Multisensory processing in event-based prospective memory

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Ethics

All of the procedures performed in studies involving human participants were conducted in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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Abstract

Failures in prospective memory (PM) – that is, the failure to remember intended future actions – can have adverse consequences. It is therefore important to study those processes that may help to minimize such cognitive failures. Although multisensory integration has been shown to enhance a wide variety of behaviors, including perception, learning, and memory, its effect on prospective memory, in particular, is largely unknown. In the present study, we investigated the effects of multisensory processing on two simultaneously-performed memory tasks: An ongoing 2- or 3-back working memory (WM) task (20% target ratio), and a PM task in which the participants had to respond to a rare predefined letter (8% target ratio). For PM trials, multisensory enhancement was observed for congruent multisensory signals; however, this effect did not generalize to the ongoing WM task. Participants were less likely to make errors for PM than for WM trials, thus suggesting that they may have biased their attention toward the PM task. Multisensory advantages on memory tasks, such as PM and WM, may be dependent on how attention resources are allocated across dual tasks.

Keywords: Prospective memory, working memory, multisensory, n-back, audiovisual, attention.

Highlights

- Semantically congruent multisensory information can enhance event-based prospective memory.
- Multisensory enhancement effects do not generalize to all memory processes.
- Multisensory advantages on memory tasks may depend on attentional allocation across memory tasks.

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1. Introduction

Prospective memory (PM), namely, the ability to remember and fulfill future intentions (Ellis, 1996), is fundamental to successful human functioning. This kind of memory process constitutes a recurrent part of our daily lives. As such, there can be significant negative consequences following lapses in PM (e.g., forgetting to pay the bills in time, or else forgetting to pick-up the kids from school). Event-based PM requires the execution of an intention when a particular environmental trigger occurs (Einstein & McDaniel, 1990), whereby the latter serves as a cue for the intended actions (e.g., having a set of keys in the door to remind oneself to take them when leaving the house).

1.2 Prospective memory

It has been hypothesized that PM consists of two components: one prospective and the other retrospective (Einstein & McDaniel, 1990, 1996). The prospective component deals with the occurrence of the intention at a suitable future point in time. Depending on the task demands, it can be automatically triggered by cues or participants can strategically monitor for cues in the environment that influence PM retrieval (McDaniel & Einstein, 2000). On the other hand, the retrospective component involves details about the intention. This component is thought to be consciously controllable and consists of information associated with the intention that is to be executed. For example, remembering to pass on a message to a colleague involves the intention to pass the information upon seeing the colleague (i.e., the person themselves serves as the cue), which comprises the prospective component, while the content of the message comprises the retrospective component of the PM.

The prospective component of PM is thought to depend on perceptual information, whereas conceptually-driven processing (i.e., the involvement of semantic information to complete tasks) influences the retrospective component. In this regard, manipulating the perceptual salience of a cue has been shown to modulate action upon the PM cue. For instance, Cohen, Dixon, Lindsay, and Masson (2003) conducted an experiment in which the participants had to press specific keys if they saw the letters 'B' and 'D' in strings of letters presented in a horizontal line. In this case, the retrospective component was accurate if the correct key was pressed, while the prospective component was represented as a response to the PM cue, regardless of whether the correct key was pressed or not. The detection of the cue was significantly better when the PM cue was spatially displaced so as to appear above the letter string than when it was spatially aligned with it. However, this effect was only significant for the prospective but not for the retrospective component of the PM cue, as participants remembered to respond, just not always with the correct button response.

Salient cues facilitate PM processes, especially when the PM task is embedded in demanding ongoing activities. As is frequently the case for PM, intentions are often formed and executed during other ongoing activities. In order to perform PM intentions, an ongoing activity needs to be interrupted, and attention needs to be directed to the PM tasks. Unsurprisingly, therefore, cue salience has been shown to enhance performance particularly when the PM task is embedded in other demanding ongoing activities. Studies have used uppercase letters to represent and increase the salience of distinct PM targets amongst lowercase letters. This has been shown to improve PM performance (e.g., Einstein & McDaniel, 1990). As expected, throughout demanding ongoing tasks, the more salient a PM cue is, the higher the probability of it being detected amongst environmental distractors (e.g., Cohen, West, & Craik, 2001; Trawley, Law, Brown, Niven, & Logie, 2014). Indeed, salient targets capture attention, and this prompts further processing as individuals monitor the environment to look for PM cues. Upon the detection of a cue, intentions are spontaneously retrieved and the PM-related response is then executed without much effort (Einstein & McDaniel, 2010; McDaniel & Einstein, 2000).

If an ongoing task is effortful, PM performance may suffer even with salient cue (Marsh, Hancock, & Hicks, 2002). It is generally agreed that performance on both PM and ongoing tasks are dependent on the allocation of attention. If attention is allocated to two tasks, then the nature of this allocation can lead to task impairment in either or both tasks (Marsh, Hicks, & Cook, 2005). In a study by Bisiacchi and colleagues (2009), the participants were expected to perform the PM tasks in two conditions; a) a task-switch condition whereby they were supposed to switch from the ongoing task and respond only to the PM cue, and b) a dual task in which they were expected to respond to both the PM cue and the ongoing task. Participants responded more rapidly during the dual-task than the task-switching condition. The authors suggested that dual-tasking facilitated awareness of both the PM and ongoing tasks, whereas the task switch condition required additional cognitive processing to suppress responding to the ongoing task, and prioritize the PM task for execution. However, to date, it is unknown how such task-demands influence PM performance with multisensory signals and cues, which are well know to modulate participant's awareness and attention to information.

1.2 Multisensory integration

Multisensory integration refers to the merging of information from different senses that leads to significantly different responses than the component unisensory events (e.g., see review by Stein et al., 2010). Input from multiple sensory systems can enhance information processing at both the behavioral and neural level (e.g., Spence, 2018; Stein & Meredith, 1993). For example, an auditory stimulus can facilitate the detection of visual stimuli (e.g., Noesselt, Bergmann, Hake, Heinze, & Fendrich, 2008; Spence & Ngo, 2012), and multisensory stimulation can increase the speed of motor reaction times (RTs) in both children and adults (e.g., Barutchu, Crewther, & Crewther, 2009). Such a multisensory enhancement effect is generally observed for stimuli in close spatial and temporal proximity. For instance, Van der Burg and colleagues (2008) had their participants detect a vertical or horizontal target line among diagonal distractors. They found that presenting a short sound that was temporally coincident with the onset of the change in color of the line dramatically reduced search latencies for target stimuli. That said, such multisensory enhancement effects are highly task-dependent and can be influenced by factors such as the semantic congruency and the task relevance of the stimuli (e.g., Barutchu, Freestone, Innes-Brown, Crewther, & Crewther, 2013; Chen & Spence, 2010, 2011; Downing, Barutchu, & Crewther, 2014; Koppen, Alsius, & Spence, 2008; Molholm, Ritter, Javitt, & Foxe, 2004; Morey et al., 2012; Raij, Uutela, & Hari, 2000). For example, Molholm and colleagues (2004) demonstrated that participants respond more rapidly to congruent audiovisual stimuli and relatively slower to incongruent stimuli, even though the novelty of such incongruences would make these stimuli more salient. However, more recently, Barutchu, Spence, and Humphreys (2018) reported similar multisensory enhancements for congruent and incongruent stimuli when the congruence of the stimuli was irrelevant to the task at hand. Thus, the effect of stimulus congruence on multisensory processing would appear to be task-specific and the salience of multisensory stimuli cannot explain all multisensory effects. Further research is therefore needed in order to investigate how multisensory semantic congruency influences memory.

Some studies have shown that multisensory processing can also have a positive effect on learning and memory (Alais & Cass, 2010; Bonnici, Richter, Yazar, & Simons, 2016; Fifer, Barutchu, Shivdasani, & Crewther, 2013; Kim, Seitz, & Shams, 2008; Kuo & Hooper, 2004; Lehmann & Murray, 2005; Quak, London, & Talsma, 2015; Stine, Wingfield, & Myers, 1990; van Ee, van Boxtel, Parker, & Alais, 2009). For example, participants are better at monitoring and recalling stimuli presented simultaneously audio-visually than dual audio-audio or visual-visual stimulus streams (Martin, 1980; Thompson & Paivio, 1994; Treisman & Davies, 1973). Similarly, Goolkasian and Foos (2005) documented higher recall rates for stimuli presented in picture/spoken and written/spoken dual presentation conditions. Nyberg and colleagues (2000) additionally demonstrated that words that were presented auditorily and visually, activated at recognition, both unisensory sites in the brain even though the words were presented only visually. Multisensory encoding typically activates a broader brain network than unisensory processing (e.g., Murray, Foxe, & Wylie, 2005; Murray et al., 2004), which, as a result, may contribute to improved memory encoding. Nevertheless, multisensory effects on memory can be sensory specific. For example, while visual cues can enhance visual spatial working memory (WM), no such enhancements are observed with auditory cues, yet spatially congruent audiovisual cues result in larger enhancements than either unisensory cues (Botta et al., 2011). Additionally, other studies have shown that while task relevant semantically congruent information can enhance memory, task irrelevant and incongruent sensory information can interfere with task relevant representations in other sensory modalities (Thelen & Murray, 2013; Thelen, Talsma, & Murray, 2015). Interesting, these studies have also failed to yield any significant correlation between the reaction times during the encoding and retrieval phase of the memory task, suggesting initial memory encoding cannot explain the observed multisensory memory interference effect at retrieval (Thelen, Cappe, & Murray, 2012). Although multisensory enhancement and interference effects have been shown in learning and WM tasks, the effect of multisensory processing on PM remains elusive.

The present study was designed to investigate the effects of multisensory versus unisensory stimuli on PM and an ongoing WM task. Prior research has demonstrated that PM performance depends on task load and the intentional demands of the ongoing task (e.g., Bisiacchi et al., 2009). Therefore, in order to assess the effects of ongoing task load, the participants in the present study performed a 2-back or 3-back WM task, while performing a dual PM task that required them to remember to respond to a randomly selected infrequent pre-specified letter. The participants were presented with a random sequence of unisensory visual letter stimuli, or multisensory stimuli (i.e., letters with congruent phonemes, incongruent phonemes, or with a burst of white noise). Based on prior research, it was posited that PM and WM would be enhanced by congruent multisensory stimuli, while incongruent stimuli were predicted to have an interfering effect (Quak et al., 2015; Thelen et al., 2012). We also predicted that performance on the

WM task at the retrieval phase would not depend on the signal type at encoding. Prior studies have shown that PM can be enhanced by cue salience (e.g., Cohen et al., 2001; Trawley et al., 2014), however, as highlighted above salient multisensory signals can have an interfering effect under various incongruent conditions (e.g., Barutchu et al., 2013; Molholm et al., 2004). Thus, the multisensory white noise condition was included in order to assess the effects of multisensory signal salience on PM and WM independent of semantic congruence.

2. Methods

2.1 Participants

Twenty-eight, right handed participants (*mean age* = 25.04 years*; SD* = 4.25*; males* = 16) with no known prior psychiatric or neurological history participated in the study. Individuals were compensated at the rate of £10 per hour for their participation.

All of the participants provided informed consent prior to taking part in the study, and all procedures were ethically approved and strictly adhered to the guidelines of the University of Oxford Central University Research Ethics Committee.

2.2 Stimuli

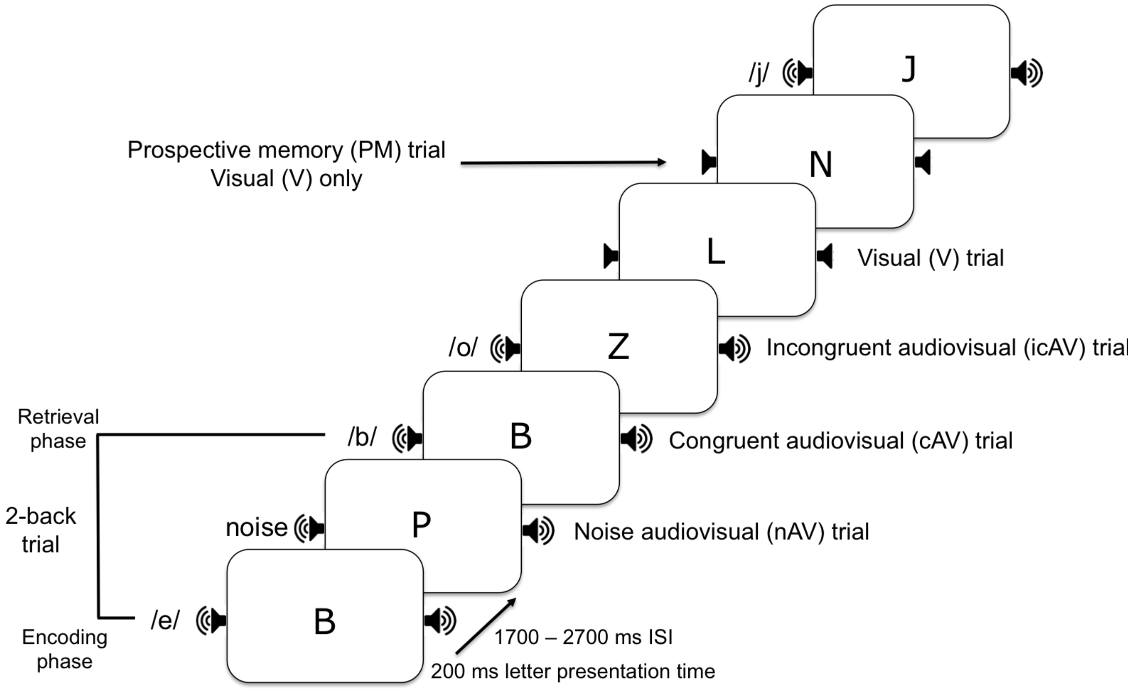

Figure 1. A sequence of trials illustrating a 2-back trial with an audiovisual incongruent (icAV) stimulus at the encoding phase and a congruent stimulus (cAV) at retrieval. For this sequence of trials, the prospective memory (PM) cue was defined as the letter 'N' and it is represented as a visual (V) only trial.

The experimental stimuli consisted of visual and auditory letters from the English alphabet (i.e., all graphemes and phonemes except for A, U, C, and K), and auditory white noise presented an intensity that peaked at 70 dB. Note that A, U, C and K were excluded because these graphemes often represent the same phoneme in the English language (e.g., the graphemes C and K are often both associated with the phoneme /k/), therefore, they could not be consistently defined as incongruent relative to each other. The visual stimuli were black uppercase letters in the "MS Reference Sans Serif" font with a size of 150 (approximately 2.5 cm in height). The letters were presented centrally on a 15-inch monitor with a white background. The auditory stimuli were presented at equal intensity, of approximately 75dB, from two speakers, one positioned on either side of the computer screen. Both visual and auditory stimuli were presented for 200ms, with an inter-stimulus interval (ISI) randomly varying between 1700ms to 2700ms.

The auditory and visual stimuli were combined in order to create four types of stimuli: visual only (V), audio-visual congruent (cAV – e.g., the letter "T" with the phoneme /*t*/), audiovisual incongruent (icAV – e.g., the letter "T" with the phoneme /*b*/), and audiovisual with white noise (nAV – e.g., simultaneous presentation of a visual letter with auditory white noise).

The experiment was programmed using MATLAB and Psychophysics Toolbox (2012b).

2.3 Procedure

The participants were seated in a quiet, dark room approximately 70cm from the screen. They had to fixate centrally and perform both the PM and the WM tasks simultaneously (i.e., under dual task conditions). The stimuli for both the PM and WM tasks were presented randomly in 10 blocks with 200 stimuli per block (five blocks of stimuli for the 2-back and five blocks of stimuli for the 3-back task).

In the PM task, the participants were instructed to respond only when they detected a pre-specified visual target. The target letter was selected randomly from all possible letters and the participants were only instructed about its identity at the start of the practice and the experiment session. The target letter was then constant for a given participant throughout the 5-blocks of each n-back task. In each block of 200 stimuli, the PM target letters were presented randomly with a ratio of 8% and an equal probability of each stimulus type (2% per stimulus type). Thus, at the completion of the experiment, there were 20 PM trials for each stimulus type (i.e., 4 trials per block across 5 blocks). The participants were instructed to press a key upon the detection of the target letter.

For the n-back tasks, the participants had to press a button only when the current letter matched with letters that they had seen trials 2- or 3-back. The first letter (encoded letter) at the encoding phase and the matched letter that participants responded to at the 2- or 3-back retrieval phase were randomly selected from each stimulus type: Visual (V), Congruent audio-visual (cAV), Incongruent audio-visual (icAV), and Noise (nAV). A 20% target ratio with equal probability for each stimulus type was set for the n-back tasks. Therefore, for each n-back condition, there was a total of 200 n-back trials across 5 blocks randomly allocated to each of the 16-stimulus type (4 encoding stimuli x 4 retrieved/matching stimuli: V, cAV, icAV and nAV); at the completion of the experiment there were approximately 12 trials for each condition.

The participants were instructed to pay equal attention to both tasks, to ignore all sounds, and to respond only to the visual stimuli for both tasks. They were instructed to press the right and the left arrow keys on the keyboard using the right hand index and middle fingers for both the PM and WM tasks. The two response keys were counterbalanced across the PM and WM tasks and participants. As stimulus presentation was randomly determined, it was possible for a given trial to be part of both the PM and WM tasks and, in such instances, the participants were instructed to press both of the assigned keys. These dual response trials were analyzed separately from the main PM and n-back trials (see the Results subsection for details). The participants were allowed up to 50 trials of practice to familiarize themselves with the n-back and PM tasks. The order of the 2-back and 3-back tasks was counterbalanced. Participants were allowed up to 1-minute break between each block and 10–15 minutes break between the two WM tasks. The completion time for the entire experiment was approximately two hours. At the end of the study, the participants were debriefed, paid, and thanked for their time.

2.4 Analyses

Data were collated for each stimulus condition and task, and the percentage of errors calculated. The RTs were not analyzed as they were deemed unreliable due to the low number of samples for each condition (less than 20), and the high level of error rates observed across some conditions. For the PM task, there were three types of errors: a PM error where participants failed to respond, a retrospective error, where participants responded using the wrong key, and an error where both keys were pressed. Similarly, for the n-back task, errors where participants failed to respond to a trial using the correct key (i.e., an error of omission), when the wrong key was pressed, and where both keys were pressed were analyzed. Given that participants were required to press both buttons on some trials, it is difficult to dissociate whether ‘both button press’ errors represent a failure in PM (i.e., a retrospective error of uncertainty that the trail has a prospective component) or WM error (uncertainty whether the trial was part of the n-component of the task), or weather the participants identified the trial as requiring a dual response. Therefore, we analyzed the both button press error responses separately. We also analyzed errors of commission (i.e., false alarms) for invalid trials that did not require a response.

Repeated measures analysis of variance (ANOVAs) were used to assess differences between the contrasting types of stimuli. Statistical significance was set at alpha = .05 and Greenhouse-Geisser corrections were applied if Mauchly's test of sphericity was violated. Significant main and interaction effects were followed by planned contrasts assessing differences between the unisensory visual condition and the three multisensory conditions with Bonferroni corrections where appropriate.

We also ran additional analyses to assess error rates for dual-task trials. For dual trials (i.e., a letter that was a PM and a n-back trail where participants were instructed to press both buttons), error rates were extremely low, thus leading to gross violations of normality. In these cases, transformations could not be applied, thus, non-parametric tests were used. Friedman's tests were followed-up with Wilcoxon Sign rank tests and Bonferroni corrections.

3. Results

3.1 Prospective memory analysis

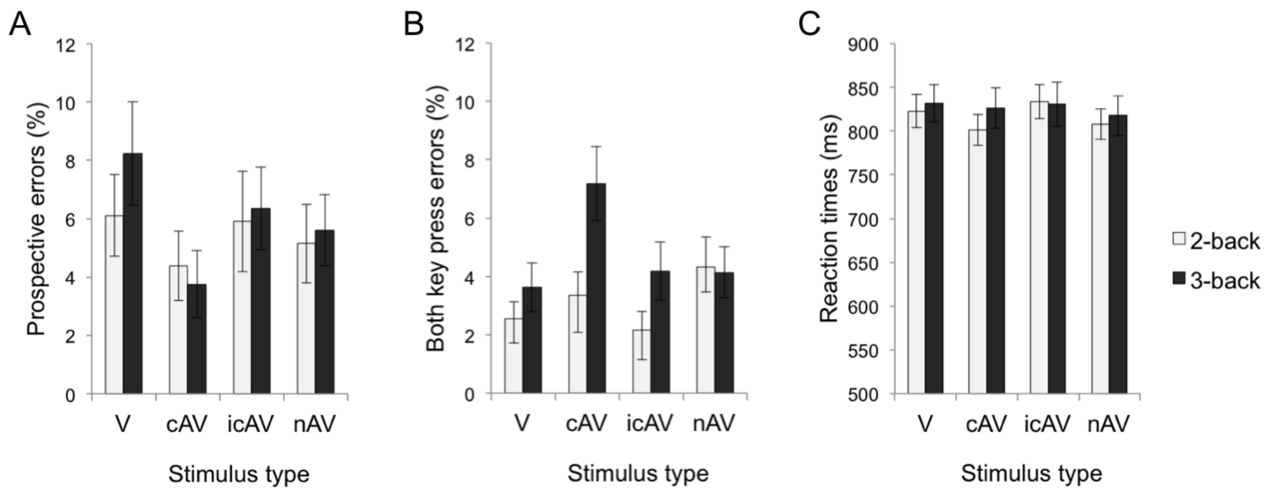

Figure 2. Mean percentage of prospective errors (A), both key press errors (B) and reaction times (C) (+SEM) for PM trials in the n-back conditions and for the four stimuli type: visual only (V), congruent audio-visual (cAV), incongruent audio-visual (icAV), and audiovisual stimuli with noise (nAV).

The mean percentage of prospective errors, where participants failed to respond, on the PM task during the 2-back and 3-back WM tasks are shown in Figure 2. The error rates were lowest for congruent audiovisual trials for both n-back tasks. A 2 (n-back conditions) x 4 (stimuli presentation type: V, cAV, icAV, and nAV) repeated measures ANOVA assessed the effects of the ongoing n-back task and multisensory stimulation. The results revealed a significant main effect of stimulus type, $F(3, 81) = 3.13$, $p = 0.03$, $\eta^2_p = 0.10$, $\beta = .71$. Follow-up main effects analyses using pairwise comparisons revealed a significantly lower PM error rate for the congruent audiovisual condition than for the visual only condition ($p = .009$), suggesting a congruent audiovisual condition advantage during the PM task. The difference between the cAV and nAV was borderline significant (p = .05), while the difference in PM errors between cAV and icAV conditions failed to reach significance (p = .09). The main effects for the n-back condition, $F(1, 27) = 0.24$, $p = 0.63$, $\eta^2_p = 0.01$, $\beta = .08$, and the interaction between n-back and stimulus type were not significant $F(3, 81) = 0.55$, $p = 0.65$, $\eta^2_p = 0.02$, $\beta = .16$.

Responses consistent with retrospective errors, whereby participants responded using the incorrect button were very rare, averaging a mean error rate of less than 1% (Med = 0) for all conditions. Therefore, there were gross violations of normality and these retrospective responses were not analyzed further. However, participants often made a third type of error, where they pressed both buttons upon the detection of the PM signal (see Figure 2B). For both button press errors, a 2 (n-back conditions) x 4 (stimulus type: V, cAV, icAV and nAV) repeated measures ANOVA revealed a significant main effect for the n-back condition, $F(1, 27) = 6.02$, $p = 0.02$, $\eta^2_p = 0.19$, $\beta = .67$, and a significant main effect for stimulus type, $F(2.76, 74.66) = 3.01$, $p = 0.03$, $\eta^2_p = 0.10$, $\beta = .70$. The interaction between the n-back conditions and stimulus type did not reach significance, $F(2.15, 57.92) = 2.51$, $p = 0.09$, $\eta^2_p = 0.09$, $\beta = .50$. Participants were significantly more likely to press both buttons during the 3-back than the 2-back task (p = .02). Furthermore, participants were more likely to press the both buttons for the cAV than both V (p = .005) and icAV (p = .02), but not the nAV (p = .2).

3.2 N-back analysis

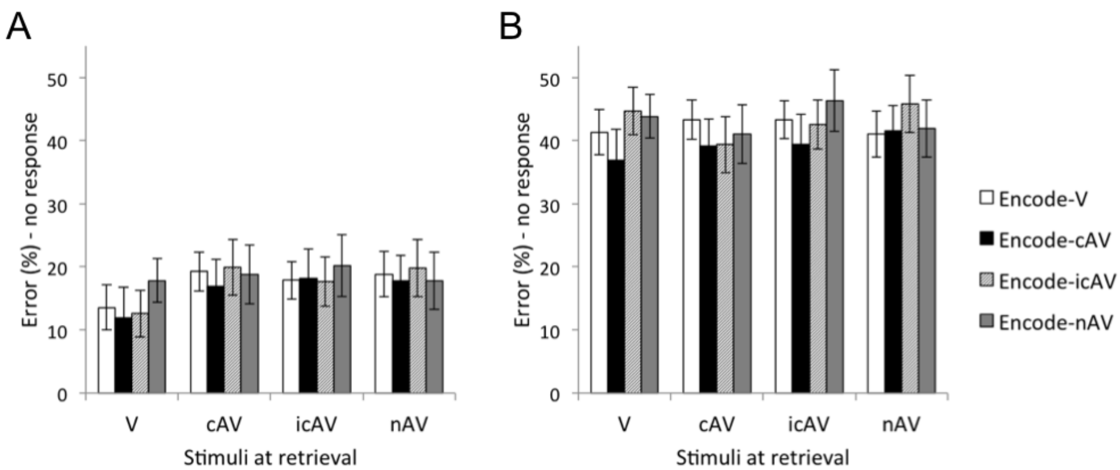

Figure 3: Mean percent error of omissions (+SEM) during the 2-back (A) and 3-back (B) tasks at the encoding (pre) and retrieval phases for the four types of stimuli: visual only (V), congruent audio-visual (cAV), incongruent audio-visual (icAV), and audiovisual stimuli with noise (nAV).

For the nBack trials, the most common type of error was of omission, i.e., a failure to respond (see Figure 3). Participants made very few errors of commission and pressed the wrong button or both buttons at once (for all n-back trials and stimulus conditions $M < 5\%$ and $Med = 0$), therefore, these errors were not analyzed further. The participants made fewer errors of omission for those trials with visual only (V) stimuli at the retrieval phase than for the multisensory trials during the 2-back task. A 4(encoding phase stimuli: V, cAV, icAV, and nAV) of the n-back) x 4(retrieval phase stimuli: V, cAV, icAV, and nAV) ANOVA was used to assess the effects of stimulus type on each WM task. For the 2-back task, normality was violated, however, here we chose not to transform because only a few variables were significantly affected, and the relatively mild skew was in the same direction for all variables. A significant main effect of stimulus type at the retrieval phase was observed, $F(3, 81) = 2.96$, $p = 0.04$, $\eta^2_p = 0.10$, β =.78. There were significantly less errors when the stimulus at the retrieval phase was visual (V) only than icAV ($p = .02$) and nAV ($p = .01$) condition, with the difference between the V and cAV condition ($p = .08$) failing to reach significance. The main effect for the stimulus type at the encoding phase of the trial, $F(3, 81) = 0.39$, $p = 0.39$, η^2_p = 0.04, $\beta = .27$, and the interaction effect, $F(9, 243) = 0.59$, $p = 0.81$, $\eta^2_p = 0.02$, $\beta = .29$, were not significant either. For the 3-back task, the 4 (encoding phase stimuli) x 4 (retrieval phase stimuli) ANOVA failed to reveal significant effects for the main effect for retrieval phase, $F(3, 81) = 0.23$, $p = 0.87$, $\eta^2_p = 0.01$, $\beta = .09$, encoding phase $F(3, 81)$ = 1.30, $p = 0.28$, $\eta^2_p = 0.05$, $\beta = .33$, and interaction effect, $F(9, 243) = 0.64$, $p = 0.77$, η^2_p = 0.02, $\beta = .31$.

3.3 Dual Task Trials

Although trials requiring a response for both the PM and the n-back task were rare (approximately 2% of trials), error rates were analyzed in order to ascertain whether participants' attention was equally distributed between the tasks or else was skewed toward one or other task. We ran additional analyses to compare errors of omission, i.e., failure to press keys related to the PM vs. the n-Back tasks (note that for these trials participants were required to press both response keys). For the 3-back task, the data from 27 participants were considered for this analysis. The dual trials were determined purely randomly and by chance one participant did not receive any dual trials in the icAV condition; their data were not considered.

As seen in Table 1, errors in the PM tasks were lower than in the n-back task, suggesting that participants either prioritized the PM task, or found the WM task to be more difficult. Significant differences were observed for both the 2-back, χ^2 (7) = 53.60, $p < 0.001$, and 3-back tasks, χ^2 (7) = 89.20, $p < 0.001$. Multiple comparisons revealed that there were significantly lower error rates for PM trials than n-back trials for all stimuli type ($p < 0.003$). Additionally, PM errors did not increase significantly between the 2-back and the 3-back task, χ^2 (7) = 11.74, $p = 0.11$. However, n-back errors were significantly higher for the 3-back than the 2-back task, χ^2 (7) = 45.04, $p < 0.001$.

Table 1. *Mean (SD) Percentage of Errors for Dual Tasks Trials in the 2-back and 3-back Conditions.*

	Prospective memory			Working memory		
2 Back *(n = 28)*	***Mean***	***SD***	***Median***	***Mean***	***SD***	***Median***
V	2.20	6.57	0.00	23.95	38.78	0.00
cAV	2.98	11.16	0.00	26.31	39.31	0.00
icAV	0.00	0.00	0.00	27.87	38.19	5.56
nAV	2.50	7.39	0.00	27.86	40.43	0.00
All conditions	1.92	6.28	0.00	26.49	39.18	0.00
3 Back *(n =27)*						
V	5.06	11.06	0.00	48.23	40.59	40.00
cAV	11.70	25.26	0.00	56.98	34.25	60.00
icAV	5.70	14.42	0.00	54.72	37.59	66.67
nAV	4.75	10.33	0.00	48.32	40.02	50.00
All conditions	6.80	15.27	0.00	52.06	38.11	54.17

Note: V = visual; cAV = congruent audio-visual; icAV=incongruent audio-visual; nAV= noise

3.4 False alarms – PM and WM tasks

Table 2. *Mean (SEM) of False Alarms (Invalid Trials) in the n-Back Tasks for the Four Stimuli Presentation Conditions.*

Stimuli type	**V**	**cAV**	**icAV**	**nAV**
2-back	1.763 (0.23)	1.66 (0.24)	1.27 (0.22)	1.56 (0.26)
3-back	3.95 (0.43)	4.13 (0.50)	3.41 (0.39)	3.69 (0.48)

Note: V = visual; cAV = congruent audio-visual; icAV=incongruent audio-visual; nAV= noise.

False alarms or errors of commission (i.e., keys pressed on trials that did not require a response) were also analyzed. The most common type of error was where participants responded using the n-back button (see Table 2). For invalid trials, participants rarely pressed the PM button or both buttons at once (for all trials $M < 5\%$ and $Med = 0$), therefore, these errors were not analyzed further. A 2 (n-back) x 4 (stimulus type: V, cAV, icAV, and nAV) repeated measures ANOVA revealed a significant main effect for the n-back tasks, $F(1, 27) = 46.01$, $p < 0.001$, $\eta^2_p = 0.63$, $\beta = 1.0$. As can be observed in Table 2, the participants made fewer false alarm errors, by pressing the n-back key, during the 2-back task than the 3-back task for all stimuli type. The main effect of stimulus type, $F(3, 81) = 2.26$, $p = 0.09$, $\eta^2_p = 0.08$, $\beta = .55$, and the interaction between stimulus type and the n-back task, $F(3, 81) = 0.28$, $p = 0.84$, $\eta^2_p = 0.01$, $\beta = .10$, were not significant.

4. Discussion

This study is the first to demonstrate that PM can be selectively enhanced by congruent multisensory stimulation. PM errors were significantly lower for congruent multisensory trials than for visual only trials, though these trials did not differ significantly from the multisensory noise and incongruent trials. Interestingly, and contrary to our expectations, the same advantage was not observed for the ongoing WM task. Auditory noise and audiovisual incongruence at the retrieval phase of the 2-back WM task significantly increased errors when compared to the visual only condition. Thus, multisensory enhancements cannot be generalized to all memory tasks. Analysis of the dual trials requiring a response for both the PM and WM tasks revealed significantly lower error rates for the PM than for the WM trials in both n-back conditions. This finding suggests that the multisensory advantage for the PM task, and the lack of such an advantage and increased multisensory interference for the WM task, may be partly related to a skew in attention resources toward the PM task.

Previous studies have shown an effect of audiovisual congruency on memory (e.g., Goolkasian & Foos, 2005; Stine et al., 1990). The present study expands on these previous studies by showing that this multisensory advantage extends to PM. In the present study, congruent audiovisual stimuli selectively enhanced the prospective, but not retrospective component of PM. Participants rarely made retrospective errors where they pressed only the incorrect button. However, participants were significantly more likely to press both buttons during the 3-back task, particularly, for the audiovisual congruent condition than for the visual only condition. This further suggests an enhancement for PM accuracy since participants were more likely to remember the PM cue with audiovisual congruent cues. The fact that the n-back button was also pressed could represent a WM error in that the participants were not certain whether the trial required a dual response. Alternatively, however, the participants may have been unable to inhibit their responses to the n-back task, thus pressing both buttons. When semantically congruent stimuli are presented in two different modalities, the signals may be perceived in a unified manner, and this may provide a stronger cue to PM (Raij et al., 2000; Stein & Rowland, 2011). Thus, congruent multisensory signals may help participants to remember that a button needs to be pressed (i.e., the prospective component), but not for the retrospective component of PM (i.e., which specific button to press). Additionally, audiovisual stimuli may have enhanced the salience of the PM cues, with the cues providing a stronger signal to respond. This study may support an effect of salience since

PM error rates for letters coupled with auditory noise and incongruent letters did not significantly differ from the congruent audiovisual letters. Indeed, the novelty of incongruent signals is likely to up-regulate signal salience and, in turn, improve PM. However, given that a significant advantage over the visual only condition was only observed for congruent multisensory stimuli, salience alone cannot explain the observed significant multisensory advantage. Stimuli consistent with prior experience, such as congruent multisensory letters, may bind more effectively to enhance PM if attended. This suggests that PM may partly rely on prior experiences when cues by multisensory signals.

The observed PM advantage for congruent audiovisual stimuli did not interact with the ongoing task load. Errors related to PM did not significantly differ between the 2-back and the 3-back task; however, the participants were more likely to press both buttons for PM trials. Participants may have recognized the PM cue but made more retrospective errors in the 3-back task. Indeed, effortful tasks can impair PM. However, in general, this is believed to be dependent on the allocation of attention (Marsh et al., 2002). The present study used a dual task design where participants had to respond to both the PM cue and ongoing task at the same time. The participants were also instructed to pay attention to both tasks. Previously, Bisiacchi and colleagues (2009) have shown that participants respond more quickly during a dual task than the task-switching condition, which requires more effort to suppress responses to the ongoing task. Similarly, the dual task nature of present study, and the fact that participants were able to respond to both tasks simultaneously, may have facilitated awareness of both the PM and ongoing tasks. Alternatively, it may be that both the 2-back and the 3-back versions of the WM task may have been substantially harder and more demanding than the PM task, thus leaving the latter sensitive to the effects of multisensory processing, irrespective of WM task load. Future studies are needed in order to investigate the effects of task load on multisensory processing under task switching conditions; an increase in PM errors with increased task load under task-switch conditions may result in enhanced multisensory advantages. Future studies are also need to better control for the effects of task difficulty between the PM and the ongoing task.

Previous WM studies have revealed superior performance with multisensory as compared to unisensory stimuli (e.g., Botta et al., 2011). In particular, Botta et al. used multisensory cues to enhance visual spatial WM. In this study, we used multisensory signaling at the stimulus encoding and retrieval phase of the n-back task, instead of cues, which did not enhance WM performance, but rather hindered performance at the retrieval phase of the task. For the 2-back task, errors of omissions were significantly lower for the visual only compared to the audiovisual incongruent and noise conditions. This interference was shown at the retrieval, but not the encoding phase of processing. Similarly, previous studies have shown that multisensory integration can interfere with processes related to memory (e.g., Quak et al., 2015; Thelen & Murray, 2013). Furthermore, past studies have also shown that responses at the encoding and retrieval phase of memory tasks may not be related, which is also consistent with the present finding. Thus, incongruent or audiovisual information can hinder performance while retrieving information from WM.

In the present study, the lack of multisensory advantage for the WM task may be related to how attention was allocated across the two ongoing tasks. Given that the incidence of the PM task (occurring on only 8% of the trials) was much lower than that of the WM task (20% of trials), the participants may have prioritized the PM task over the WM task. Indeed, the WM tasks were harder and participants made more WM-related errors than PM errors on those trials requiring a dual response, suggesting that their attention was skewed to the PM task. This may, in turn, have enhanced the effects of multisensory integration for the PM task but at the expense of an effect on the WM task, with multisensory processing having an interfering effect on WM performance instead. Previous studies have indicated that multisensory integration is dependent on one's attentional state; multisensory enhancements are primarily observed for attended tasks, and when attention is directed to both sensory signals relevant to the task at hand (Alsius, Navarra, Campbell, & Soto-Faraco, 2005; Barutchu et al., 2013; Miller, 1982, 1986; Talsma & Woldorff, 2005). In the present study, participants only attended to the visual signal and ignored all sounds, thus, reducing the likelihood of a multisensory advantage. In addition, with attention skewed to the PM task, and thus, less recourse to suppress distractors, this may have increased the semantic interfering effect of the incongruent multisensory signals. Although a similar pattern of errors was observed with the 3-back task, these failed to reach significance. The low to moderate observed power may have been a contributing factor to this lack of significance. Alternatively, however, the 3-back task may have been so demanding on attention that there may not have been enough recourse left for multisensory processes to modulate task performance.

Future studies need to further investigate the effects of attention and stimulus relevance on PM and multisensory memory, by balancing the attentional load between the tasks, or skewing attention to the ongoing (WM) task. If attention is directed to both sensory modalities (i.e., if participants had to respond to both auditory and visual signals), and if attention is skewed, or solely dedicated, to the ongoing task (i.e., the WM task in this case), then the multisensory advantage may be observed for the ongoing WM task instead. Future research should consider the effects of multisensory processing on RTs to PM and WM trials, which were not considered here; due to low sample numbers, the RT data were deemed unreliable.

In conclusion, the current study demonstrated for the first time an advantage of having congruent multisensory stimuli presentation for event-based PM, and that such advantages do not always generalize to other memory tasks even when performed simultaneously. How such multisensory processes up-regulate different type of memory processes is an important question for future research.

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