Effects of Long Term Memory on Auditory Spatial Attention

by

Jacqueline Zimmermann

A thesis submitted in conformity with the requirements for the degree of Master of Arts (MA)

Psychology
University of Toronto

© Copyright by Jacqueline Zimmermann 2014
Effects of Long Term Memory on Auditory Spatial Attention

Jacqueline Zimmermann

Master of Arts
Psychology
University of Toronto
2014

Abstract

We examined how associations between real world auditory scenes and the location of an embedded auditory target influence spatial attention after a delay period. Healthy young adults (N= 16) formed strong memories for spatial locations of targets within sound scenes, which biased attention one hour later. Participants showed gains in reaction time (100ms) and accuracy (12% increase) to locate targets proceeded by valid memory cues (scenes for which target-context associations were formed) compared to neutral cues. We also found a positive relationship (r =.55, p <.05) between memory for target location and attentional orientation across participants. Preparatory and target-related AEFs were measured using magnetoencephalography to identify memory-guided attentional shifts. However, neither a source analysis nor analysis of global field power captured changes in brain activity. Despite the null MEG findings, strong behavioural effects provide some of the first direct evidence for effects of auditory LTM on deployment of spatial attention.
Acknowledgments

Thank you so much to Claude Alain, my supervisor, for all your help and guidance throughout the project. I have learned a lot this year, it’s been a great journey. Thank you for always being so kind and understanding, it’s really been a pleasure working with you. You’re the best supervisor I could have asked for. I also want to thank everyone at the Alain lab for helping me out, I especially want to thank Jeff Wong for his great help with setting up the experiment. Thank you also to Morris Moscovitch for his valuable input and feedback throughout the year.
# Table of Contents

Acknowledgments........................................................................................................................................................................

Table of Contents.............................................................................................................................................................................

List of Figures..................................................................................................................................................................................

List of Appendices..............................................................................................................................................................................

1 Introduction.........................................................................................................................................................................................
   1.1 Visual memory effects on perception and attentional orientation..........................................................
   1.2 Auditory memory: similarities and differences with visual memory..............................................
   1.3 Auditory memory and attention....................................................................................................................
   1.4 The current study: effect of long term memory on auditory spatial attention..........................
   1.5 Summary of objectives and hypotheses.................................................................................................

2 Methods.........................................................................................................................................................................................
   2.1 Participants..........................................................................................................................................................
   2.2 Sound stimuli...........................................................................................................................................................

3 Experimental procedure....................................................................................................................................................................
   Overview..................................................................................................................................................................................
   3.1 Determining individual signal-to-noise 80% detectability thresholds..............................................
   3.2 Learning task..........................................................................................................................................................
   3.3 Explicit spatial memory recall task..................................................................................................................
   3.4 Testing task (examining memory-guided modulation of attention)..................................................

4 Analyses........................................................................................................................................................................................
   4.1 MEG data acquisition and analyses..............................................................................................................
      4.1.1 Source analysis..............................................................................................................................
      4.1.2 Global field power analysis........................................................................................................
   4.2 Statistical analyses: behavioural data........................................................................................................
4.2.1 Learning task........................................................................................................................................

4.2.2 Explicit spatial memory recall task........................................................................................................

4.2.3 Testing task........................................................................................................................................

5 Results........................................................................................................................................................

5.1 Formation of associations between complex acoustic scenes and the location of an auditory target: Learning task........................................................................................................................................

5.2 Memory for auditory target-context associations: Explicit spatial memory recall task
........................................................................................................................................................................

5.3 Memory guided modulation of auditory spatial attention: Testing task.............................................

5.3.1 Behavioural results............................................................................................................................

5.3.2 MEG results........................................................................................................................................

6 Discussion..................................................................................................................................................

6.1 Formation of long term associations between an auditory target and complex acoustic scenes
...................................................................................................................................................................

6.2 Memory guided modulation of auditory attention.............................................................................

7 Limitations, future directions, and conclusions..................................................................................

References....................................................................................................................................................

Appendices..................................................................................................................................................
List of Figures

Figure 1. Stimulus presentation for one trial in the testing task

Figure 2. Source locations for the surrogate model

Figure 3. Formation of auditory target-context memory associations: gains in a) reaction time and b) accuracy to detect the auditory target over time

Figure 4. Memory guided modulation of spatial attention: memory based gains in reaction time to detect the auditory target

Figure 5. Relationship between memory for target location and attentional orientation

Figure 6. Auditory evoked fields elicited by memory cue (S1: first presentation of the auditory scene) with accompanying magnetic field topographies

Figure 7. Auditory evoked fields elicited by memory cue and auditory target (S2: second presentation of the auditory scene) with accompanying magnetic field topographies

Figure 8. Source waveforms representing neuromagnetic responses to the auditory scene (S2) and embedded target

Figure 9. Source waveforms representing response related activity to locate the target tone within auditory scenes

Figure 10. Global field power associated with memory cue and auditory target
List of Appendices

Appendix A: List of Auditory Scene Clips Used
1 Introduction

In the fields of cognitive psychology and cognitive neuroscience, attention and memory are two important and highly studied concepts. In recent years, there has been a shift away from studying these two processes in parallel, as there is an increasing interest in understanding how memory and attention interact with one another. The majority of research and related theoretical frameworks focus on how attention influences what is effectively encoded, stored and retrieved from memory (Ciaramelli, Grady, Levine, Ween, & Moscovitch, 2010; Dulas & Duarte, 2013; Silva, Groeger, & Bradshaw, 2006). However, comparatively few studies have been dedicated to the reverse relationship between the two concepts – that is, how memory can influence attention.

Yet, the impact of past experience on shaping perception has been acknowledged for hundreds of years. For example, Hermann von Helmholtz, an important pioneer of modern science, described perception as arising from a combination of an external stimulus and judgements we make about the stimulus based on knowledge gained through experience (von Helmholtz, 1867). The limited number of experimental studies that do examine memory effects on attention focus on investigating the relationship within the visual modality.

In fact, no study to date has provided comparable and direct evidence that memory for auditory stimuli influences subsequent biasing of auditory attention. Yet, in everyday life, auditory memory often appears to play an important role in guiding attention towards sound objects in our environment. For instance, in a noisy gathering, our attention is often drawn toward a familiar voice of a friend or family member (Holeckova, Fischer, Giard, Delpuech, & Morlet, 2006). At home, the ringing of a telephone or sound of a car in the driveway may capture attention, especially if it indicates a highly anticipated visit.

Early work on auditory selective attention conducted by Moray (1959) provides some of the first experimental evidence that familiar sound object strongly encoded in memory (such as our own names) can bias attention and enhance perceptual sensitivity. For example, when presented with two separate narratives, listeners are often distracted when they hear their name presented within the task-irrelevant auditory stream. More recent work has demonstrated that strong familiarity with voices can not only aid in perception of the familiar stimulus (e.g., tracking a familiar voice among distractors), but can also enhance perception of other stimuli (e.g., effective ignoring of a
familiar voice) (Johnsrude, Mackey, Hakyemez, Alexander, Trang & Carlyon, 2013). Although Moray's (1959) research, and more recent related experiments (Holeckova et al., 2006), indicate that auditory memory strongly influences perception, very few studies have examined the direct effect of auditory memory on attention. One area of related investigation that has received some attention in recent years is the role of working memory (WM) in auditory selective attention. Current theories suggest that higher WM load increases interference by task-irrelevant distractor stimuli thereby reducing our ability to attend selectively to auditory objects (Dalton, Santangelo, & Spence, 2009; Sörqvist, Stenfelt, & Rönnberg, 2012). However, these studies have only examined the effects of WM load, rather than content of WM, on attentional processes.

The influence of long term memory (e.g., one hour) on auditory attention remains largely unexplored. Compared to the auditory domain, a significant amount of research has been dedicated to investigating how long term memory for target characteristics (e.g., location) of visual stimuli influences subsequent biasing of attention (Patai, Doallo, & Nobre, 2012; Summerfield, Rao, Garside, & Nobre, 2011; Woodman & Chun, 2006). Although, the mechanisms underlying visual and auditory memory are likely to be similar (Bigelow & Poremba, 2012; Snyder & Gregg, 2011), it remains to be determined whether auditory memory would influence attention in a similar fashion as visual memory.

Evidence from visual studies suggests that participants are able to memorize the location of targets within visual scenes, which can then help them in orienting attention towards learned target locations. These learning effects can last up to twenty-four hours (Patai et al., 2012; Summerfield et al., 2011). In other words, memory for a visual target location increases perceptual sensitivity to remembered locations, which occurs both in terms of faster response times and enhanced electrophysiological activity for targets presented in learned spatial contexts (Patai et al., 2012). However, the interaction between memory and attention may differ for auditory stimuli since the nature of auditory memory itself differs from visual memory due to: less experience with remembering auditory objects, and also because auditory memory is largely verbal in nature (Snyder & Gregg, 2011). Based on a detailed review of similarities and differences between visual and auditory memory (Snyder & Gregg, 2011), we developed a modification of the experimental design used by parallel visual studies (Patai et al., 2012; Summerfield et al., 2011). The current study is the first to examine the direct effects of auditory memory on deployment of attention and enhancement of perceptual sensitivity to sound stimuli.
1.1 Visual memory effects on perception and attentional orientation

Numerous studies using various experimental paradigms have demonstrated the effects of memory-guided allocation of attention using visual stimuli. Examining the more well developed field of visual memory and attention can inform our understanding of parallel auditory processes, and provide a framework for developing a related paradigm using auditory stimuli.

Using a visual search task, Chun and Jiang (1998) showed that long term memories can guide orientation of visuo-spatial attention. In their study, when the spatial arrangement of distractor stimuli was repeated from a previous trial, participants were faster at detecting a target stimulus within the array, suggesting that implicit memory acquired earlier in the experiment influences deployment of attention. This orienting effect of remembered target locations during visual search has been labelled “contextual cueing” by its pioneers. Since then, many studies have produced evidence for both improved behavioural performance (e.g., Jiang & Leung, 2005) and modulation of brain activity (Chaumon, Hasboun, Baulac, Adam, & Tallon-Baudry, 2009) associated with contextual cueing. Although contextual cueing experiments have provided a strong theoretical foundation for understanding long term memory effects on allocation of attention, there are several limitations of these studies. In visual search tasks, target stimuli are presented within distractor arrays, making it difficult to disassociate target elicited processes, such as decision making, stimulus-driven attentional changes, and response selection, from activity elicited by memory cues. It is possible that improved performance for targets appearing within previously presented contexts was not a result of contextual cueing in these experiments, but rather occurred as a result of facilitation of response related processes (Schankin & Schubö, 2009). Furthermore, the paradigms used to examine contextual cueing rely on artificial and simple visual stimuli rather than ecologically relevant stimuli, such as complex visual scenes, calling into question whether the results are generalizable to real world visual experiences.

Since the birth of contextual cueing, many novel paradigms have been used which address the limitations of earlier experiments, and provide more direct and ecologically relevant evidence for the influence of memory on attentional orientation. These experiments also provide insight into the relationship between implicit memory-guided attention and more explicit remembering of
target-context associations. For example, Ciaramelli, Lin, and Moscovitch (2009) showed that the automatic facilitating effect of memory on biasing of attention may be related to subjective memory for contextual cue stimuli, but not related to objective contextual memories. They developed a memory task where seeing a word or picture stimulus originally viewed on one side of space automatically biases attention towards that location. Specifically, participants learned the location (right or left) of a set of word or picture stimuli during a learning task. Subsequently, during a testing phase, either a familiar or new word/picture stimulus was presented centrally, and one second later, a dot appeared on one side of the screen. The target location was either congruent with the word/picture or incongruent. The main question was whether contextual memories for the location of the word/picture would bias attention toward remembered locations. Ciaramelli et al. (2009) found that participants indeed responded more quickly to targets in congruent than incongruent trials, providing further evidence for the automatic facilitating effect of contextual memory retrieval on orientation of attention. Moreover, the degree to which memory retrieval captured attention was related to subjective reports of memory strength, but not to objective recollection of spatial context. Specifically, subjective indicators were assessed by participants' reporting on the degree to which they felt they were re-experiencing the encoding context during retrieval. They were presented with previously viewed word or picture stimuli located either at the same or different location from spatial context at encoding (during the learning phase), and asked to indicate whether they remembered the location of the stimulus, or whether they were merely familiar with the stimulus without being aware of its spatial context (right or left side). Objective indicators of memory strength were taken by asking participants to explicitly recall where each word/picture stimulus was located at encoding. Based on the results, it appears that while explicit memory for encoding context does not interact with memory-guided attentional capture, more implicit feelings of re-experiencing of encoding context are indicative of memory retrieval effects on attentional change.

A group of related research conducted by Summerfield et al. (2011) and Patai et al. (2012) has focused on identifying the effects of long term memory on biasing perceptual sensitivity for targets embedded in photographs of outdoor and indoor scenes, such as a river scene or the interior of a house. The paradigms used by both groups of researchers allowed for a disassociation of cue-related preparatory processes and target-related activity by separating presentation of the target from the presentation of scenes guiding contextual memories for target
location. These studies demonstrated that retrieval of contextual memories bias preparation and
target selection within cluttered scenes up to twenty-four hours after contextual memories are
acquired. Furthermore, the experiments conducted by Summerfield et al. (2006, 2011) and Patai
et al. (2012) served as a foundation for the development of an appropriate, related paradigm for
the investigation of auditory memory effects on spatial attention.

In Summerfield et al. (2011), participants were first given the opportunity to familiarize
themselves with complex visual scenes, presented multiple times over learning blocks. Half of
the scenes contained a small target key stimulus embedded anywhere within the scenes, half did
not contain a target. Participants were instructed to explore each scene, detect and learn the
location of the target key stimulus, or indicate no key was present in target-absent scenes. The
training phase aimed to facilitate the association between visual scenes and target location. By
the end of training, participants acquired a strong contextual memory for the location of the
target within target-present scenes (valid scenes), while no specific target-context associations
were formed for the target-absent scenes (neutral scenes). Twenty-four hours later, participants
returned to complete a memory-guided attention orienting task. During this orienting task,
participants were cued with previously viewed scenes (with no target present), and following a
brief interstimulus interval (ISI), the target key was briefly overlaid upon each scene.
Participants detected the presence of the target key stimulus by pressing a button. They were
faster in responding to targets presented within learned spatial contexts. In other words, pre-
exposure to scenes which had previously contained a target provided valid memory cues which
served to guide attention towards the remembered location of the target key. Moreover, an
explicit memory task that required participants to recall the location of the target key within each
scene indicated that participants had indeed formed strong contextual memories for the key
within scenes.

Summerfield et al. (2011) and Patai et al. (2012) also recorded event-related potentials (ERPs).
They identified both preparatory memory-cue related changes in ERPs as well as modulation of
perceptual ERP responses to target stimuli. The preparatory activity was seen during the inter-
stimulus interval separating the presentation of the cue scene (S1) and the target stimulus (S2)
during the testing phase. This cue-target paradigm served to disassociate top-down preparatory
processes related to memory-guided biasing of attention (cue-related activity) from modulation
of perceptual responses to the target by these biases (target-related activity) (Patai et al., 2012).
To identify memory-guided biasing of attention, Summerfield et al. (2011) compared activity elicited by valid memory cues with the activity elicited by scenes which were not associated with a specific target location (neutral scenes). They reported differences in spatial biases between valid and neutral scenes during later stages of processing, with activity lateralized contralateral to the anticipated target location for valid cues. Moreover, non-lateralized effects of memory cues were also found by both Summerfield et al. (2011) and Patai et al. (2012), with valid memory cues eliciting greater negativity over midline electrodes, and more positive sustained potential over posterior regions.

In addition to generating spatial biases in neural activity in anticipation of a target stimulus, long term memories for target location within scene contexts also enhanced perceptual sensitivity to the target stimulus (target-related activity). In a modification of the paradigm developed by Summerfield et al. (2011), Patai et al. (2012) used a more challenging perceptual discrimination task which allowed for a better investigation of whether memory-guided attention can improve perceptual sensitivity to targets. In particular, Summerfield et al. (2006, 2011) used transient targets that were easily detectable and required only a quick and simple detection process, which, therefore, made it difficult to examine memory effects on modulation of perceptual sensitivity to targets. Patai et al. (2012) addressed this limitation by increasing the difficulty of target detection during the orienting task by instructing participants to search for targets within scenes using only covert attention. With a more challenging discrimination task, Patai et al. (2012) were able to test memory-guided attentional orientation effects on improving perceptual sensitivity to detect targets and participants' ability to locate their presence within the scene. The ERP analysis focused on the N2pc component, which is thought to reflect selective attention to targets in visual short-term memory arrays (Kuo, Rao, Lepsien, & Nobre, 2009), compared between the two memory-cue conditions. The amplitude of the N2pc was modulated by memory-cue, with the N2pc being significantly attenuated for targets presented within valid scenes as compared to targets appearing within neutral scenes, indicating a long term memory effect on processes related to target sensitivity and selection. Summerfield et al. (2011) also reported greater P100 amplitude in response to targets embedded within scenes that served as valid memory cues compared to neutral scenes. Both P100 and N100 responses were lateralized contralateral to the field of presentation, and memory-guided orientation also affected latency of the N100 response,
with targets within valid memory cue scenes resulting in shorter latencies than targets embedded within neutral scenes which had no association with a specific target location.

In summary, visual long term memory can bias attention and enhance perceptual sensitivity, providing a theoretical foundation for the investigation of similar effects in the less-studied field of auditory memory and attention. An examination of auditory memory and attention, and how these differ from visual processes, can further inform the issue.

1.2 Auditory memory: similarities and differences with visual memory

The comparison of visual and auditory attention and memory has received a significant amount of attention in recent years, and is especially important for the development of appropriate theories and paradigms of auditory processing based on the more well-developed area of visual processing. Analogous to the movement of research within the visual modality towards examining memory for more complex and ecologically relevant visual stimuli, research in the auditory domain has also shifted towards the study of auditory scenes (e.g., audio clips). Yet, there are still relatively few studies dedicated to investigating the processing of recognizable and semantically relevant scenes (Alain, 2007; Backer & Alain, 2012; Snyder & Gregg, 2011). Comparing long term auditory and visual memory for natural, ecologically-relevant scenes is important for the development of an appropriate auditory parallel to the paradigm used by Patai et al. (2012) or Summerfield et al. (2011) to investigate memory-guided biasing of attention.

Using a recognition task to compare memory across modalities, Cohen, Horowitz, and Wolfe (2009) suggested that long-term auditory memory may be inferior to visual memory for scene objects. Moreover, lower recognition accuracy for auditory objects persists even when auditory clips are labelled with descriptions in order to increase their semantic relevance. Other studies have found similar advantages of recall of visual scene objects over auditory scene clips across various developmental stages (Siegel & Allik, 1973). It is possible that the superiority of visual over auditory memory for non-verbal scene objects may be the result of the stimuli used in these experiments. In particular, while visual scenes used in memory experiments are static, auditory scenes are dynamic and changing over time (e.g., soundtrack of a zoo), and may therefore contain more information, making them more difficult to encode and retain in memory. Other
research indicates that short term visual memory, for example, is limited by the number of objects to be encoded or scene size (Cowan, 2010), which may not be the case for auditory memory (Demany, Trost, Serman, & Semal, 2007). While recognition accuracy may not differ significantly between modalities for short durations, auditory memory becomes increasingly deficient with greater retention intervals (Bigelow & Poremba, 2012). In fact, the superiority of visual memory for non-verbal stimuli is evident even for retention demands of several seconds. Overall, the capacity of auditory memory for dynamic, ecologically-relevant sound clips (e.g., zoo scene), like those which were used in the current experiment, seems to be more limited compared to the capacity of visual memory for static scenes like those used by Patai et al. (2012) or Summerfield et al. (2011), which were used as visual parallels in modelling our experiment.

Indeed, although verbal auditory memory has shown advantages over memory for visually presented text (Penney, 1975), memory for non-verbal auditory stimuli in general may be inferior to visual memory due to our having less experience with remembering these kinds of auditory objects (Cohen, Evans, Horowitz, & Wolfe, 2011; Snyder & Gregg, 2011). In comparison, we have much greater experience attentively viewing visual scene stimuli; thus, it is possible that we have developed more neural resources dedicated to encoding, storage and retrieval of visual objects. Moreover, since auditory memory is largely verbal in nature, memory for scenes may suffer in the auditory modality, as compared to visual processing where visual scenes are one of the primary sources of input (Snyder & Gregg, 2011).

However, despite comparisons with visual memory that often portray auditory memory as deficient, there is ample evidence that sufficient learning can create well-formed auditory memories that are retained for several weeks. For example Agus, Thorpe and Pressnitzer (2010) demonstrated that repeated exposure to even meaningless noise patterns results in the formation of robust auditory memories which emerge quickly, and are long-lasting. Furthermore, as suggested earlier, semantic relevance of auditory stimuli increases the likelihood of effective encoding of sounds in memory (Cohen et al., 2009; Gregg & Samuel, 2009). As the stimuli used in the current study were ecologically relevant sound clips, we were confident that adequate exposure to these stimuli should result in formation of strong auditory memories.
Moreover, as visual and auditory memory largely rely on similar mechanisms (Snyder & Gregg, 2011), we expected similar memory effects in the current study as those reported by parallel visual experiments (e.g., Summerfield et al., 2011; Patai et al., 2012).

1.3 Auditory memory and attention

Although little is known about the role of auditory memory in modulating attention to sound objects, there are several lines of research that can inform the issue. One example that illustrates the interaction of auditory memory and attentional processes is the phenomenon of change deafness, which refers to a failure to detect a change within an auditory scene. Both change deafness, and its visual parallel, change blindness, indicate that changes in natural acoustic and visual scenes can go unnoticed and that both auditory and visual memory during perception of scenes can be quite error prone. Studies using a wide range of auditory stimuli have demonstrated change deafness, including work with speech and voices (Vitevitch, 2003), music (Agres & Krumhansl, 2008), and complex auditory scenes (Puschmann et al., 2013). The utilization of similar paradigms to examine change deafness and change blindness can provide insight into the similarities and differences between auditory and visual memory. For example, greater rates of error in detecting changes within auditory compared to visual scenes provide further evidence that auditory memory may be more error prone to its visual counterpart (Eramudugolla, Irvine, McAnally, Martin, & Mattingley, 2005; Gregg & Samuel, 2008). Closely related to the current study, both change deafness and change blindness demonstrate that short term memories for acoustic or visual scenes can subsequently influence attention. For example, objects which are better encoded in memory will be more strongly attended to than objects less salient in memory (Mitroff, Simons, & Levin, 2004; Snyder & Gregg, 2011).

In addition to change detection research, which highlights memory differences between modalities, several recent studies can provide more direct insight into the nature of memory-guided auditory attention. For example, Dalton et al. (2009) reported that WM load affects ability to selectively attend to a target sound stimulus, providing the first evidence for the causal role of WM in modulating attentional interference of auditory distractors. Specifically, participants' ability to selectively attend to target auditory stimuli became increasingly disrupted under high WM load conditions, indicating that limited WM capacity affects selective attention abilities.
Furthermore, Backer and Alain (2012) conducted a seminal study which demonstrated that attention can be oriented towards a sound object within auditory short term memory. In particular, the study examined whether an informative cue given after the presentation of a complex acoustic scene (therefore requiring activation of STM) can bias attention towards an auditory stimulus representation in memory. However, the direct effects of memory on biasing of attention were not studied. Nevertheless, the experiment demonstrated that attention can indeed be oriented towards a sound object within auditory memory. In the current study, we were interested in seeing the reverse, that is, whether memory for an auditory stimulus can facilitate orienting of attention to an incoming target. While Backer and Alain (2012) studied reflective attentional processing, (i.e., attending to sound object representations in memory), we explored the mechanisms of perceptual attention (i.e., how memory cueing influences deployment of attention). Moreover, the auditory scenes used by Backer and Alain (2012) were generated by combining three concurrent, but semantically separable, sounds (e.g., animal sound, human sound, musical sound), where participants were cued to attend to one of the individual sounds. In contrast, we utilized audio clips (i.e., recordings of naturally occurring sounds) such as multiple birds chirping or street sounds, which are likely, therefore, to be more easily encoded and maintained in memory (Golubock & Janata, 2013).

1.4 The current study: effect of long term memory on auditory spatial attention

The current study investigated auditory memory effects on attentional orientation. We examined whether long term auditory memory can bias attention and enhance perceptual sensitivity to an auditory target presented in learned spatial locations. Specifically, the goal of the current experiment was to determine whether memory for the location of a target tone within an audio clip influences subsequent deployment of attention (one hour later). We measured auditory event related fields (using MEG) in addition to behavioural performance in an effort to identify when contextual memories for target location influence performance. In the current study, we chose to utilize MEG rather than EEG methods during the critical testing phase of the experiment due to the short duration of this task. Moreover, the MEG should capture similar neurophysiological processes as the EEG, but localized with greater accuracy. Moreover, neuromagnetic recordings are an effective method by which we can study allocation of attention to auditory objects in
cluttered acoustic environments where there may be several sound objects (Backer & Alain, 2014). Furthermore, the advantage of using MEG over other techniques such as fMRI is that ERFs are better able to capture separate processes which may be overlapping in time, in this case the commingling of memory-cue processes and target selection. Measurement of neuroelectric signals has been used in similar cueing paradigms, where activity is generally enhanced contralaterally to the attended auditory field (Gamble & Luck, 2011).

We utilized a similar training paradigm to that employed in visual research, which served to create robust target-scene contextual memories. To ensure memory acquisition, participants were given ample opportunity to listen to audio clips and learn the location of a pure tone target within them. A spatial memory recall task was administered following the learning phase in order to determine whether participants formed robust memories for the target location within the audio clips. We used a one hour retention interval (between the initial learning task and the memory-guided attention testing task) in order to develop a preliminary understanding of the mechanisms involved in auditory memory effects on attention, and because of the uncertainty regarding how long auditory objects are maintained in memory (Bigelow & Poremba, 2012; Cohen et al., 2009). In accordance with Patai et al. (2012), who used a more challenging detection task than Summerfield et al. (2011) by instructing participants to use only covert visual attention to detect targets within scenes, we adjusted target detectability for each participant to ensure effortful listening for the target tone within auditory clips.

Moreover, to guarantee effectiveness of the training task (e.g., to ensure participants form strong memories for the location of target tones within auditory clips) we utilized a slightly modified learning paradigm compared to those used in similar visual studies, since learning and remembering the location of a target may be more difficult in the auditory modality. Specifically, within each learning task block, audio clips were repeated until participants correctly detected the location (right, left or none) of the embedded pure tone target.

Furthermore, we used a relatively long duration of the memory-cue scene prior to the presentation of the target tone. Specifically, participants heard each familiar audio clip presented twice (consecutively) during the critical test phase to ensure effectiveness of the memory cue. The first time each familiar clip was presented during the test phase served only to allow participants to recall the location of the embedded target tone from the training task (but no
target tone was presented). During the second presentation of each familiar acoustic scene clip, participants heard 2000 ms of the clip prior to the onset of the embedded target tone (see Figure 1). In contrast, cue scenes within vision studies were presented once and for only about 100 ms (Patai et al., 2012). Due to the dynamic nature of acoustic stimuli, increasing the length of the memory cue should also increase its informativeness compared to visual stimuli, where viewing a visual scene object for 100ms seems sufficient to extract and remember details of that scene.

An additional modification to parallel visual studies was the presentation of the target tone at one of only two possible locations (left or right auditory field) during both memory training and the testing task. In comparison, the target key was embedded at any random location within scenes in visual paradigms (Summerfield et al., 2011; Patai et al., 2012). In addition to practical constraints of using multiple auditory sources, we utilized only two target locations due to expected limitations in encoding a wide range of sound locations within memory. Specifically, in contrast to visual scenes, which provide abundant contextual information that can be used to bind target location in memory (e.g., remembering that the target stimulus always appears next to the door in a particular scene depicting the exterior of a house), it is more difficult for sound clips to provide such a rich orienting context. Furthermore, we used a smaller stimulus set, composed of only eighty audio clips, due to the limitations of auditory memory discussed above (Cohen et al. 2009).

1.5 Summary of objectives and hypotheses

In summary, we hypothesized that auditory memory can bias the deployment of auditory spatial attention. To test whether auditory memory enhances perceptual sensitivity and guides attention, we compared accuracy, reaction time, and brain activity measured using MEG when participants were presented with audio clips that contained a target tone embedded within a previously learned location (valid trails) versus when participants heard audio clips that contained a target tone presented for the first time (neutral trials).

Hypothesis 1: We predicted that participants will be more accurate and faster in detecting target tones embedded within valid scenes compared to targets within neutral scenes.
We expected shorter reaction times for target tones within valid scenes because valid memory cues should bias attention towards remembered locations prior to target tone onset, while cue scenes not associated with a memory for a specific target location (neutral scene cues) should not guide attention towards any location. Therefore, we hypothesized that individuals would be quicker to respond to targets within locations that are being selectively attended (which is the case for valid scenes) than to targets presented within scenes where attention is divided between the left and right auditory field (which is the case for neutral scenes).

Also, we expected targets embedded within valid scenes to be detected with a greater accuracy compared to targets within neutral scenes because valid cues often serve to reduce hearing thresholds for targets. This hypothesis was based on numerous studies where valid cues presented prior to a pre-defined target decreased thresholds for detecting sounds embedded within noise backgrounds (Huang, Xu, Wu, & Li, 2010; Hübner & Hafter, 1995).

**Hypothesis 2:** The enhanced performance will coincide with larger amplitude and shorter latency of target-related brain response (event related fields) over the parietal scalp region and auditory cortices. We also anticipated that the sustained activity elicited during the processing of the audio clip prior to target onset would be larger and lateralize over the hemisphere contralateral to the target in the valid trials compared to the neutral trials.

Based on similar visual paradigms, we hypothesized that memory for target location should influence both target-related activity as well as activity related to the memory cue itself (prior to the onset of the pure tone target).

For activity associated with target selection (assessed after onset of the pure tone target), we expected an N1m (the magnetic counterpart of N1) response to be lateralized contralateral to the field of presentation. We hypothesized that N1m responses would be larger for valid trials, indicating that participants are selectively attending to the remembered channel. We also expected to observe a smaller P2m response for valid scenes also indicating biasing of attention. In addition, we hypothesized that participants would demonstrate an earlier and larger response-related response for valid scenes compared to neutral scenes, indicating allocation of attention to learned target locations, which should differ from longer responses to unlearned target locations.
We hypothesized that the earlier and larger response-related activity would correspond to shorter reaction times and greater accuracy to detect targets within remembered locations.

We also expected differences in preparatory activity in response to memory cues prior to the onset of the target tone. In particular, the beginning of the audio clip (S1 and S2 before target onset) should elicit a preparatory sustained potential which should be lateralized contralateral to the expected location of the target tone for auditory scenes with spatial memory associations for targets (valid scenes), indicating memory-guided deployment of attention, which should not occur for neutral trials.

2 Methods

2.1 Participants

We recruited sixteen healthy young adults ($M = 23.5$ years; range 19-33 years), with normal hearing and normal or corrected to normal vision. There were six male participants and ten female participants. Hearing was assessed using pure tone thresholds for octave frequencies ranging from 250 to 8000 Hz, with the criteria for normal hearing being thresholds lower than or equal to 25 dB and less than or equal to a 15 dB difference between the two ears at each octave frequency. In addition, all participants were right-handed (for the purpose of MEG testing), fluent in English to ensure understanding of the experimental process and have no history of psychiatric or neurological illness or other major illness. Participants were recruited from the Rotman Research Institute participant database, and received monetary compensation for their participation. Lastly, all participants provided informed consent prior to taking part in the experiment according to Research Ethics Board at Baycrest.

2.2 Sound stimuli

Eighty audio clips (i.e., acoustic scenes) were used in the experiment, all retrieved from "http://www.freesounds.org/". The scenes were cluttered, but were chosen to maintain considerable semantic relevance (e.g., bar scene, several dogs barking, amusement park) in order to increase the likelihood that an appropriate association could be formed and labelled in long term memory (See Appendix A for the list of acoustic scenes used). The same eighty scenes
were used in the learning task, testing task, and explicit spatial memory recall task. All acoustic scenes were prepared using Adobe Audition 1.5 (Adobe Systems Inc., San Jose, CA); scenes were cut to a length of 2500 ms with a 100 ms rise and fall time, down-sampled to a standard sampling rate of 44100 Hz, and batch normalized to a total RMS of -23dB (expressed as the difference between the volume at each ms interval and peak volume).

In addition to the acoustic scenes, a 500Hz 200 ms pure tone target was embedded within some of the auditory scenes (valid scenes) in the learning phase and within all acoustic scenes in the testing phase of the experiment. Specifically, the target tone was embedded at 2000 to 2200 ms following scene onset. The volume of the pure tone was adjusted in the learning and testing phases based on each participant's individual signal-to-noise (SNR) 80% detectability ratio (as measured in the first task, see experimental procedure section). Specifically, the target tone was presented at a volume 10% (of scene volume) above each individual's SNR threshold as measured at the beginning of the experiment. The goal was to present the target at a volume which would involve effortful listening, in order to ensure that participants maintain attention and to enable us to test whether perceptual sensitivity can be enhanced by memory driven attentional orientation (which would not be possible with a very easily detectable target that would create a pop-out effect). At the same time, the volume of the pure tone target was raised from the originally calculated 80% detectability SNR (by 10% of scene volume) since many of the acoustic scenes used during the learning and testing tasks disguised the embedded target when the original SNR was used in a pilot study. The chosen volume of the pure tone target allowed for approximately 80-90% detection accuracy of the target tone within acoustic scenes during the learning and testing tasks. Moreover, the SNR ratio was held constant across the learning and testing tasks as to not disrupt learned target-context associations.

Four additional 500 ms acoustic scenes which were also down-sampled to 44100 Hz and batch normalized to a total RMS of -23dB, and a 500 Hz pure tone target presented for 500 ms were also used in the first phase of the experiment, during which individual SNR was established.

All stimuli were presented through headphones, at a listening volume of approximately 60 dB, with some sounds peaking at about 80 dB, as measured using a Larson-Davis (Depew, NY) System 824 Sound Level Meter. Acoustic stimuli and visual cues were presented using Presentation software (version 13, Neurobehavioral Systems, Albany, CA).
3 Experimental procedure

Overview

Participants completed a total of four experimental tasks. The purpose of the first task was to establish individual SNR thresholds which would later be used to adjust the pure-tone target volume in the learning and testing phases of the experiment. Establishing individually tailored volumes of the pure tone target within auditory scenes ensured that all participants were engaging in effortful listening during these tasks, which was particularly important during the testing task where a not-so-easily detectible target allowed us to better examine the effects of memory driven attentional orientation on enhancement of perceptual sensitivity to target location (Patai et al., 2012).

Following the first task, participants completed a learning task during which they became familiarized with a set of eighty audio clips, and learned the location of a pure tone target within half of them. Having completed the learning task, participants acquired a strong contextual memory for the location of the pure tone target within auditory scenes where a target was present (valid scenes), but no contextual memory was formed for scenes where no target was present (neutral scenes). However, all scenes became equally familiar to the participants.

Immediately following the learning task, participants completed an explicit spatial memory recall task, allowing us to determine whether an explicit memory for the location of the target within each scene (or memory for no target) was formed.

A one hour break separated the learning and testing tasks, during which participants were free to leave the testing room. The break served as a memory retention interval, allowing us to investigate the effect of long-term memory on allocation of attention. The goal of the following testing phase was to determine whether having a contextual memory for a target sound (acquired during the learning phase of the experiment) can guide attention to the remembered target location (i.e., left or right hemispace). Specifically, during this task, participants were asked to identify the location of the pure tone within previously studied acoustic scenes. Each familiar acoustic scene was presented consecutively twice during the testing task (with the first repetition of the scene containing no pure tone target). The first repetition of each scene and the beginning
of the second repetition of each scene (before target onset) served as a memory cue to guide attention towards the remembered location, if a spatial memory for target location was formed for that scene (See Figure 1).

Prior to the experimental tasks, an audiometric test was administered to confirm normal hearing thresholds. All four experimental tasks were performed in a sound attenuating testing booth, where participants were seated in a comfortable chair approximately 1 m from a computer screen.

3.1 Determining individual signal-to-noise 80% detectability thresholds

For each participant, we identified the SNR needed to detect a (500 Hz) pure tone target tone embedded within a subset of four auditory scenes with an 80% detection accuracy level. The scenes used during the calibration task were not used in the other phases of the experiment in order to prevent any potential memory contamination effects. Each acoustic scene was presented twice during each trial for a length of 500 ms, with a 500 ms interval between the first and second presentation of the scene. The target (500 ms) was embedded in the first or second scene at random. Using a two alternative forced choice procedure, participants indicated which stimulus held the target tone using a keypress response. Participants were given 2000 ms to respond following the offset of the second scene repetition, after which visual feedback was presented. The 80% detectability SNR was estimated using a three-down one-up algorithm (Levitt, 1971). Specifically, beginning with a 0.7 SNR, following three consecutive correct responses, the SNR was decreased by a factor of 5, while one incorrect response increased SNR by a factor of 5. The final SNR threshold was calculated by taking an average of the last 8 of 12 SNR reversals.

3.2 Learning task

A total of 80 audio clips were used in the experiment. These were divided into valid and neutral trials (40 each). In the valid trials, a pure tone target was paired with the auditory scenes. In 20 of the valid scenes, the target was presented in the left ear. In the remaining 20 scenes, the target was presented in the right ear. In the neutral scenes, no target was presented. Each participant
was presented with the same 80 trials over eight learning blocks (640 trials in total) to ensure participants acquired a strong memory for the location of the pure tone target within each auditory scene if a target was present. In addition, to strengthen memory for target-scene associations, the trials for which participants made an incorrect or miss response to localize the target sound were repeated until a correct response was made within each block. The order of trials (valid right ear, valid left ear, and neutral) was random within each block. Within the valid scenes, the target tone was played 2000 ms after scene onset, and lasted for 200 ms. Participants were instructed to listen for and memorize the location of the target tone within each scene. Specifically, after hearing each scene, their task was to indicate whether the pure tone target was played from the left side, right side, or if no target tone was present using a keypress response. Participants were given 2000 ms to respond following the offset of the scene, and subsequently received visual feedback for 500ms. Participants were asked to respond as quickly, but accurately as possible. The purpose of the learning task was for participants to acquire a strong contextual spatial memory for the target tone in valid scenes, as compared to neutral scenes where no such contextual memory was formed.

3.3 Explicit spatial memory recall task

Immediately following the learning task, a recall memory task was administered to determine whether participants formed explicit memories for the location of the pure tone target within each scene. Participants heard all 80 scenes from the learning task, but with no target tone present in any of the scenes. Their task was to indicate where they remember the target tone being located in each scene (right or left ear) or whether no target was present within the particular scene during the learning task using a keypress response. Participants were given as much time as they need to make their response. Subsequently, participants were also asked to indicate how confident they were in their response, using a 3-step scale keypress response (1 indicating not confident at all, 2 indicating fairly confident, 3 indicating very confident). There was a 500 ms time window before the next trial.
3.4 Testing task (examining memory-guided modulation of attention)

Following an hour retention interval, participants returned to complete a memory-guided orientation task. MEG was recorded continuously throughout the task. Participants heard the same eighty acoustic scenes from the learning task, each repeated twice. A 500ms interstimulus interval separated the first (S1) and second (S2) presentation of the sound scene. While the first presentation of each sound scene (S1) did not contain a target tone and only served as a memory cue to guide attention towards remembered target location, the second repetition of each sound scene (S2) always contained an embedded pure tone target (see Figure 1).

Figure 1. Stimulus presentation for one trial in the testing task. Note: S1 and S2 represented two presentations of each complex auditory scene, heard binaurally. A pure tone target is embedded within the second repetition of the scene (S2), presented from either the left or right ear.

For scenes that contained a target tone in the learning phase of the experiment, the tone was presented at the same location. For neutral scenes that did not previously contain a target tone, the tone was now presented from either the left or right side at random. While valid scenes were associated with a specific spatial memory for the location of the target acquired during the learning task, the neutral trials were equally familiar from the learning task, but were not associated with a specific contextual spatial memory for the target. Scenes were randomly intermixed throughout the task. The first repetition of each audio clip and the beginning of the second repetition (before target onset) served as a memory cue to guide attention towards the remembered target tone location in the valid scenes (Patai et al., 2012; Summerfield et al., 2011).
In contrast, for neutral scenes, there was no associated spatial memory which would guide orientation of attention, thus leaving attention divided equally between left and right fields. The utilization of lengthy and repeated memory cueing (e.g., presenting each auditory clip twice during testing) was chosen based on an initial pilot test which indicated that lengthy exposure to cues is needed to activate auditory memory for target location – context associations.

Another pilot test was conducted to determine optimal temporal placement of the target tone within the acoustic scenes. In order to increase informativeness of the memory-cue, we chose to embed the target tone within all scenes at 2000-2200ms from scene onset. Participants were instructed to indicate whether the pure tone target was presented from the right or left headphone source within each scene using a keypress response. A 2500 ms time window was given for responses starting from the onset of the pure tone target (therefore 2000ms after scene offset), and 500 ms preceded the onset of the next trial.

The testing task was repeated twice for each participant to increase the number of trials for MEG analysis.

4 Analyzes

4.1 MEG data acquisition and analyses

MEG data was recorded in a magnetically shielded testing room using a helmet shaped whole head neuro-magnetometer with 151 channels (OMEGA, CTF Systems, VSM Medtech Inc., Vancouver, Canada). Participants were asked to keep very still throughout the recording to minimize movement artifacts. Neuromagnetic activity was recorded continuously and sampled at a rate of 625 Hz, and low-pass filtered at 200 Hz. All data pre-processing and analysis was performed using Brain Electrical Source Analysis (BESA) software (version 5.2; MEGIS Software, GmbH, Gräfelfing, Germany). The initial pre-processing was used to remove eyeblink, cardiac, and muscle artifacts from the data, as well as any large artifacts caused by dental metal. Only those trials for which correct responses were made were included in the MEG analysis.

Once the MEG data was imported into BESA, the continuous data was cut into epochs according to memory cue and response. The data was divided into the following conditions within each
trial interval: S1 and S2 (first and second repetition of the auditory scene) were each divided into valid left, valid right, and neutral memory cue conditions, and responses were divided into one of four conditions based on target side and memory cue (valid left (e.g., response to locate the target on the left hemispace and memory cueing that the target is on the left side), valid right, neutral left (e.g., response to locate target on the right side and no memory cue), and neutral right. Auditory scene stimuli (S1 and S2) serving as memory cues were baselined to a 200 ms pre-stimulus period, epochs lasting for the duration of the sound scenes (2500ms). Response data was baselined to a 2000ms pre-stimulus interval (in order to capture preparatory processes), and a 500ms post-stimulus interval. Then, any excessively noisy channels were interpolated, using BESA’s spherical interpolation process. No more than three channels were interpolated for any given participant. Activity was averaged separately for each sensor location, experimental condition and response, and each testing session and participant and then filtered, using a high frequency cutoff filter removing all frequencies above 40 Hz.

We performed two kinds of data analysis. First, we modelled the averaged MEG data with 11 sources across the cortex, including left and right auditory, frontal and parietal cortices, and five sources across the midline (frontalpolar midline, frontal midline, central midline, parietal midline, posterior midline). Second, we performed an analysis of global field power (GFP) to summarize brain activity over the left and right hemispheres separately.

Electrophysiological data was collected from two sessions of the testing task for each participant (N = 16). However, 4 of the total of 32 testing sessions were excluded from the analysis due to incomplete data set or movement artifacts.

4.1.1 Source analysis

We used BESA software to reduce the data to fit across eleven sources across the cortex. The source model consisted of three symmetrical sources (in both hemispheres) in the frontal lobes, auditory cortex and parietal cortex, and five midline sources (see Figure 2).
We extracted a source waveform for each condition and response for each session and participant separately. The source waveforms for each condition and response were calculated based on fixed source locations and orientations. Due to a low signal to noise ratio used in the current paradigm, we used a single source model applied to all participants. To reduce the effects of noise, source waveforms were then averaged across participants.

We conducted a series of repeated measures ANOVAs testing the effects of memory cue (valid, neutral) on the activity associated with the cue (e.g., preparation), target-related activity as well as activity associated with motor responses to locate the target tone within the auditory clips.

We assessed the effect of memory cue on mean amplitude of the source waveforms, as well as on peak amplitude and peak latency of waveforms over specific trial intervals (see below) over the auditory cortices. To increase power, we combined activity elicited by targets located on the left and right side of space (combining valid right and valid left trials and similarly neutral right and neutral left trials), preserving the relationship between side of the target and side of the electrode (contralateral and ipsilateral). Neuromagnetic activity over the other sources (e.g., other than auditory cortices) was not analyzed statistically due to marginal differences across conditions.
To assess preparatory responses associated with memory cues (e.g., memory based attentional preparation), we compared the sustained potential elicited by valid and neutral trials during the second repetition of the sound scene (S2), prior to the onset of the target tone. We did not conduct statistical analyses to determine the effect of memory cue (valid, neutral) on activity during the first repetition of the sound scene (S1), since a preliminary source waveform diagram for this period did not indicate any differences based on memory cue. Moreover, since only the second repetition of the sound clip (S2) required participants to make motor responses to locate the target tone, we expected greater memory cue based preparatory effects during this interval. The critical period for analysis of preparatory shifts in attention was the time window between the onset of acoustic scene (S2) and the onset of the pure tone target sound, which served as a contextual memory-cue. Specifically, based on related research, we created epochs to assess cue-related activity beginning at cue onset and ending 2000ms after presentation of cue scenes, just prior to presentation of the target tone (Otten, Quayle, & Puvaneswaran, 2010). We hypothesized that valid memory cues should elicit larger and earlier responses (e.g., higher mean amplitude, larger and earlier peak of the source waveform) than neutral memory cues prior to the onset of the auditory target. The effect should be pronounced in the auditory cortex contralateral to the expected location of the target based on memory. However, due to the length of the memory cue (2000ms), we expected that it may be difficult to capture an effect of memory cue during the preparatory period (e.g., time based differences across participants; activity may not be time-locked to the event).

Activity related to the target tone was also analyzed by comparing size, peak amplitude and latency of the source waveforms across memory cues. We created epochs from 100 to 400 ms following the onset of the target tone in order to capture higher-order (e.g., attention modulated) processing components (P2m and response-related activity). Similarly as with the previous analysis (e.g., of preparatory activity), we expected a larger target-related response (greater mean amplitude over the epoch, and larger and earlier peak of the source waveform) for valid memory cue trials where attention should be modulated by the memory cue, compared to neutral cue trials where memory cannot guide spatial attention.

In addition to analyzing the effect of memory cue condition on the source waveforms at each auditory cortex source, we also performed another analysis to investigate lateralization of activity for each memory cue separately. Specifically, we conducted repeated measures
ANOVAs to compare activity in the left auditory cortex to activation in the right auditory cortex in response to each of the valid target conditions (valid left, valid right). While targets proceeded by valid left memory cues should elicit greater activation in the right auditory cortex than the left, the opposite was expected for valid right trials. To increase power, we combined activity elicited by targets located on the left and right side of space (valid right and valid left trials), preserving the relationship between side of the target and side of the electrode (e.g., comparing contralateral and ipsilateral activity). We hypothesized that activity should be stronger contralateral to the expected target location for valid trails, indicating modulation of attention to the target based on memory cue.

Lastly, we analyzed activity associated with target selection (e.g., responses to locate the target tone), to determine whether behavioural response results would be accompanied by earlier and larger response-related activity for targets in remembered locations. Again, we analyzed the effect of memory cue on source waveforms in terms of mean amplitude over epochs from 0 to 400 ms of motor responses, as well as on peak amplitude and latency during this time period.

4.1.2 Global field power analysis

In addition to the source analysis, we performed a GFP analysis to compare activity in the left and right hemispheres for each memory cue condition. In MEG, GFP expresses the distribution of magnetic energy across the cortex; it is an assessment of map strength (Lehmann and Skrandies, 1980). The measure of GFP is a more direct measure of activation compared to output of source analyses, as the data is not fit to any model, but reflects the overall distribution of energy across all channels (in the right and left hemisphere separately).

We calculated GFP for each hemisphere separately for each memory cue condition (valid left, valid right, neutral left, neutral right), summarizing activity from all channels except those along the midline for each hemisphere. GFP was calculated over the duration of S2 (epochs baselined at 200ms prestimulus, until 2500ms post stimulus onset). We grand-averaged GFP across participants for each condition.

For the analysis of GFP, we conducted repeated measures ANOVAs to compare activity elicited by valid and neutral memory cues in the hemisphere contralateral to the target, which is where we would expect to find the largest differences in attentional modulation based on memory cue.
Specifically, we compared GFP in the left hemisphere in response to valid right versus neutral right memory cues throughout S2 (epochs baselined 200ms prestimulus lasting until stimulus offset). Similarly, in the right hemisphere, we compared GFP in response to valid left versus neutral left memory cues throughout S2. Since we analyzed GFP throughout S2 (e.g., entire second presentation of the auditory scene, including the embedded target tone), we were able to capture both preparatory activity (e.g., before onset of the target) as well as target-related processes (e.g., interval from target onset to offset of the auditory scene). We expected that valid memory cues should elicit stronger GFP than neutral cues contralaterally to the target, indicating memory-guided attentional modulation.

In addition, we also compared GFP elicited by valid left vs valid right memory cues in each hemisphere to further investigate whether attention is modulated based on expected target location in memory.

Last, for valid memory cue trials, we combined activity elicited by targets located on the left and right side of space, preserving the relationship between side of the target and side of the electrode, in order to compare activation contralateral to the target (e.g., activity in the left hemisphere in response to valid right memory cue trials combined with activity in the right hemisphere in response to valid left trials) with GFP ipsilateral to the target (e.g., activity in the left hemisphere in response to valid left memory cue trials combined with activity in the right hemisphere in response to valid right trials).

4.2 Statistical analyses: behavioural data

4.2.1 Learning task

Both reaction times and accuracy were recorded to assess whether participants created associations for the target over the course of the learning blocks. Trials where RT was faster than 100ms, incorrect response trials, missed response trials as well as outlying trials (trials where RT was more than two standard deviations from the mean) were excluded from the analysis. To measure the learning effects, we created linear contrasts over the eight learning blocks using a series of repeated measures ANOVAs.
4.2.2 Explicit spatial memory recall task

We used within-subject repeated measures ANOVAs to compare the recollection of the location of the target tone across reported confidence levels. In addition, conducted one-sample t-tests to compare recall of target-context associations to chance levels, for all trials (to examine memory for target presence and target location), as well as for target-present trials only (to examine memory for target location only).

4.2.3 Testing task

To answer the main research question, the behavioral (e.g., accuracy, response time), and electrophysiological data from the testing task was analyzed using repeated measures ANOVAs. Evidence for memory effects was revealed in the main effect of trial type (valid, neutral).

For the behavioural data, we first analyzed RTs and accuracy for all valid trials compared to neutral trials. We also performed a second analysis between remembered valid scene trials and neutral scenes, therefore excluding those valid trials for which a correct memory for the pure tone target location was not formed as assessed using the explicit memory task. The analysis of RTs and accuracy excluded incorrect trials, missed trials, trials with excessively rapid RTs (faster than 100 ms), and trials with outlying RTs.

In addition, we performed a simple bivariate correlation between participants' accuracy in recalling target locations during the memory task and memory guided attentional allocation during the testing task (as measured by difference scores in RT to detect the target within valid compared to neutral memory cue trials).

Furthermore, in order to examine whether the effect of auditory memory on perceptual processes persists over time, as well as to investigate memory contamination effects, we compared RT difference scores over the two testing task sessions.
5 Results

5.1 Formation of associations between complex acoustic scenes and the location of an auditory target: Learning task

Participants' performance in detecting the presence of the pure tone target sound within auditory sound scenes improved over the course of the eight learning blocks, demonstrating strong learning effects. For instance, participants were quicker to locate the target tone over the learning blocks (e.g., block 1: mean RT to detect target = 509.38 ms (SE = 32.45); block 4: $M = 428.12$ ms (SE = 49.72); block 8: $M = 396.64$ ms (SE = 40.01)), and located the target with greater accuracy.

To assess gains in RTs, we conducted a two factor repeated measures ANOVA to test the effect of learning block and pure tone target presence (e.g., valid vs neutral trials) on RTs to detect presence/location of the target tone (e.g., RT to indicate whether target was presented from the left or right side or no target). The analysis revealed main effects of learning block, target presence, and an interaction of these factors. Specifically, RTs decreased significantly over learning blocks, $F(7, 105) = 7.49, p < .001$, indicating that participants were acquiring memories for the location of the target tone within individual auditory scenes with increasing exposure. Moreover, measures of effect size revealed that differences over learning blocks accounted for 33% of total variance in the data. Further evidence for learning effects was confirmed through a test of within subject contrasts, which revealed that RTs decreased linearly over learning blocks, $F(1, 15) = 41.63, p < .001$, with a marginal but insignificant quadratic trend suggesting a classic learning curve over time (Figure 3A – All Trials). Moreover, there was a steep decrease in RT from the first to the second learning block (difference between block 1 and 2 = 64.58 ms, mean difference between other consecutive blocks = 8.02 ms), indicating that auditory target-context associations are formed quickly and additional exposure may not strengthen these associations comparably. In terms of the main effect of target presence, RTs were slower for target absent trials ($M = 503.31$ ms, $SEM = 38.32$) compared to target present trials ($M = 352.55$ ms, $SEM = 47.86$), $F(1, 15) = 32.82, p < .001$, which was expected based on results from similar target search paradigms. The interaction of learning block and target presence revealed that participants
were quicker at learning whether a target tone was presented within auditory clips than learning where it was presented from (left or right side), $F(7, 105) = 5.98, p < .001$ (see Figure 3A). This was expected based on previous auditory memory studies which indicate that binding of auditory targets to specific spatial locations may be more difficult in comparison to similar visual tasks (Bigelow & Poremba, 2012; Cohen et al., 2009).

The ANOVA on accuracy data revealed a main effect of learning block ($F(7, 105) = 14.00, p < .001$), with accuracy increasing progressively over the course of the experiment. Moreover, contrasts over learning blocks indicated that the increase in accuracy was significantly linear $F(1, 15) = 17.23, p < .01$, and quadratic $F(1, 15) = 35.35, p < .001$ reflecting a classic learning curve trend. Similar to RT results, the largest gains occurred over the first couple of learning blocks (Figure 3B).

Based on the significant interaction of learning block and target presence, we performed a third analysis using only target present (valid) trials to determine whether localization of the target improved over the course of the learning task. In terms of RT the main effect of learning block did not reach significance due to large variability in search times across participants, although the means did reflect a slight decrease in search time over the course of the task (block 1: $M = 388.03, SD = 156.95$; block 4: $M = 356.53, SD = 223.02$; block 8: $M = 350.67, SD = 185.83$). (Figure 3A – Target present trials). However, accuracy improved significantly (block 1: $M = 74\%, SE = 3.84\%$; block 4: $M = 89.06\%, SE = 1.81\%$; block 8: $M = 91.25\%, SE = 1.29\%$), $F(7, 105) = 8.079, p < .001$. In fact, the gain in response accuracy over time was larger for target-present trials (17.19 \% increase over learning blocks) than the gains calculated using all trials (target-present and target-absent trials) (13.52\% increase over learning blocks), indicating that individuals can form strong associations between sound scenes and a specific auditory target location (Figure 3B).
Figure 3. Formation of auditory target-context memory associations. A) Participants responded quicker to target present compared to target absent trials, with a significant interaction between learning block and target presence. B) Participants detected targets with increasing accuracy over learning blocks.

5.2 Memory for auditory target-context associations: Explicit spatial memory recall task

The recall task required participants to indicate whether and where the pure tone target had been located within each familiar auditory scene (left, right or no target response). The results confirmed that participants formed strong associations between auditory scenes and the embedded pure tone target. Participants correctly recalled the presence/location of the pure tone target within 75% of the auditory clips (\(M = 60.3/80\)), significantly more than the proportion expected by chance (\(M = 26.67/80\)), \(t(15) = 10.74, p < .001\). Moreover, participants correctly responded to a large proportion of trials (\(M = 25/40; 62.5\%\)), even when target absent (neutral) trials were excluded from the analysis \(t(15) = 4.93, p < .001\) (compared to chance), indicating that individuals not only remembered whether a pure tone target was paired with a specific auditory scene, but also remembered its spatial location. There was a significant interaction of correct recall and confidence level, \(F(2, 30) = 14.41, p < .001\), indicating that participants were able to correctly gage whether they had recalled the location of the pure tone target.
5.3 Memory guided modulation of auditory spatial attention: Testing task

5.3.1 Behavioural results

We conducted repeated measures ANOVAs testing the effect of memory cue (valid, neutral) and target side (left, right) on RT and accuracy to locate the embedded target tone within sound scenes. To understand memory based modulation of attention, the primary analysis was performed using only those stimuli for which a correct target-context association was formed (e.g., those sound scenes where the target was correctly detected/located in the previous memory task). Results confirmed the hypothesis that auditory memory biases spatial attention. Specifically, in terms of RT, we found a main effect of memory cue, $F(1, 15) = 37.28, p < .001$, with auditory targets embedded within valid scenes (e.g., auditory scenes which provide a valid memory cue for the location of the target tone) being detected faster ($M = 489 \text{ ms}, SD = 25$) than target tones within neutral scenes (e.g., auditory scenes that do not provide a memory cue to guide spatial attention; $M = 583 \text{ ms}, SD = 24$). There was also a significant effect of memory cue (valid, neutral) on response accuracy, with targets for which target-context spatial memory associations were formed being located with greater accuracy ($M = 95.54\%, SE = 1.63$) than targets for which such an association did not exist ($M = 82.86\%, SE = 2.04$), $F(1, 15) = 19.93, p < .001$. Surprisingly, there was also a significant difference in accuracy to locate the target based on target side, with targets heard from the right side being detected with greater accuracy ($M = 91.44\%, SE = 1.36$) than targets coming from the left ear ($M = 86.96\%, SE = 1.71$), $F(1, 15) = 5.08, p < .04$.

We also performed an analysis using all trials (i.e., correct and incorrect at the memory task). The pattern of findings was essentially identical. The effect of memory cue on RTs was significant, $F(1, 15) = 34.19, p < .001$, with a similar gain in response speed as the memory correct trial analysis for valid memory cue trials ($M = 520 \text{ ms}, SE = 26$) compared to neutral trials ($M = 611 \text{ ms}, SE = 23$) (Figure 4).
The effect of memory cue on accuracy also remained significant, $F(1, 15) = 21.87, p < .001$, with a similar gain in accuracy to locate targets within valid trials as when only memory-correct trials were analyzed.

To further assess memory-guided attentional modulation, we calculated a bivariate correlation between the number of correctly recalled target-context associations for each participant and the gain in RT based on memory cue (calculated as the difference in RT to locate targets within valid versus neutral memory cue trials). We hypothesized that a greater number of correctly remembered target-context associations (higher accuracy result on memory task) should be associated with a greater difference in RTs between valid and neutral cue conditions. In other words, individuals with a better memory for the target-context associations should also demonstrate stronger memory-guided modulation of spatial attention. Results confirmed the hypothesis, as there was a positive relationship ($r = .55, p < .05$) between memory accuracy and memory cue effects, indicating that auditory memory is closely related to spatial attention (Figure 5).

*Figure 4.* Effect of memory cue on response time to locate the auditory target. Error bars represent standard error of the mean.
In addition to the mentioned analyses, which were all performed using data from the first session of the testing task, we also analyzed the effect of memory cue on RT using data from the second run, to investigate whether the effect of auditory memory on biasing attention persists over time and is resistant to potential memory contamination (e.g., from the first testing session). We excluded one participant from the analysis due to an incomplete dataset (N = 15). Repeated measures ANOVAs (conducted using memory correct trials only) revealed that the memory-guided attentional orientation effect persisted during the second run of the task, with faster RTs ($F(1, 14) = 13.32, p < .005$), and higher accuracy ($F(1, 14) = 12.19, p < .005$) in valid than neutral scene trials. Moreover, the effect of memory cue on RT (Session 1 valid: $M = 489$ ms, $SE = 25$, Session 1 neutral: $M = 583$ ms, $SE = 24$; Session 2 valid: $M = 478$ms, $SE = 24$, Session 2 neutral: $M = 554$ms, $SE = 23$) and accuracy (Session 1 valid: $M = 95.54\%$, $SE = 1.63$, Session 1 neutral: $M = 82.86\%$, $SE = 2.04$; Session 2 valid: $M = 94.34\%$, $SE = 1.43$, Session 2 neutral: $M = 86.90\%$, $SE = 1.63$) did not differ significantly between the two blocks of trials.

5.3.2 MEG results

5.3.2.1 Source analysis

We analyzed source waveforms (in terms of mean amplitude, peak amplitude and peak latency) to identify differences in brain activity elicited by valid versus neutral memory cues. Separate analyses were conducted to assess these effects in terms of preparatory activity (e.g., before...
target onset), target-related activity (e.g., at target onset), and response related activity (e.g., accompanying motor responses to locate the target) within the auditory cortices. We did not conduct statistical analyses to examine the effect of memory cue across the other sources based on a preliminary analysis, which did not show any differences based on memory cue.

Figures 6 and 7 show the time course of auditory evoked fields (AEFs) for both presentations of the auditory scene over one sensor (medial right temporal) for a representative participant, as an overlay of all MEG sensors was contaminated by background noise. Waveforms elicited by memory cue scenes (S1 and S2) demonstrated classic AEFs, with habituation effects from the first to the second presentation. Source waveforms elicited by auditory scenes serving as valid and neutral memory cues were analyzed to identify memory guided shifts in spatial attention (e.g., preparation). However, there were no statistical differences between valid and neutral memory cue conditions.

For target-related activity (epochs 100 to 400 ms following onset of the target tone), we observed well formed and clearly visible early AEFs (N1m and P2m) over auditory cortices, which showed classic distributions and time latencies (e.g., see Figure 7C), despite the low perceptual discriminability of the target stimulus (e.g., low signal-to-noise ratio). Specifically, the N1m peaked at a mean latency of 117 ms (ipsilaterally) and 110 ms (contralaterally) following the onset of the auditory target, and the P2m peaked at 249 ms at ipsilateral sources and at 245 ms contralaterally to the target. The effect of memory cue (valid, neutral) on mean amplitude, and peak amplitude and latency of the source waveform was not significant.

We conducted an additional analysis to compare activity in the left and right auditory cortex for each memory cue (namely, valid left and valid right memory cue trials) separately during the presentation of the target tone (during the epoch 100 to 400 ms following onset of the target tone). As for the previous analysis, there was no reliable difference in amplitude and/or latency elicited by the target between the valid and neutral scenes.

Further, to increase power, we combined activity elicited by targets located on the left and right side of space (valid right and valid left trials), preserving the relationship between side of the target and side of the electrode (contralateral and ipsilateral). The observed differences in activity in contralateral and ipsilateral auditory cortices were small and not statistically reliable.
Finally, we examined source waveforms over the auditory cortices accompanying motor responses time-locked on the button press (Figure 9). There were no significant differences in activity elicited based on memory cue.

Figure 6. S1 (first presentation of the auditory scene): AEFs recorded from one sensor in the right medial temporal lobe, demonstrating classic A) N1m and B) P2m with accompanying magnetic field topographies.
Figure 7. S2 (second presentation of the auditory scene, with target tone embedded at 2000ms): AEFs recorded from one sensor in the right medial temporal lobe, demonstarting A) N1m and B) P2m, and C) early responses to the target, with accompanying magnetic field topographies.

Figure 8. Source waveforms represent neuromagnetic responses to the auditory scene (S2) and embedded target (epoch 0 to 2500ms of S2).
Figure 9. Source waveforms representing response related activity to locate the target tone within auditory scenes (epoch from 2000ms prior to motor response to 500ms after response).
5.3.2.2 Analysis of global field power (GFP)

As the source analysis did not reveal any significant differences in activity based on memory cue, we conducted an analysis of GFP to further assess memory guided modulation of spatial attention. As for the analysis of the source waveform, we did not find differences in GFP between valid and neutral trials nor was the interaction between condition and hemisphere significant. A second analysis comparing activation contralateral and ipsilateral to the target for valid memory cue trials, also revealed no significant differences. However, we observed a slightly higher GFP ipsilaterally to the target over the presentation of the target tone (see Figure 10).

![Figure 10. GFP calculated over the duration of S2.](image)

6 Discussion

6.1 Formation of long term associations between an auditory target and complex acoustic scenes

Taken together, the results of the learning task demonstrate that participants improved in both detecting and localizing auditory targets embedded within a large number of real world sound scenes with increasing exposure. Gains in both RT and accuracy were quite large, with gains in response speed being greater than 100ms over the course of the learning task, and correct target tone detection increasing from an 81% level within the first learning block to near perfect
detection by the end of the learning task (95% for block 8). This improvement in performance suggests that memory for auditory target-context associations is formed quickly and may improve perceptual sensitivity over time.

Furthermore, learning of auditory target-context associations occurs quickly - individuals can create these memory contingencies after a single exposure to the auditory stimulus. The greatest increases in learning, both in terms of accuracy and RT to detect embedded targets within the acoustic scene, occur over the first few exposures (learning blocks).

Moreover, despite evidence which suggests that formation of spatial memories for sound (e.g., location of target tone within larger sound scene) may be problematic, our results suggest that spatial memory formation (e.g., learning to localize targets within target present trials) follows a similar time course to simple target detection learning (e.g., learning to associate an auditory scene with target presence/absence). In other words, individuals not only create auditory target-context associations (e.g., learning whether a specific sound scene is associated with a target tone or not), but are also surprisingly efficient in binding an auditory target in space (association between target location and embedding sound scene). Moreover, the trend over learning blocks is similar for both target present and target absent trials.

Based on the results, we concluded that the learning task successfully facilitated the formation of associations between auditory scenes and embedded target tones, which would later be used to assess auditory memory-guided attentional effects, which was the main research question.

Moreover, results from the memory task (recall of target-context associations for each auditory scene stimulus), which was administered after a one hour retention interval following learning, indicate that memory for complex auditory sound scenes is robust even after a few exposures. Individuals are able to bind an embedded auditory target to a specific spatial location within a larger sound scene, and are able to hold a large number of these associations in memory. Moreover, target-context associations are largely explicit in nature.
6.2 Memory guided modulation of auditory attention

Analyses of RTs and accuracy indicate that individuals use auditory memory to modulate spatial attention within auditory sound scenes. The presentation of valid memory cue scenes (S1 and beginning of S2 before target onset) facilitated preparation of attention towards remembered target location based on target-context associations in memory. Thus, attention was allocated towards the location of the pure tone target before its onset, allowing for quicker RT to locate auditory targets embedded within valid memory cue scenes compared to targets embedded within neutral scenes, where attention was divided between left and right hemispace (e.g., no memory-guided bias of attention).

Moreover, the difference in RT and accuracy between valid and neutral memory cue conditions was quite large, with nearly 100ms gains in RT and over 12% accuracy advantages, suggesting a strong memory guided modulation of auditory attention. However, since there were no catch trials in the current paradigm, it is difficult to disassociate memory processes (e.g., whether greater accuracy to locate targets within valid memory cue trails was just an artifact of memory) from memory guided attention (e.g., greater perceptual sensitivity to targets within remembered locations). While the reported advantage in response time to detect targets within valid memory cue trials compared to neutral memory cue scenes demonstrates an effect of auditory memory on modulation of spatial attention, future research which incorporates target-absent (catch) trials within the critical testing task would allow us to confirm that the observed differences between valid and neutral conditions is indeed evidence for enhanced perceptual sensitivity based on memory.

In the current analysis, we were not able to separate implicit processes (e.g., looking at trials which were not remembered explicitly in the memory task) from explicit memory effects due to the limited number of trials and high memory recall results. In future work, increasing the number of trials, and thus the number of trials where target-context associations were not explicitly remembered, would allow us to investigate whether auditory attention can be modulated by purely implicit memory associations.
We were also interested in examining whether the effect of auditory memory on biasing of spatial attention is resistant to fading over time. Taken together, the results from the second session of the testing task indicate that auditory associations in memory have a strong effect on deployment of auditory attention and perceptual sensitivity to auditory stimuli across retention intervals, and that the memory-guided attentional orientation effect is not susceptible to fading over time. Evidence that the effect is robust and persists over testing sessions lays the foundation for studying the influence of longer term auditory memory.

In terms of neuromagnetic activity, we were not able to capture a modulation of spatial attention based on memory cue that would reflect the behavioural effect. Neither the source analysis nor the analysis of GFP over hemispheres revealed significant differences between valid and neutral memory cues, or lateralization of activity in response to spatial memory cues (i.e., differences between contralateral and ipsilateral activity in response to valid memory cues). This was surprising in light of the strong observed gains in accuracy and response time to detect targets embedded within valid memory cue scenes.

There are several limitations in the experiment to which we attributed the null MEG findings. First, the paradigm consisted of a relatively low number of trials per experimental condition ($N = 20$), and few participants were tested ($N=16$, 1 participant excluded due to incomplete dataset), resulting in a significant amount of background noise in the data. We selected a total of 80 auditory sound scenes to include in the paradigm (therefore 20 trials per condition) based on limitations in auditory memory (i.e., difficulty in remembering a large number of auditory scenes) and to ensure stimuli were easily discriminable from one another. However, in future experiments, advantages to increasing the number of auditory clips (i.e., reducing background noise) may outweigh limitations (i.e., difficulty to remember associations for a large stimulus set). Second, although there are many advantages to using MEG (e.g., spatial and temporal resolution), it may not be the most effective technique by which to capture memory-based processes, which are associated with deeper physiological structures (hippocampus, amygdala). In the future, combining MEG and EEG methods in this task would allow us to investigate deeper brain signals to identify neural correlates to the observed behavioural effect (Huizenga, Van Zuijen, Heslenfeld, & Molenaar, 2001).
In addition to the mentioned limitations, we proposed that the time course of memory-guided attentional modulation may vary over trials and across participants. With a long duration of the memory cue (2500ms of S1 and 2000ms of S2 before target onset) and variable acquisition of information during recall, it may be difficult to isolate memory based shifts in spatial attention in grand averaged data. For instance, while auditory clips for which target-context associations were strongly remembered may modulate spatial attention shortly after onset of the memory cue, other stimuli may be recalled after a lengthier time period and thus bias attention much later. In a future analysis, we propose to conduct a time frequency analysis for the MEG data to capture attentional shifts in response to memory cues, which may not necessarily be phase-locked to the memory cue event.

7 Limitations, future directions, and conclusions

In the current study, we attempted to disassociate memory-cue elicited preparation (cue-related activity) from activity associated with target selection, such as decision making, stimulus-driven attentional changes, and response selection (target-related activity) by using a cue-target paradigm. Cue related activity was assessed prior to the onset of the target tone (both during first presentation of the auditory scene (S1) and during the second presentation of the auditory scene (S2) before target onset), and therefore was relatively independent of target related processes. As discussed, to better disassociate cue and target related processes, future experiments should examine activity elicited by target-absent trials with cue scenes for which participants have learned a target location. This was done by Patai et al. (2012) in their parallel experiment using visual stimuli. By testing activation elicited by target-absent trials (that were however associated with a specific target location from the learning phase of the experiment), Patai et al. (2012) was able to verify that the observed post-target activation in target-present trials was elicited by target selection within remembered context rather than simply being a result of deployment of attention to remembered target location (cue-related activity).

A second suggestion for improving our paradigm is to increase the perceptual difficulty to locate the target tone within auditory scenes. By lowering the signal to noise ratio (making it more difficult for individuals to hear the tone (signal) within sound scenes), individuals will rely more on memory (e.g., target-scene associations) rather than simple perceptual processes when searching for the target. Although we did calculate an SNR for each participant separately in the
initial phase of the experiment in order to ensure 80% detectability of the target tone for each individual, the calibration task used to calculate this ratio utilized a limited number of auditory scenes which were different from those used later in the experiment. Therefore, signal to noise ratio used within the critical phases of the experiment resulted in approximately 89% detectability of the target tone. By using a lower SNR value in future studies, we may better capture the effects of auditory memory on deployment of attention.

Furthermore, in our paradigm, valid and neutral scenes only differed in having an association with a specific target location, however all scenes were equally familiar. We considered including a novel auditory scene condition, but due to difficulty in selecting enough sound scenes which would be distinct and recognizable from one another, we used only neutral (40 auditory scenes) and valid conditions (40 auditory scenes). In future experiments, the inclusion of novel and unfamiliar scenes would allow investigation of how familiarity with context itself, regardless of specific target-context associations, influences perception of auditory stimuli. For example, related studies suggest that familiarity of context within which a sound is presented may modulate brain activity (Kirmse, Jacobsen, & Schröger, 2009).

In addition, in the current study, we looked at the influence of memory for dynamic auditory stimuli on deployment of attention. In comparison, parallel studies (memory-based deployment of spatial attention) with visual stimuli (Summerfield et al. (2006, 2011); Patai et al. (2012)) have only analyzed memory for static visual objects (e.g., photographs). By conducting a similar experiment using dynamic visual stimuli in the future (e.g., short movie clip), we may better understand the similarities/differences in memory-based attentional mechanisms between modalities.

Moreover, in addition to quantitative differences between sensory memories (better memory, better identification, etc), there may also be qualitative distinctions between auditory and visual memory. For instance, while all sensory systems may share similar characteristics and rely on comparable mechanisms as revealed by previous research (Snyder & Gregg, 2011) as well as our findings, each system may be unique in different ways. For example, it could be the case that auditory stimuli may be predominant in some circumstances, and visual ones, in another. It may be interesting to examine whether attention is better allocated when both scene and target are presented in the same modality as compared to different modalities (e.g., visual scene and
auditory target tone). Moreover, we could examine coordination between audition and vision using dynamic stimuli (e.g., a visual movie clip with a soundtrack).

In the current study, we wanted to develop a preliminary understanding of the effects of auditory memory on attention, which has remained a vastly uncharted area until now. Indeed, this study was the first to demonstrate that memory for auditory stimuli can influence deployment of attention some time later (one hour later), laying the foundation for a host of related investigation. For example, we could extend retention intervals in future studies to investigate how long term auditory memory interacts with attentional systems. Moreover, further research testing whether auditory memory-guided attentional modulation holds for longer durations could inform comparisons with parallel visual experiments, such as Patai et al. (2012) or Summerfield et al. (2011) who demonstrated effects of visual memory on deployment of attention even twenty-four hours later. Furthermore, once auditory memory-guided attention mechanisms are better understood, the theory can be applied to the optimization of hearing and communication in ageing populations or acoustically-affected stroke patients.
References


Appendices
Appendix A: List of Auditory Scene Clips Used

ALARMS  CONSTRUCTION
AMUSEMENTPARK  COOKING
ANGRYMOB  COWBELLS
APPLAUSE  COWSMOOING
ARCADES  DEMOLITION
BABIES  DOGS
BALLDRUMMING  DRAGCARRACE
BASEKETBALLGAME  EERIEFOREST
BEESANDINSECTS  EMERGENCY
BLACKSMITH  FACTORY
BOMBING  FIREBURNING
BUBBLING  FIREWORKS
CATS  FROGPOND
CHEERINGCROWD  GEESE
CHICKEN  GLASSBREAKING
CHILDREN  HAIRDRYING
CHIMES  HIGHWAY
CHRISTIANPRAYER  HORRORSOUNDSCAPE
CHURCH  HORSES
CLASSROOM  LAUGHING
<table>
<thead>
<tr>
<th>LEAVES</th>
<th>SHEEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIGHTNING</td>
<td>SICK</td>
</tr>
<tr>
<td>MACHINERY</td>
<td>SMASHINGGUITARS</td>
</tr>
<tr>
<td>MARCHINGBAND</td>
<td>STREEHOCKEY</td>
</tr>
<tr>
<td>MEDIEVALBATTLE</td>
<td>SUMMERNIGHT</td>
</tr>
<tr>
<td>MONKEYSZOO</td>
<td>SUPERMARKET</td>
</tr>
<tr>
<td>MONKSPRAYING</td>
<td>TABLETENNIS</td>
</tr>
<tr>
<td>NOISYOFFICE</td>
<td>THROWINGGLASS</td>
</tr>
<tr>
<td>ORCHESTRATUNING</td>
<td>TOILET</td>
</tr>
<tr>
<td>OWLS</td>
<td>TRAFFIC</td>
</tr>
<tr>
<td>PARADE</td>
<td>TRAIN</td>
</tr>
<tr>
<td>PARROTS</td>
<td>TRIBALAFRICAN</td>
</tr>
<tr>
<td>PEOPLETALKING</td>
<td>TRIBALCHANT</td>
</tr>
<tr>
<td>PIGS</td>
<td>UNDERWATER</td>
</tr>
<tr>
<td>POOL</td>
<td>WALKINGINWOODS</td>
</tr>
<tr>
<td>PRESSCONFERENCE</td>
<td>WARGUNSHOTS</td>
</tr>
<tr>
<td>RAINING</td>
<td>WASHINGDISHES</td>
</tr>
<tr>
<td>RIVER</td>
<td>WINDSHUTTERS</td>
</tr>
<tr>
<td>SCARYPLAYGROUND</td>
<td>WOLVES</td>
</tr>
<tr>
<td>SCREAMING</td>
<td></td>
</tr>
<tr>
<td>SEAGULLS</td>
<td></td>
</tr>
</tbody>
</table>