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Effects of modality and repetition in a continuous recognition memory task: Repetition has no effect on auditory recognition memory☆

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ABSTRACT

Previous research has shown that auditory recognition memory is poorer compared to visual and cross-modal (visual and auditory) recognition memory. The effect of repetition on memory has been robust in showing improved performance. It is not clear, however, how auditory recognition memory compares to visual and cross-modal recognition memory following repetition. Participants performed a recognition memory task, making old/new discriminations to new stimuli, stimuli repeated for the first time after 4–7 intervening items (R1), or repeated for the second time after 36–39 intervening items (R2). Depending on the condition, participants were either exposed to visual stimuli (2D line drawings), auditory stimuli (spoken words), or cross-modal stimuli (pairs of images and associated spoken words). Results showed that unlike participants in the visual and cross-modal conditions, participants in the auditory recognition did not show improvements in performance on R2 trials compared to R1 trials. These findings have implications for pedagogical techniques in education, as well as for interventions and exercises aimed at boosting memory performance.

1. Introduction

Recognition memory concerns being aware of previously encountered information (Mecklinger & Jäger, 2009) and is defined as the ability to discriminate previously presented stimuli from not previously presented stimuli (Squire, Wixted, & Clark, 2007). It has been widely established that multi-sensory stimuli have a large impact on behaviour in a wide variety of tasks compared to uni-sensory stimuli (visual, auditory, or tactile). For instance, multisensory stimuli lead to quicker responses in simple reaction time tasks than uni-sensory stimuli (Mahoney, Li, Oh-Park, Verghese, & Holtzer, 2011; Molholm et al., 2002).

The redundancy and/or complementary information from different modalities can improve recognition and accuracy compared to just one modality (Amedi, von Kriegstein, van Atteveldt, Beauchamp, & Naumer, 2005). This is explained by *the dual code theory* (Thompson & Paivio, 1994), where multi-sensory stimuli (in this case, two sensory modalities) are represented in two codes and hence encoded twice, leading to enhanced memory performance. In contrast, uni-sensory stimuli are only presented in one code, and therefore encoded only once. Therefore, the robustness in encoding multi-sensory stimuli over uni-sensory stimuli facilitates memory retrieval (see Mastroberardino, Santangelo, Botta, Marucci, & Olivetti Belardinelli, 2008, for review). Accordingly, when comparing between uni-sensory and multi-sensory stimuli in recognition memory, past research suggests that, in continuous recognition tasks, initial encounters in multi-sensory modalities improve subsequent discrimination in a uni-sensory modality compared to initial encounters in uni-sensory modality (Lehmann & Murray, 2005; Moran et al., 2013; Murray et al., 2004; Thelen, Talsma, & Murray, 2015; Von Kriegstein & Giraud, 2006).

Neuroimaging studies have found that exposure to multi-sensory stimuli incorporates a distinct neural network, which can be activated with just repetition of visual stimuli alone (Nyberg, Habib, McIntosh, & Tulving, 2000). For instance, when participants were required to make old/new discriminations to repeated visual stimuli, stimuli that had previously been presented cross-modally (visually and auditorily) led to higher activation in the visual object recognition areas (right lateral-occipital complex) compared to repeated visual stimuli that had previously been presented uni-modally (Murray, Foxe, & Wylie, 2005). Electrophysiological results show that discrimination of visual stimuli that had been previously presented cross-modally elicited waveforms approximately 60–136 ms earlier compared to visual stimuli that had previously been presented uni-modally, suggesting that prior presentation of multi-sensory stimuli causes formation of memory traces

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that are distinct from memory traces formed through presentation of visual stimuli alone (Murray et al., 2004). These memory traces are then activated upon the repeated presentation of even uni-modal visual stimuli.

Among uni-sensory modalities, research comparing recognition memory performance shows that auditory recognition is generally poorer compared to visual recognition (Cohen, Horowitz, & Wolfe, 2009). With respect to the capacity of visual memory, Brady, Konkle, Alvarez, and Oliva (2008) showed that participants successfully remembered the details of approximately 2500 objects only after a single exposure, suggesting a large capacity of visual memory in storing details. On the other hand, Cohen et al. (2009) showed that recognition memory for sounds ranging from complex sounds, such as talking in a pool, to isolated sounds, such as a dog barking, was generally poorer compared to recognition memory for visual stimuli. Additionally, recognition memory did not improve even with pairing of these sounds to pictures during the encoding stage or with pairing of descriptions along with the sounds. In a related study on trained musicians, although their auditory recognition for sounds was significantly better than non-musicians', it was poorer than their visual recognition (Cohen, Evans, Horowitz, & Wolfe, 2011). Cohen et al. (2009) suggested two reasons for poorer auditory memory compared to visual memory. First, the psychophysics of auditory memory may cause a higher tendency for information to be forgotten compared to visual memory. Second, the capacity of auditory memory may be smaller compared to visual memory.

Recognition of auditory stimuli has also been found to be poorer compared to that of tactile stimuli. Bigelow and Poremba (2014) examined participants' recognition memory using visual (silent videos of scenes and events), auditory (complex everyday sounds) and tactile (common physical objects hidden from view presented to participants to touch and manipulate) stimuli. Results showed that recognition of auditory stimuli were significantly poorer compared to recognition of visual and tactile stimuli when tested the next day and even one week later, with no significant differences between the visual and tactile modalities.

Repetition has been shown to have a large impact on memory performance (Buchsbaum, Lemire-Rodger, Bondad, & Chepesiuk, 2015). It has been shown to enhance recognition due to the formation of multiple memory traces with every exposure of the target item, known as the *multiple trace theory* (Hintzman, 1988; Hintzman & Block, 1971). With repeated exposures, studied items serve as a cue to reactivate stored representations, which subsequently strengthen these memory traces (Thios & D'Agostino, 1976). Additionally, repetition of items facilitates the formation of multiple memory traces of target items embedded within different contexts, known as the *encoding variability hypothesis*. According to this hypothesis, as the repeated item is exposed at two or more positions on a list, multiple memory traces are formed that contain different episodic content. Exposure of repeated items placed at different positions in a list allows the presentation of target items to be preceded by a different set of items on the list at every presentation, where the target items are encoded within the context of its set. Repetition allows the target item to be encoded again within a second context of a set of items on the list. With each repetition, a different set of semantic or perceptual features is encoded for a single target item, thus forming several memory traces for a single episodic item, facilitating memory retrieval (Hintzman, 1974). Studies have consistently demonstrated that, with increasing repetitions, participants have better accuracy and faster reaction times in old/new discriminations (Buchsbaum et al., 2015; Xue et al., 2010).

It has been established that multi-sensory presentation leads to better recognition compared to uni-sensory presentation and that auditory recognition is inferior to visual recognition. Cohen et al. (2009) reasoned that the relatively poor auditory recognition performance in comparison to visual recognition performance might be due to the capacity of auditory memory being different or smaller. This difference is thought to exist as a result of our dominance in relying on our visual senses; as mentioned earlier, even among trained musicians, who rely on their auditory senses more than the general population, auditory recognition performance was still poorer than their visual recognition performance (Cohen et al., 2011).

In non-human primates, a clear anatomical difference contributing to poorer auditory memory was suggested to underlie differences in auditory and visual recognition processes, where the perirhinal and entorhinal cortices were found to support visual and tactile memory, but not auditory memory (Fritz, Mishkin, & Saunders, 2005; also see review by Munoz-Lopez, Mohedano-Moriano, & Insausti, 2010). While the differences in anatomical pathways in the processes supporting auditory and visual recognition in humans are not as well understood as in non-human primates, past studies clearly suggest the existence of fundamental differences between processing of auditory and visual stimuli, and the consistent advantage of visual stimuli over auditory stimuli in recognition, with a limited capacity to retain auditory information among humans (Bigelow & Poremba, 2014; Cohen et al., 2009; Cohen et al., 2011).

Visual stimuli have distinct features that, when a target item is repeated, it allows the item to be encoded within different semantic and perceptual contexts, forming multiple memory traces. In contrast, because auditory memory may have a smaller capacity, be less memorable, and do not share the varied perceptual features of visual stimuli, presenting the target auditory stimuli embedded in different auditory contexts during repetition may not facilitate the formation of multiple memory traces. This difference in the way multiple memory traces are formed for visual and auditory stimuli may underlie the reason for the reportedly poorer auditory recognition compared to visual recognition. The aim of this study is therefore to understand how modality affects recognition performance following subsequent repetition by comparing recognition performance across the three modalities, namely visual, auditory and cross-modal, and to determine the effects of repetition among these three modalities.

2. Method

2.1. Participants

Sixty-three undergraduate students at the University of Nottingham Malaysia Campus between the ages of 18–22 participated in the study. Data from 2 participants were removed from the analyses due to extreme data indicated by scores 3SD away from the mean. This removal resulted in a final number of 20 participants in the auditory and cross-modal conditions, and 21 participants in the visual condition (visual: M age = 20.38, SD = 1.87; auditory: M age 20.95, SD = 2.43; cross-modal: M age = 20.80, SD = 2.06). All participants had normal or corrected-to-normal vision and reported no visual or auditory impairments. All participants understood English as either a first or second language and English is the medium of instruction of their undergraduate studies. All participants gave informed consent and were compensated with RM5 for their time. The Science and Engineering Research Ethics Committee at the University of Nottingham Malaysia Campus provided institutional ethics approval for this study.

2.2. Materials

The visual stimuli of the experiment were 2D line drawings in standard block colours (blue, red, yellow, green) of familiar images presented against a black background, whereas the auditory stimuli were sound clips of spoken English words in both male and female voices. These visual and auditory stimuli were associated pairs, such as *cat* (image) paired with *mouse* (spoken word), obtained from past research (Kilborn et al., 2009). In the cross-modal condition, participants were presented with the visual and auditory associative pairs simultaneously. In the visual and auditory conditions, participants were only