earworm.**

11. Please complete the following statement:

On average, I experience earworms ____________.

- ◯ Never
- ◯ Once a month
- ◯ Once a week
- ◯ Several times a week
- ◯ Several times a day
- ◯ Almost continuously

---

12. For each of the following items, please choose the response that best describes your earworm experience:

| | Always | Most of the time | Sometimes | Not very often | Never |
|---|---|---|---|---|---|
| I try hard to get rid of my earworms | ○ | ○ | ○ | ○ | ○ |
| It worries me when I have an earworm stuck in my head | ○ | ○ | ○ | ○ | ○ |
| I find my earworms irritating | ○ | ○ | ○ | ○ | ○ |
| My earworms agitate me | ○ | ○ | ○ | ○ | ○ |
| The experience of my earworms is unpleasant | ○ | ○ | ○ | ○ | ○ |
| I wish I could stop my earworms | ○ | ○ | ○ | ○ | ○ |
| When I get an earworm I try to block it | ○ | ○ | ○ | ○ | ○ |
| The rhythms of my earworms match my movements | ○ | ○ | ○ | ○ | ○ |
| The way I move is in sync with my earworms | ○ | ○ | ○ | ○ | ○ |
| When I get an earworm I move to the beat of the imagined music | ○ | ○ | ○ | ○ | ○ |
| My earworms result from unresolved matters | ○ | ○ | ○ | ○ | ○ |
| Personal issues trigger my earworms | ○ | ○ | ○ | ○ | ○ |
| The content of my earworms mirrors my state of worry or concern | ○ | ○ | ○ | ○ | ○ |
| I find my earworms help me focus on the task that I'm doing | ○ | ○ | ○ | ○ | ○ |
| Earworms help me when I'm trying to get things done | ○ | ○ | ○ | ○ | ○ |

13. On average, my earworm (the section of music that is stuck) lasts:

- ○ Less than 5 seconds
- ○ Between 5 and 10 seconds
- ○ Between 10 and 30 seconds
- ○ Between 30 seconds and 1 minute
- ○ More than 1 minute

14. On average, one earworm episode (a period of time when one particular tune gets stuck) lasts:

- ○ Less than 10 minutes
- ○ Between 10 minutes and half an hour
- ○ Between half an hour and 1 hour
- ○ Between 1 and 3 hours
- ○ More than 3 hours

**Appendix F** : Induction Procedure Tasks

***PITCH DIFFERENTIATION TASKS***

In the following three tasks, you will be asked to compare the note or pitch at which each of the capitalised words/lyrics is sung.
Each line comes from the song you have been listening to ('Just the way you are' by Bruno Mars).
Please try to decide whether one word is sung higher (that is, has a higher pitch/ is sung at a higher note) than the other, or if they are sung at the same pitch. Please complete the task WITHOUT singing or humming the song.
JUST the WAY you are

- ○ JUST is higher than WAY
- ○ WAY is higher than JUST
- ○ They are the same
- ○ Not able to judge/decide

There's not a thing that I WOULD CHANGE

- ○ WOULD is higher than CHANGE
- ○ CHANGE is higher than WOULD
- ○ They are the same
- ○ Not able to judge/decide

And WHEN you SMILE

- ○ WHEN is higher than SMILE
- ○ SMILE is higher than WHEN
- ○ They are the same pitch
- ○ Not able to judge/decide

***COMPLETING LINES***

Please try to complete the NEXT two lines of lyrics/words that FOLLOW the extract you have just heard.

Try to remember or replay relevant part of the song 'in your head', and write down whatever words you can, using '...' for any words or parts of the lines you are unsure of.

***COUNTING LINES***

Please count how many words were in the extract you just listened to.

**Appendix G**: Self-Reported INMI Frequency

**How frequently did you experience a song 'in your head' during the task?**

o Not at all

o Infrequently

o Frequently

o Most of the time

**Appendix H** : Follow-Up Questions

15. Overall, how distracting did you find chewing the gum?

- Not at all
- A little
- Somewhat
- Very much

**MI ANT 2016**

16. Overall, how distracting did you find hearing the foreign voice?

- Not at all
- A little
- Somewhat
- Very much

**MI ANT 2016**

17. Would you be willing to participate in future research linked to this study?

- Yes
- No

## **Appendix I** : Compensation Survey

**You have now been redirected to a different survey site that is not connected to the questionnaires you have just completed.**

**Here, you will have an opportunity to provide personal details that will enable you to earn research participation credits (Psychology I students) and to enter a lottery draw for a prize (a set of over-ear headphones).**

**Please note that, because this is a separate survey, there is no way to connect the information you provide here with your responses to the previous questionnaires. All of your previous responses will remain entirely anonymous.**

1. Are you currently registered for Psychology I (PSYC1009 or PSYC1010)?

◯ Yes

◯ No

**MI ANT 2016 Follow-UP**

2. Students currently registered for Psychology I can claim course credit for research participation by entering their names and student number in the space provided below, as required by the Psychology I Student Research Participation Programme.

Please note that this information is provided ONLY in order to claim course credit. No attempt will be made to identify any participants, nor to link any responses you have provided in the other survey to your identity. Once the list of names and student numbers has been extracted, it will be deleted from this survey. Your anonymity of responses is thus ensured.

Surname: ________

Name: ________

Student/ Person Number: ________

3. As a token of appreciation for your participation in this research, we would like to offer you the opportunity to enter into a lottery prize draw for one set of Philips over-ear headphones.

If you would like to be entered into this prize draw, please provide the following details to enable us to contact you should you be the lucky winner:

Surname: ________

Name: ________

Preferred email address: ________