Jurnal Psikologi Malaysia 23 (2009): 57-67

The Effects of Multimodal Interference in Working Memory

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ABSTRAK

Kajian ini menyelidik kekekalan maklumat auditori dan visual dalam keadaan gangguan terhadap ingatan. Sebanyak 76 peserta mengambil bahagian dalam dua eksperimen berasingan (ujian ingatan auditori dan visual) di mana peserta perlu menyelesaikan sesuatu tugas berkaitan dengan ingatan dalam keadaan gangguan auditori atau visual. Perbandingan prestasi dilakukan dengan kumpulan kawalan tanpa gangguan. Didapati bahawa ingatan auditori mudah dipengaruhi oleh gangguan auditori tetapi tidak terpengaruh oleh gangguan visual. Ingatan visual mudah dipengaruhi oleh gangguan tanpa menghiraukan apapun modalitas. Kesan dari kombinasi unik gangguan terhadap ingatan menyokongkan pendekatan pelbagai komponen yang dikemukakan oleh Baddeley (2002) terhadap ingatan.

INTRODUCTION

The layman and the psychologist both think. The layman has a vague idea of what is thinking. The psychologist recognizes this as the function of working memory, which holds information temporarily while allowing manipulation and processing to occur (Baddeley & Hitch, 1994).

In everyday life, the senses we rely on most are vision and hearing. As an example, we are able to drive and make spatial judgments, while listening to a friend and are able to comprehend auditory information. While working memory allows us to integrate both incoming and preexisting information, the limits of working memory in managing information coming in through the senses will be the focus of the present paper.

Auditory information (sound) and visual information (sight) first enter sensory memory and then into short-term memory if they are attended to (Sternberg, 2006). There, we consider them within the boundaries of working memory, if in addition to mere storage we begin the active processing of the information. Since we are faced with so much information in these two modalities each day, it is worth exploring if they overwhelm one another. Several studies have investigated this interaction between auditory and visual information after they have been stored in memory.

Morey & Cowan (2005) investigated if auditory information would interfere with a task related to visual memory. Twenty-six participants were shown visual arrays with shaded squares of varying positions. Participants had to determine if a first array shown to them matched a second array after an interval. During the interval, participants attended to auditory information (sequences of seven randomly selected digits). They either listened to the sequence (and/or had to repeat it at the end of each trial), or vocalized or sub-vocalized a sequence given to them. Performance in successful matching of the visual stimuli in these trials was compared to control trials where participants did not experience auditory interference.

Having to vocalize a series of numbers significantly interfered with visual memory. Morey & Cowan (2005) postulated that rehearsing auditory information requires central resources that are taken away from the maintenance of visual information. This central resource is said to be synonymous with attention (Cowan, 2001, cited in Morey & Cowan, 2005), and its focus can only hold limited items at a time (Garavan, 1998, cited in Morey & Cowan, 2005). The researchers found that multimodal interference indicates a central form of storage when information is held for processing. A point to note in the task is that there was active rehearsal and processing of auditory information, consistent with the role of working memory (Baddeley, 2002).

In looking at interference when different demands are placed on working memory, Duff (2000) conducted two experiments using a dual-task methodology. In experiment one, the performance of 20 participants on separate visual and auditory tasks were measured as a baseline. Participants had to remember a pair of digits, and remember the position of a marked square in an array. Next, these two tasks were combined (the digits were shown within the array of squares) and participants had to recall the digits and their position. The results indicated that the dual-task situation did not interfere with memory at the encoding and recall stage, as auditory and visual information were presented together. According to Duff (2000), this suggests that mere storage of multimodal information does not interfere with memory of that information.

In the second experiment of the study by Duff (2000), 19 participants completed separate auditory and visual tasks, and their performance was compared with their performance on a combined task (similar to the first experiment). This time, the tasks required attention beyond the encoding stage. In the auditory task, a recording of a mixed list of words and nonsense words were played to participants, who had to repeat every proper word after hearing it. The visual task was similar to the one in the previous experiment, except that now participants had to move a cursor on a computer to click on the marked square. In the dual-task condition, both these tasks were performed simultaneously. The results showed a non-significant decline in the auditory task but a significant decline in the visual task. It was concluded that this pointed towards shared resources in processing of information (when attention was required throughout the task) in memory for the separate modalities. According to Baddeley (2002), this would be consistent with the function of working memory when compared to the first experiment, which tested the traditional conception of short-term memory (passive storage minus active processing).

The most popular model of working memory is Baddeley's (2002) multi-component model, which deals primarily with components managing auditory and visual information. This model comprises several separate components, and the operation of these components leads to its functional nature, compared to more passive conceptions of short-term memory where simple storage is the emphasis (Atkinson & Shiffrin, 1968, cited in Baddeley, 2002).

When we attempt to remember a new phone number that has been spoken to us, a common strategy is to 'repeat' the number to ourselves until we remember it. This active processing would fall under the role of working memory, and in particular, the phonological loop (PL), which is the component that stores auditory information (Baddeley, 2002). In addition to the storage capabilities of the PL, an articulatory rehearsal system was proposed to explain how information was kept in memory beyond two seconds (which was found to be the lifespan of unattended information). This reflects our strategy of 'repeating' a new phone number to ourselves to hold it in memory. The traditional view of working memory has suggested that the limit of short-term memory is approximately seven pieces of information, called 'chunks' (Shiffrin & Nosofsky, 1994). However, findings by Chen & Cowan (2005) suggest that under the conditions of serial recall (there is continuous processing and recall of information as it is presented, as compared to free recall conditions), there appears to be a length limit for auditory information stored in memory. This means that the persistence of rehearsed information is limited by the amount we are able to verbalize in a given time.

This may hint at trace decay being the source of forgetting auditory memory (Baddeley & Hitch, 1994). However, the presence of interference has also been shown to be detrimental to memory, as evidenced by the irrelevant speech effect. Various studies have shown that in the presence of other auditory information, recall of auditory information is decreased (Norris, Baddeley & Page, 2004; Page & Norris, 2003). The term irrelevant speech reflects the fact that the methodology used in these studies do not consider the active processing of the distracters (i.e. they are not meaningful). Most of these studies have used verbal information (Jones, 1993, cited in Baddley & Hitch, 1994), but it has been shown that non-verbal information can interfere with auditory recall (Macken & Jones, 2003). For example, rhythmic tapping procedures interfere with storage of verbal information, supposedly by interrupting the articulatory rehearsal system. Thus, when information cannot be rehearsed due to interference, it is lost.

According to Baddeley (2002), visual information is temporarily stored and manipulated in the visuospatial sketchpad (VSSP). While research on the assumptions and functions of the PL has been vast, there has been comparatively little research on the VSSP (Baddeley & Hitch, 1994). It has been shown that irrelevant visual information can interfere with the abilities of the VSSP (Quinn & McConnell, 1996, cited in Baddeley, 2002); much like the irrelevant speech effect discussed above interferes with the PL. However, few studies have looked at the nature and dynamics of interference in the visual modality with sufficient depth. The methodology utilized in studying the PL obviously cannot be generalized here, for the differences posed by the contrasting modalities (for example, auditory information must always be presented sequentially, while visual information can be presented simultaneously).

In addition to this, visual memory is susceptible to more forgetting than auditory information due to the fact that it cannot be rehearsed like auditory information (Baddeley & Hitch, 1994). This hints at a lack of an articulatory rehearsal system as in the PL, but is probably also due to the difficulty in verbalizing visual information. Thus, maintaining visual information requires attentional resources. Baddeley (2002) proposes that this is the function of the central executive (CE), the subcomponent of working memory that focuses, divides and switches attention between modalities. It in fact determines what we are most attentive to. Although this is an inadequate description of its full role, it is enough for the purpose of this paper that we recognize its role in moderating processing between stores/modalities. While the PL can maintain information with minimal attention (due to its independently operating articulatory rehearsal system), the VSSP requires attention from the CE to hold visual information.

While most research on interference has looked at auditory and visual stores separately, several studies have looked specifically at the interference between modalities, finding that cross-modal interference does occur (Oberauer & Gothe, 2006; Morey & Cowan, 2005; Duff, 2000). However, the present study recognises several limitations of these studies. Firstly, they did not consider all combinations of interference. For example, Morey & Cowan (2005) used auditory information to interfere with a visual task, and concluded that the multimodal interference that occurred suggested a central storage for both modalities contrary to Baddeley's (2002) multiple storage systems. However, due to the differences in auditory and visual storage, it may be that the specific combination of modalities will yield specific degrees of interference. Secondly, not all the experiments mentioned involved the use of a processing task as interference. This is necessary for the interference task to tap into the resources of working memory (Baddeley & Hitch, 1994), in order to see if working memory 'interferes with itself'.

Based on these weaknesses and the literature in this area, the present study seeks to investigate the effects of multimodal interference in working memory. In two experiments (testing the durability of auditory and visual information in working memory respectively), participants were required to maintain and process information in the presence of interfering information that was either similar or dissimilar in modality. For experiment one (the auditory experiment), two hypotheses were forwarded. Firstly, it was hypothesised that participants who did not experience interference (control group) would score higher on the recall task than those who experienced auditory interference. Secondly, it was hypothesised that there would be no significant difference in recall scores between participants who did not experience interference and those who experienced visual interference. For the second experiment (the visual experiment), another two hypotheses were postulated. First, it was hypothesised that participants in the control group would score higher on the recall task than participants in both auditory and visual interference conditions respectively. Finally, it was hypothesised that recall scores of participants in both the auditory and visual interference conditions would not differ significantly.

METHOD

Participants

A total of 56 participants of either gender took part in experiment one while 20 participants took part in the second experiment. They were all psychology majors from HELP University College participating for extra credit in various courses. There were no other stipulations for participation.

Design

The present study consisted of two separate experiments. Each was a three-level independent design experiment, with one session for each condition. In both, the independent variable (IV) was the modality of the interference task. Experiment one was termed the auditory experiment, and the three conditions were no interference (control group), interference from the similar modality (auditory interference) and interference from a different modality (visual interference). The dependent variable (DV) in this experiment was auditory recall, defined as successful completion of the auditory task. Experiment two was termed the visual experiment, with its three conditions being no interference (control group), interference from the similar modality (visual interference) and interference from a different modality (auditory interference). The DV here was visual recall, indicated by the number of correct responses in a visual array task.

Materials

Audio Stimuli

The audio stimuli were sound recordings of five digits being spoken. The digits ranged from 'zero' to 'nine'. Each sound clip lasted almost five seconds (with slightly less than one second per digit). The sequences were formed using a random number generator, and it was ensured that the same digits were not repeated in each sequence. One of the digits in each sequence was randomly selected to be the probe digit, with the exception of the first digit.

Visual Stimuli

Each visual stimulus was a 6 x 6 array of squares presented on screen. In each array, three of the squares were shaded black. The arrays were constructed by randomly selecting three squares in a blank array, with certain stipulations to avoid an inadvertent pattern. Firstly, the shaded squares were not to fall in the same rows or columns as each other. Secondly, they were all not to be on the same half of the array. We then randomly determined the axis on which the array had to be flipped (vertical or horizontal) during the recall task of visual information. This was indicated to participants by a red line running through either the X or Y-axis of a visual array shown on screen. The arrays were randomly allocated to the respective trials via drawing of lots.

Response Sheets

The visual response sheet was a 6 x 6 array of squares on which participants had to mark out the appropriate squares. The auditory response sheet was simply a blank strip of paper on which participants had to write down the correct number.

Procedure

The procedure for a trial was explained to participants (instructions varying according to condition). Participants then underwent a practice trial (after which they were allowed to ask questions again) and eight actual trials during the experiment. Each trial consisted of participants being presented with a stimulus (auditory or visual), followed by a distracter task (except for the control conditions), which were stimuli that they had to respond to right away, and finally a task related to the initial stimulus that was presented. The different conditions basically consisted of different combinations of the auditory and visual tasks being presented to participants.

Auditory Tasks

The auditory tasks consisted of the aforementioned sequences being played to participants at the encoding stage. At the recall stage coming after the interference, participants were presented with a probe digit belonging to the sequence for five seconds onto a screen in front of them. They were required to recall the digit coming before the probe digit. When auditory tasks were used as interference (auditory tasks as the intervening task), the probe digit was shown for one second after the sequence was played (to fit it within the six seconds allocated for interference tasks).

Visual Tasks

The visual tasks consisted of participants being presented with the aforementioned visual arrays at the encoding stage for five seconds (shown on screen). At the recall stage after the interference, participants were shown the array with a red line along the X or Y-axis. They then had to mark out the shaded boxes from the original array after they had been reflected along the red line Marking the boxes in the response sheet with an 'X' was sufficient. In the case of visual interference, the visual arrays were shown for six seconds with the red line on the same array (so participants could mark out the reflected boxes immediately).

Experiment One

In each of the trials, participants first listened to the sound recording of five digits being spoken, which they were required to remember during the trial. In the next stage of the trial, participants were presented with interference depending on the condition (the control group were presented with no interference, the auditory group were presented with another series of digits and had to respond to the task, and the visual group were presented with a visual array and had to respond to the task). Immediately, participants were required to respond on the response sheets. Next, participants were shown the probe digit for the earlier sequence they listened to. They then had to write down the correct digit in the appropriate response sheet.

Experiment Two

In each trial, participants were first shown a visual array with three shaded squares, which had to be remembered for the trial. The different groups were then exposed to interference as stated above. After responding to the interference task, an array with a red line running through either the vertical or horizontal axis was shown. Participants had to mark the appropriate boxes on their response sheets.

RESULTS

Data for the two experiments were tabulated separately, and separate independent one-way ANOVAs were used to analyze the data. Participant's total recall scores were divided by eight to reflect the average score per trial, with participants in the auditory experiment scoring between zero and one, while participants in the visual experiment scores between zero and three (as a maximum score denoted correctly identifying three squares). A significance level of .05 was used for the analyses. Results are presented accordint to the experiment. Participants' performance on the interference task were not entered as data, but was used as a manipulation check. If a participant did not attempt to complete the task, their data would be excluded for interference may not have occurred. However, no participants were excluded for this reason.

From Table 1, it can be seen that the mean scores differ substantially. This represented a significant effect for interference, with $F(2, 53) = 75.807$, $p < .001$. The effects effects size was large, with $R^2 = .741$. Using a Bonferroni correction, it was found

that the mean recall score when there was no interference ($M = .8429$) was significantly higher than in the presence of auditory interference ($M = .2782$), with $p < .001$. It was also found that the mean recall score in the visual interference group ($M = .9076$) was significantly higher than the auditory interference condition, with $p < .001$. The mean recall scores did not differ significantly between the control (no interference) group and the visual interference group ($p > .05$). In summary, compared to the control group, recall scores were significantly lowered in the presence of auditory interference. However, visual interference did not cause recall scores to decrease.

Table 1: Experiment one: Descriptive statistics

Interference	Mean	Standard deviation	N
None	.8429	.1789	20
Auditory	.2782	.1933	19
Visual	.9076	.1331	17

Table 2: Experiment two: Descriptive statistics

Interference	Mean	Standard deviation	N
None	2.016	.6424	8
Visual	.9821	.4918	7
Auditory	.7500	.5184	6

The difference in mean scores by condition represented a significant effect for interference, with $F (2, 18) = 10.479$, $p = .001$. Similar to experiment one, the effects size here was large, with $R^2 = .538$. Due to the small sample in this experiment, the observed power was computed as a precaution, and was found to be sufficiently high (.971). Using a Bonferroni correction, it was found that the mean recall score in the control condition ($M = 2.016$) was significantly higher than in the presence of both auditory interference ($M = .7500$) and visual interference ($M = .9821$), with $p < .005$ and $p < .01$ respectively. The mean recall score in the visual and auditory interference groups did not differ significantly, with $p > .05$. The results indicate that the presence of both auditory and visual interference decreased recall scores, compared to the control group. However, there was no difference depending on the modality of interference.

DISCUSSION

Experiment One

The results for the auditory experiment showed that recall scores were equally high in the control group and in the visual interference condition, but were significantly lower in the auditory interference condition. The difference in the mean scores was significant ($p < .001$), with a large effects size ($R^2 = .741$). The key finding here is that only interference in the auditory modality was able to interfere with the auditory information stored in working memory. Visual interference did not interfere with the auditory information stored there.

Both hypotheses for this experiment were supported. It was hypothesized that the control group would have higher recall scores than the auditory interference group, and the results showed a significant difference in this direction ($p < .001$). It was also hypothesized that there would be no significant difference in recall between the control group and the visual interference group. While the visual interference group scored significantly higher than the auditory interference group ($p < .001$), they scored as high as the control group as no significant difference was found ($p > .05$), supporting the hypothesis.

Because the task required participants to maintain auditory information in memory at the encoding stage and perform a search through the sequence at the recall stage, the task more likely taps into the function of working memory than a straightforward serial recall task. In the control group, participants would have been able to hold the digits in memory for the duration of the trial quite easily through maintenance by the articulatory rehearsal system (Baddeley & Hitch, 1994). This allowed rehearsal of the digits without the use of attentional resources from the central executive (Baddeley, 2002), which would only have been invoked at the recall stage to identify the correct digit in the sequence based on the presented cue.

In the presence of visual interference, auditory memory is not impaired. This is consistent with the second experiment of Duff's (2000) study, which found that dual processing tasks impaired visual but not auditory memory. In the present experiment, attention is needed for processing the visual interference, but the auditory information persists even if it is left unattended. This is quite easily explained by the articulatory rehearsal system's ability to maintain auditory information with minimal attentional resources (Baddeley & Hitch, 1994). In the presence of auditory interference (another sequence of digits), however, auditory recall was lowered. This can be explained by the length limit of the phonological loop, as indicated by Chen & Cowan (2005) – even though the sequences could be rehearsed, the time it took to rehearse them (when there were two sequences, or ten digits) exceeded the duration of the auditory information. Thus, by the time the last digits were rehearsed, the earliest digits would have already decayed. An alternative explanation is that participants expend more attention to maintain both sequences of digits, which decreases the amount of attention available at the cued-recall stage – affecting the accuracy of the search for the right digit.

Experiment Two

In the visual experiment, it was found that participants in the control group scored higher on the recall task than participants in both interference conditions. There was no significant difference in recall scores between both the auditory and visual interference conditions. The effect of interference here was significant ($p = .001$), with a large effects size ($R^2 = .538$). In summary, it can be seen that interference regardless of modality (either auditory or visual) decreases recall of the visual information stored in working memory.

Both hypotheses for this experiment were also supported. The first hypothesis was that the control group would have better recall than both the auditory and visual interference conditions. The results showed the control group scored significantly higher than both these conditions ($p < .005$ and $p < .01$ respectively), in line with the hypothesis. Secondly, it was hypothesized that recall scores in both the auditory and visual conditions would not differ. They were equally low relative to the control group, and did not significantly differ from one another ($p = 1.000$).

Consistent with findings by Morey & Cowan (2005), auditory interference decreased the recall of visual information. The present experiment also extends the findings to the visual modality, and to tasks involving active processing. In Morey & Cowan's (2005) study, participants simply had to determine if two visual arrays matched. In the present study, participants had to engage in a mental transformation that tapped into the manipulation capabilities of working memory. This was in line with findings by Duff (2000) and Oberauer & Gothe (2006) that having to engage in two processing tasks simultaneously decreased a person's ability on the visual task. Duff (2000) in particular, points out that visual information is more susceptible to interference than auditory information because maintenance of visual information requires attentional resources from the central executive. Thus, the presence of the interference tasks regardless of modality, which involves processing of auditory or visual information, steals attention from the original stimulus, which then is lost in memory (Baddeley, 2002).

CONCLUSION

Morey & Cowan (2005) suggested that because multimodal interference occurs, it hints at the existence of central storage for information from all modalities. However, the present study demonstrates that memory reacts differently to interference depending of the modality. These differences are predicted and easily explained within the framework of Baddeley's multicomponent model of working memory (Baddeley & Hitch, 1994).

Furthermore, the two experiments taken together suggest that the findings concerning interference in memory (Norris, Baddeley & Page, 2004; Page & Norris, 2003) can be extended beyond procedures that test merely the storage of memory from different modalities. Indeed, they also readily apply to the information processing function of working memory (Duff, 2000; Oberauer & Gothe, 2006).

All these findings taken together show empirical support for the continued use of Baddeley's (2002) model of working memory as a framework of how individuals temporarily hold and manipulate information. Since different combinations of interference for the auditory and visual modalities yield different degrees of interference, a multicomponent model of working memory accounts for the findings better than simpler models with central storage (Morey & Cowan, 2005). Additionally, interference as a result of tapping into the processing abilities of working memory lends support to the central executive, which modulates attention required for active processing (Duff, 2000).

Research on working memory poses great practical implications for individuals in situations where there is a great amount of incoming information with which they have to deal with. Jobs like air traffic controllers and pilots in particular, require immediate processing of information from multiple modalities. Thus, research on the limits of working memory in holding and processing information would provide guidelines on ideal working conditions, but the application of these findings in real life situations is beyond the scope of the present study. The biggest implications, however, are theoretical in nature.

By addressing several questions that have been raised by research in this area (particularly in the past few years), the present study attests to the durability of the working memory paradigm, and there is clearly much research yet to be conducted on related areas.

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