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Investigation of the interaction between cross-modal stimuli and item grouping and their potential effects on working memory

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Abstract

Working memory capacity is limited and can be affected by various factors. It is suggested that working memory can hold up to 3-4 objects. Empirical research indicates that the larger the number of visual material individuals hold in working memory, the less memory is accurate. Yet, fast and accurate recognition of objects can be achieved through haptic investigation and the storage of visual-auditory items is substantially increased when individuals are presented with spoken words. The aim of this study was to investigate the potential interaction of cross-modal stimuli (visual-auditory/visual-haptic) and item grouping, along with their separate effects, on working memory. Two item presentations were utilized; one where participants were presented with visual-auditory items and one where participants were presented with visual-haptic items. All participants were presented with both grouped and non-grouped items. The items' recognition (free recall) was measured in 135 participants, using a 2x2 factorial mixed ANOVA design. Statistically significant results were observed for the main effect of item grouping on working memory [(F(1,133)=40.179, p<0.001, two-tailed, –2=0.090]. No statistically significant results were observed for the main effect of cross-modal stimuli on working memory [F(1,133)=0.36, p=0.549, two-tailed], or for the interaction between item grouping and cross-modal stimuli on working memory [(F (1,133)=2.959, p=0.088, two-tailed]. Such results indicate that item/material grouping is a contributory factor to individuals' working memory, closely related to students' learning and memorization within a classroom environment. Future research should investigate the effects of these variables, along with item familiarity, on long-term memory.

Keywords: Working memory, item grouping, cross-modal stimuli, limitations, memory capacity, visual-haptic, visual-auditory, working memory model.

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Introduction

Working memory (WM) is illustrated as the reconstructive workspace that temporarily includes information for easier access, availability, inspection and computation **[20, 42]**. As soon as cognitive tasks are completed, new information triggers the process' re-initiation. WM is vital to complex cognitive tasks, as suggested by associations with measurements of intelligence **[10, 11]**. WM is distinctly different from short-term memory, although the two terms are commonly used interchangeably **[1]**. The term 'working memory' was introduced by Baddeley and Hitch (1974), in their relevant WM model **[6]**. Their model proposes the existence of three WM components; (1) the central executive, a modality-free controlling system of limited capacity which coordinates, controls, and manipulates material in the subsystems (2) the phonological loop, handling a series of verbal and auditory information (3) the visuospatial sketchpad, handling visual and spatial/haptic information **[15]**. The episodic buffer was later added to the model as an interface between the other systems, accommodating various modalities, binding features, and holding 'chunks' based on an array of diverse dimensions (e.g. verbal, visual, semantic) **[5]**. This addition to WM model was linked to Baars' (2002, 1997) view of the role of consciousness, serving the purpose of pulling together distinct streams of data from senses and binding them into observable objects and scenes **[3, 4]**.

Various limitations accompany WM **[14, 24]**; one factor is the exposure to the items and another factor is interference, occurring when recently acquired knowledge exhibits similarity with the present one, causing limitations to the learning/memory capacity **[47]**. Wickens, Dalezman, and Eggemeier (1976) conducted a study with the aim to prove that release from such interference can occur when the new material is markedly different from the old one **[47]**. More specifically, they used semantic categories (flowers, vegetables, meat, fruit, and professions) as the new material when the original category was fruit. The results showed that the more dissimilar the categories, the less they interfered. Moreover, Oberauer, Farrell, Jarrold, and Lewandowsky (2016) demonstrated that WM capacity is affected by the set-size effect, suggesting that the larger the number of material held in WM, the less memory is accurate, thus memory capacity is reduced when individuals need to remember an increasing number of visual objects **[31, 35, 38]**.

Appropriate tasks should be designed to effectively measure WM, relevant to the characteristics of the memory system **[1]**. WM is typically measured using complex span tasks/dual-tasks that add a secondary cognitive task, which does not need to exhibit a relevance with the primary one (e.g. solving mathematical operations, deciding whether a sentence is syntactically/semantically accurate) **[44]**. However, the differentiation between complex/dual and simple span tasks cannot be characterized as entirely accurate, as the two processes overlap and there is not adequate research on the matter **[1]**.

Empirical research has focused on information processing based on stimuli in different formats **[17]**. Multisensory/cross-modal stimuli are behaviorally more advantageous, evoking an immediate response and enhanced recognition **[49]**. Moreover, bimodal/cross-modal representations (e.g. visual-auditory) have been repeatedly found to display improved free recall performance compared to unimodal ones (e.g. visual only/auditory only) **[13, 32]**. Also, the capacity of WM seems to increase for cross-modal rather than unimodal stimuli **[8]**.

Sensory perception is largely dependent on the visual system [34], yet the fast and accurate recognition of objects/items can be also achieved through the conscious touching of them (haptic investigation/perception) **[37, 40]**, which has been employed by humans as one of the simplest ways to acquire new information about the environment. Touching through kinesthetic receptors can relay information about the identity and the characteristics such as texture, shape and rigidity of the objects/items in question **[9, 18, 43]**. Research suggests that touch adds speed and accuracy in information-processing and is beneficial for one's WM **[27]**; in college-age adults, WM for objects was improved when it involved object/item touching **[26]**.

Visual-auditory discrepancies have also been detected by empirical research **[28]**; visual patterns affect WM similarly to verbal memory, as memory is susceptible to effects of similarity and is limited to around 3-4 objects/items **[45, 46]**. However, there is evidence suggesting that the capacity for complex stimuli can be fewer than three items [2], whereas when the stimuli are simple, the estimate can be considerably higher than four **[41]**. According to Penney's (1989) model of verbal information, separate streams are responsible for both visual and auditory information [39]. The auditory presentation mode is suggested to be superior, commonly known as the modality effect [19], with studies indicating that the storage of auditory items substantially increased when participants were presented with spoken words **[17]**, in accordance with WM models **[7, 33]**. Kellogg (2001) suggests that two memory components can account for the abovementioned effect; namely a sustained sensory memory for the auditory stimulus and a brief one that may cease to exist in the presence of another auditory stimulus similar to first one, commonly known as the suffix effect **[25, 36]**.

WM limitations may derive from processes that are associated with grouping or chunking as they can enable encoding of information coming from more than one item, to be processed as one larger unit **[21]**. The concept of 'chunks' **[35]** theorized that items that share common qualities such as color, shape, rhythm, or meaning belong to a semantic group that long-term memory (LTM) is already familiar with; groups that create meaning to participants are easier to recall, and remain in memory during studies and testing **[30]**. Although the solid definition of 'chunks' and their storable number are points of criticism, the concept of information grouping in terms of semantic information as storable items is still present in relevant research literature, with Cowan (2010) arguing for a number of four storable items **[12]**. Familiar objects may positively affect mental grouping, occurring when multiple items are perceived as a singular one, indirectly increasing the limit capacity. Hence, item grouping may be associated with higher WM retention, enhancing the input encoding while eliminating redundant information **[21]**. However, research has shown that individuals can memorize more objects if they belong to different categories than to the same **[48]**. In one study by Endress, Korjoukov, and Bonatti (2017) the effect of category-based grouping performance for WM was compared to multiple object tracking **[14]**. Participants were presented with either 'pure' displays of cars or faces, or with 'mixed' displays of cars and faces. Overall, the effects of category were found to be weak, confirming previous findings suggesting that WM capacity limitations in various domains are, to some extent, due to distinct mechanisms' limitations.

Nonetheless, Li et al. (2018) conducted several experiments and a meta-analytic study to examine grouping effects in WM **[29]**. They grouped memory items through illusory contour and the results showed that WM was significantly improved when presented with grouped items. Consequently, there were robust and beneficial grouping effects on WM, influenced by diverse factors.

Notably, the effects of visual-haptic objects have been mainly investigated on LTM **[40]** and not on WM directly **[23]** and there has not been adequate research on the potential associations between cross-modal stimuli (deriving from two modalities) and item grouping on WM. Hence, the novel of the present study is to investigate the potential interaction of cross-modal stimuli and semantic item grouping and their effect on WM. The study builds upon the work of Li et al. (2018) **[29]**, adding the variable of cross-modal stimuli. The research also aims at identifying the WM components in which the chosen variables are stored, based on the WM model **[6]**.

Three hypotheses are suggested; **(H_1)** there is a main effect of cross-modal stimuli on WM **(H_2)** there is a main effect of item grouping on WM **(H_3)** there is an interaction of cross-modal stimuli and item grouping on WM.

Methodology

Design

The experimental method was employed, and a 2x2 factorial mixed design was adopted; the first independent variable (between subjects) was cross-modal stimuli and its two levels were visual-haptic stimulus and visual-auditory stimulus. The second independent variable (within subjects) was item grouping, along with its two levels; grouped items and ungrouped items. The dependent variable (DV) was WM, measured in items successfully freely recalled by the participants.

Participants

135 Mediterranean College students/teachers (72 females, 63 males, N=135, Mean=22,7, SD=6), aged 18-51 years of age, were recruited, indicated by the G*Power analysis **[16]**, through opportunity sampling. Inclusion criteria stipulated that participants should be able to effectively communicate in Greek and to fall into the abovementioned age category. Participants with hearing/visual impairments or with any cognitive dysfunction were excluded from this study.

Materials

Fifteen miniature animal toys and fifteen everyday tangible objects were utilized in the experiment **[47]** (Appendix K); they were all selected to be easily recognizable and familiar. Two item presentations (Appendix H) were employed and shown via the College's classrooms' computers/projectors in the visual-auditory condition, which included two additional minuscule videos (Appendix I), found online, to act as interference. A stopwatch was further utilized to time the procedure. The data was screened and analysed using the Statistical Package for the Social Sciences (SPSS statistical software-version 25.0). Finally, all the necessary forms were also given to the participants (Appendices A,B,C,E).

Procedure

All participants were given the briefing and consent forms beforehand and were randomly allocated in the visual-haptic or the visual-auditory conditions. All items were randomly distributed to them. Sixty-eight participants took part in the visual-auditory condition and were presented with visual-auditory stimuli (pictures/sounds); half of them were initially presented with grouped items and the other half were presented with non-grouped items (counterbalancing). Sixty-seven participants took part in the visual-haptic condition and were asked to haptically explore items; half of them initially haptically explored grouped items and the other half haptically explored ungrouped items (counterbalancing). Participants in the visual-haptic conditions held their items for 10 seconds and then passed them to the other participants when hearing the signal "next" (Appendix J). In all conditions, participants watched an interference video before filling in their data collection forms (Appendix C). All participants were given debriefing notes at the end of each session.

Ethics

The research was conducted in accordance with the British Psychological Association Code of Ethics and Conduct (2014). All ethical guidelines were followed, by giving informed consent, briefing and debriefing forms to all participants. Confidentiality and anonymity were ensured, and participants were reminded of the withdrawal option at the start and at the end of the experiment. The research was also approved by the scientific committee of the Mediterranean College by obtaining a sign-off form (Appendix F).

Results

A Factorial 2x2 Mixed design was employed to analyze two independent variables with two corresponding levels, consisting of independent/repeated measures.

The data was screened to investigate the eligibility of the parametric assumptions. Since the researchers measured participants' items correctly recalled, the parametric assumption of the dependent variable being at the interval scale of measurement was fulfilled. The scores were transformed to z scores and indicated an outlier, which was replaced with the z scores' mean value (criterion +/-3 for sample sizes of <100, N=135), hence the parametric assumption of normal distribution was met. The skewness/kurtosis calculations did not surpass the +/-2.58 criterion (Appendix L). The Q-Q plots revealed two outliers, yet these participants did not deviate from the symmetrical distribution. Since N=135<200, the histograms could not display a normal looking graph because of the small data number.

The Kolmogorov-Smirnov normality test indicated that there was not a normal distribution. The Shapiro-Wilk normality test suggested that there was a normal distribution for two conditions. Consequently, the normal distribution assumption was accepted, but with caution. Since the Levene's test was not statistically significant, the assumption of homogeneity of variance was assumed. Concerning the Mauchly's test of Sphericity, sphericity was subsequently assumed.

All parametric assumptions were assumed. There were normal distribution issues, but within acceptable and non-alarming limits.

	Visual-Auditory	Visual-Haptic	Total
Grouped	11.179 (1.757)	11.013 (2.011)	11.096 (1.884)
Ungrouped	9.642 (1.856)	10.132 (2.051)	9.889 (1.965)
Total	10.410 (1.960)	10.573 (2.071)	

(Raw Data: Appendix G)

Table 1: *Means and Standard Deviations of items successfully recalled*

The table demonstrates a non-considerable difference between the visual-auditory and the visual-haptic conditions. In contrast, there are slightly notable differences between the grouped and ungrouped conditions, implying that most participants could better recall the items within the grouped and visual-haptic conditions.

The data was analyzed using a 2x2 mixed ANOVA. The results showed a significant main effect of item grouping on WM [(F(1,133)=40.179, p<0.001, two-tailed, –2=0.090], thus the second hypothesis is supported. Moreover, there was not a significant main effect of cross-modal stimuli on WM [F(1,133)=0.36, p=0.549, two-tailed], and the first hypothesis cannot be supported. Subsequently, there was not a significant interaction between cross-modal stimuli and item grouping on WM [(F (1,133)=2.959, p=0.088, two-tailed] and the third hypothesis is not supported as well.

Discussion

A Factorial Mixed Design was employed to investigate whether a main effect of cross-modal stimuli and object grouping or their potential interaction on WM is established. The first hypothesis was not supported, as there was no main effect of cross-modal stimuli on WM. The visual-haptic/visual-auditory items did not affect WM accuracy, contrary to research findings supporting that WM can be substantially enhanced with the use of touching **[26]** or listening **[17]**. This poses a profoundly interesting finding as it severely contradicts relevant research. Mastroberardino et al. (2007) claims that cross-modal stimuli enhance information storing and retrieval in WM **[32]**; however, most previous research on the subject compared cross-modal with unimodal stimuli, while the present study assessed differences of cross-modal stimuli on WM free recall.

Oppositely, the second hypothesis is supported since item grouping was found to have a significant effect on participants' retention/recall. This is in accordance to previous studies highlighting this effect **[21, 29]**. Hence, it can be argued that item grouping aids input encoding, allowing individuals to recall the desired pieces of information by eliminating redundant details that may have been included in the interference video. Grouped objects were better recalled by the participants, contrary to previous research **[14, 47, 48]** which found that there was less interference with WM when the category-based items were not similar. However, the findings are consistent with research by Li et al. (2018), as item grouping improved participants' WM **[29]**. The theory of 'chunks' as a strategy for storing and recollection is further enhanced by the findings, as it appears that item grouping had a medium to strong effect over WM.

The third hypothesis is not supported either, as there was no interaction of cross-modal stimuli and item grouping on WM. Nevertheless, this might support that different processes are associated with different areas of the brain. Specifically, visual-haptic information might be allocated in the visuo-spatial sketchpad, and visual-auditory information might be allocated in the phonological loop and the visuo-spatial sketchpad as proposed by Baddeley and Hitch's (1974) WM model **[6, 15]**. Grouping processes might be allocated within the central executive or the episodic buffer, which accesses LTM for previously organized groups of items, thus making recall easier for items that belong to the same group **[5, 15]**. However, item grouping might be directly correlated to specific/

unique grouping or chunking processes that perceive items as one unit, hence their allocation within the model's components cannot be entirely confirmed.

Remarkably, in the present study, the vast majority of the participants recalled more than 4 items in all conditions, yet previous research indicates that individuals can hold up to 3-4 objects in WM and memory capacity is markedly reduced when the number of items is larger than 4 **[45, 46]**. This contradictory finding implies that recall in WM may not be as demanding as it was initially considered. It was also observed that participants were able to recall more animal toys (grouped) than everyday items (non-grouped), thus revealing that familiarity does not affect WM; more familiar objects are not better recalled. This might also suggest that the everyday objects employed did not carry a bias, as they are widely known and commonly used, hence they were not easier to be recalled.

This study attempted to eliminate any asymmetrical order effects by counterbalancing the conditions. Moreover, the main core of the experiment, which was WM and the effects of object grouping and different type of stimuli on it, has been replicated by previous research, hence there was a solid base of research. This makes the experiment easily replicable for further research on the matter. Finally, to address WM recency or primacy effects to an extent, this study further used randomization of stimuli order.

However, some limitations should be addressed. The most apparent limitation was the relatively small sample size. Moreover, some of the items belonging to the animal category posed some difficulty for participants to discern/identify. Additionally, the items that were to be haptically investigated were relayed from one participant to the next, causing variation in the retention time, which may have acted as a confounding variable. Furthermore, participants' WM may have been influenced by relevant features of the items used that favorite or hinder memorability, despite the effort made to use items that were equally common and familiar. For instance, observation of raw data revealed that several items used in the trials (e.g. a red ball) had a greater recollection rate (83%) compared to other items. It can be further assumed that participants shaped their answers according to what they believed should be remembered. For instance, the grouped items were animals, so they could have filled in items belonging to the same category, without that meaning that they really recalled which animals were utilized in the experiment, due to the reconstructive nature of WM **[20]**.

Future research should correspondingly be able to replicate this experiment by investigating item grouping and cross-modal stimuli effects on LTM to observe whether participants' free recall works better in LTM. In addition, familiarity of objects should also be further investigated, since the present study noticed differences between familiar and non-familiar objects, but was not able to identify their actual effects on WM. It is also suggested that a pilot study be employed to examine examine whether some items are persistently and prominently more memorisable.

The present research has implications in education, presentations and learning within classroom environments as item/learning material grouping might be a sole significant contributory factor to students' WM. The usage of cross-modal stimuli (e.g. multimedia) may, in turn, be an effective strategy for enhancing binding, thus improving memorization and learning, especially for children with learning difficulties. Further research over this particular domain is also recommended, in order to devise optimal teaching strategies.

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