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Examining the influence of action on spatial working memory: The importance of selection

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Examining the influence of action on spatial working memory: The importance of selection

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We report three experiments that examine the influence of pointing-to relative to passively viewing an array of objects that participants are attempting to memorize. Recently, Chum, Bekkering, Dodd, and Pratt (2007) provided evidence that pointing to objects enhanced memory relative to passively viewing objects when pointing instruction was manipulated within trial (e.g., point to one array but passively view the other). We replicate this result but also demonstrate that when pointing instruction is blocked (e.g., participants point to or passively view all items in an array as opposed to pointing to some while passively viewing others), pointing to an array of objects actually decreases memory relative to passively viewing that array. Moreover, when pointing is manipulated within trial, the influence of action on working-memory performance appears to be attributable to an enhancement of processing of the pointed-to items as well as a subsequent inhibition of the passively viewed array. These results demonstrate that while action can enhance working memory under conditions where a subset of items is actively selected for additional processing, when selection is not a requirement (e.g., either point to everything or passively view everything), action decreases working-memory performance. Thus, the relationship between action and spatial working memory is complex and context dependent. These results are also discussed as they relate to other similar phenomena (e.g., retrieval-induced forgetting, Corsi Blocks test) in which selection during processing may be critical, and collectively these results provide important insight into spatial working memory and the factors that influence it.

Keywords: Spatial working memory; Action; Selection.

As we navigate our way through our external world, we are continually confronted with far more stimuli than can be processed simultaneously. Nonetheless, it is rare that we feel overwhelmed, as we tend to be able to interact with our environment in a seemingly effortless manner. It is actually the case though that almost all behaviour, no matter how minute,

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involves a complex series of interactions between attention, perception, memory, and action systems. Generally, attention and perception are thought of as the gateway to memory and action, such that we need to attend to and perceive a stimulus for it to be memorized and/or acted upon.

It is also the case, however, that the attention and perceptual systems can be influenced by the memory and action systems. Allport's (1989) selection-for-action hypothesis is based on the idea that attention is directed solely to aspects of our environment that we intend to act upon. In support of this idea, Bekkering and colleagues (Bekkering & Neggers, 2002; Hannus, Cornelissen, Lindemann, & Bekkering, 2005) have demonstrated that visual search performance is affected by action intentions, such that participants are more sensitive to the orientation of the targets/distractors in a visual display when they are required to grasp the target—a situation in which orientation information is highly relevant—than when they have to look at or point to the target—a situation in which orientation information is not very relevant. Moreover, Fischer and Hoellen (2004) have suggested that pointing to a target causes that target to be perceived in a more spatially oriented perceptual framework than does a simple motor response (e.g., lifting a finger when a target is detected).

Given the complex relationship between the attention, perception, memory, and action systems, a critical goal of cognitive research is to determine not just how each individual cognitive system functions, but also how these systems interact and influence one another. Along those lines, a recent question of interest in the field is how action influences spatial working memory. More specifically, when trying to memorize the location of an array of objects, what is the influence of pointing to each object as it appears relative to passively viewing the objects? On the one hand, it is reasonable to posit that pointing to an object would enhance memory for that object's location as it would lead to both visual and motor traces for the array in memory. Numerous studies have demonstrated that memory is enhanced when multiple retrieval paths can be used to access a single memory (e.g., Nelson & Hill, 1974). On the other hand, it is also possible that the requirement to point to objects as they appear will hurt memory as the resources required to plan and execute an action may leave fewer resources available to commit the array to memory. Along those lines, numerous studies have demonstrated that dividing attention during encoding impairs memory performance (e.g., C. M. Anderson & Craik, 1974; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996).

To date, the literature on influence of action on memory is mixed. Initially, it appeared to be the case that actions disrupt memory performance. For example, Abrams and colleagues (e.g., Hale, Myerson, Rhee, Weiss, & Abrams, 1996; Lawrence, Myerson, Oonk, & Abrams, 2001) had participants perform actions (limb movements, saccades, or both) during the retention interval between encoding and retrieval and demonstrated that these movements disrupted working-memory performance. More recently, however, Chum, Bekkering, Dodd, and Pratt (2007) had participants point to objects in an array or passively view objects during encoding and demonstrated that pointing actually enhanced memory.

In the Chum et al. (2007) study, participants were presented with two arrays (one array was made up of squares, the other array was made up of circles), which they were required to memorize for a subsequent memory test. Each array consisted of 3, 4, or 5 objects, which appeared one at a time at a location on an invisible 5 × 5 grid. Critically, memory was only tested for one of the arrays on each trial (circles or squares) but participants did not know which array was to be tested and, as such, had to memorize all objects. Moreover, participants were instructed to point to the objects in one of the arrays while passively viewing the objects in the other array. Under these conditions, pointing to objects actually enhanced memory relative to passively viewing objects, with the memory advantage for pointed-to objects decreasing as array size increased (when each array consisted of 5 objects, no benefit of pointing was observed). On the basis of these results, the authors suggested that action benefits spatial working memory, perhaps by encouraging a more spatially based perceptual framework for pointed-to objects than for passively viewed objects (see also Fischer & Hoellen, 2004), a finding consistent with the selection-for-action hypothesis.

One interesting aspect of the Chum et al. (2007) methodology was that the pointed-to and passively viewed objects were all presented in a single trial. As a consequence, it is difficult to determine whether increased memory for pointed-to objects is solely attributable to these items being encoded in a more spatially based perceptual framework. It could also be the case that the requirement to point to only half of the items in a trial (one of the two arrays) leads to an inhibition of motor action for passively viewed objects, which in turn hurts memory for the passively viewed array. In other words, it is difficult to determine whether the Chum et al. results are attributable to enhanced processing of pointed-to objects, decreased or inhibited processing of passively viewed items, or some combination of these factors.

The purpose of the present study is to further investigate the influence of pointing on spatial working-memory performance. In Experiment 1, we replicate Chum et al.'s (2007) basic methodology by having participants point to one array on a trial while passively viewing the other array. In subsequent experiments, we manipulate the requirement to point to versus passively view arrays between blocks as opposed to within each trial.

EXPERIMENT 1

The purpose of Experiment 1 was to simply replicate the initial Chum et al. (2007) result. To that end, we employed the exact same methodology that they had previously, with participants being presented with two arrays on each trial (one array of squares and one array of circles), which they were to memorize for a subsequent memory test. Moreover, participants were required to point to each object in one of the two arrays while passively viewing the other array.

Method

Participants

A total of 18 undergraduate students from the University of British Columbia underwent individual 60-minute sessions, receiving course credit as remuneration for participating in the study. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment.

Apparatus and procedure

The experiment, programmed in Visual C++, was individually conducted on a Pentium IV PC with a 19″ touch screen monitor in a room equipped with soft lighting and sound attenuation. Participants were seated approximately 44 cm from the computer screen and made responses by pressing the touch screen in front of them.

All aspects of the procedure were identical to that used by Chum et al. (2007) in their Experiment 1 (see Figure 1 for an example of a typical trial). Participants were initially presented with a screen containing only a small circle,

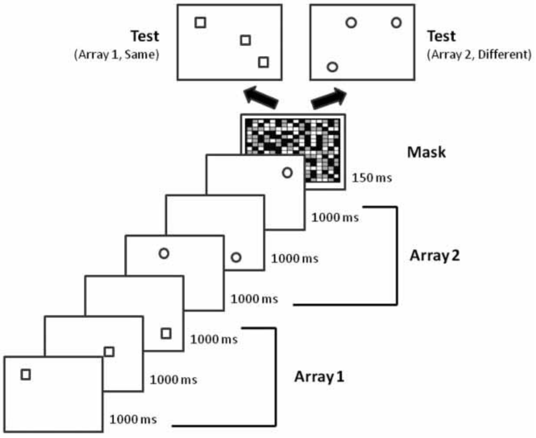

Figure 1. *Trial sequence used in Experiments 1 and 2, with an array size of three items each. Two possible memory tests are presented to show the two memory test types (same or different) though only one of the two tests was given on each trial.*

which was pressed to initiate each trial. All trials consisted of both a study phase, in which two arrays of objects were presented, and a test phase in which memory for object location in one of the two arrays was tested. In the study phase, participants viewed two arrays of objects (with one array consisting of three, four, or five white-filled squares, and the other array consisting of three, four, or five white-filled circles), with the number of objects in each array being equivalent. Each object subtended 1° of visual angle and was presented for 1,000 ms with each subsequent object appearing at the same moment that the previous object disappeared.[1] Each object appeared at one of 25 possible target areas (the 25 target areas occupied an invisible 5 × 5 grid in the centre of the screen), with the limitation that each location could only be occupied by one shape per trial. Participants were instructed to memorize the location of the objects in each array as their memory for one of the arrays would be tested at the conclusion of the study phase. Moreover, participants were instructed that they would be passively viewing the location of each object for one of the arrays (no-move array) and tapping each object as it appeared on the screen in the other array (move array). Array order was randomized—with the move array appearing first on half of all trials and the no-move array appearing first on the other half of trials—while move/no-move instruction was blocked with participants always tapping the array consisting of squares on one block of trials and always tapping the array consisting of circles on another block of trials. Participants were instructed in advance as to which array they would view and which array they would point to. There were 96 trials in each block with 32 trials for each array size. Thus, on all trials, the no-move array was encoded via a perceptual code while the move array was encoded with both a perceptual and a motor code. Participants were told that it was important to memorize not just the location of each object, but also whether the object in each location was a circle or square as the subsequent memory test would be for both object and location.

Immediately following the study phase on each trial, the participant's memory was tested for the location of objects in either the move or the no-move array. Participants did not know in advance which array would be tested, meaning that they needed to memorize both arrays at study. Following the study array, a mask containing a random matrix of small black and white squares (with each square subtending 0.4° of visual angle and the entire mask subtending 12°) was presented for 150 ms, at the end of which a test array consisting of either squares or circles was presented. In the test array, either all of the objects were presented at the same location at which they had appeared previously, or one of the objects was presented at a new location previously unoccupied by objects in either of the previously studied arrays. Participants were required to determine whether the test array was the same (respond "same") as that presented at study or whether it was different (respond "different"), with one of the objects now appearing at a new location (participants were not required to indicate which of the locations had changed position, only that a change had occurred). Two circles appeared at the bottom of the screen (one marked "S" for "same", one marked "D" for "different"), and participants were asked to tap the appropriate response button. On half of all trials, the test array was the same as the array that had been presented during study, and on the other half of trials, the test array was different. Participants were asked to take as much time as they needed for the memory test though they were encouraged to respond within 5 seconds.

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[1] In the original Chum et al. (2007) study, the array items were presented for 1,000 ms for the passively viewed array but were only presented until each item was pointed to (up to a maximum of 1,000 ms) for the pointed-to array items. We wanted to ensure that our results were attributable to action and not any difference in viewing time so we made sure each array item was presented for 1,000 ms for both arrays. Given that we successfully replicate Chum et al. in Experiment 1, viewing time does not seem to be a critical variable here.

Results and discussion

There was no difference in memory performance as a function of whether the squares array or the circles array was passively viewed, so all data were collapsed between the two blocks. Moreover, based on the results of Chum et al. (2007), we expected that memory would be affected by array order, the expectation being that memory would be better when memory was tested for the second array presented during study than when it was tested for the first array. As such, the data were initially analysed with a 2 (array order: first or second) × 2 (pointing instruction: move vs. no-move) × 3 (array size: three, four, or five items) analysis of variance (ANOVA). Unsurprisingly, there was a main effect of array order, with better memory for arrays that were presented second during the study phase. Array order did not interact with any other variables (all ps $> .41$), however, and so all data were also collapsed across this variable for subsequent analyses. Mean recognition accuracy as a function of array size and pointing instruction can be found in Figure 2. To determine the effect of pointing on spatial working memory, recognition accuracy was analysed with the 2 (pointing instruction: move or no-move) × 3 (array size: three, four, or five items) ANOVA. There was a main effect of pointing instruction, $F(1,\ 17) = 12.82$, $MSE = 0.01$, $p < .01$, with participants exhibiting better memory for arrays that they pointed to than for arrays that they passively viewed, and a main effect of array size, $F(2,\ 34) = 38.03$, $MSE = 0.00$, $p < .01$, with better memory for smaller arrays than for larger arrays. Memory performance as a function of pointing instruction and array size was essentially identical to that observed by Chum et al., with the sole exception that we did not observe an interaction between array size and pointing instruction, $F(2, 34) < 1$. Paired sample t tests indicated that participants exhibited superior memory for pointed-to relative to passively viewed arrays for all three array sizes (all ps $< .05$) and that the magnitude of this difference was equivalent across all three array sizes. Chum et al. only observed an advantage for pointed-to relative to passively viewed arrays with array size of 3 and 4, but no difference for array size 5. There were no other main effects or interactions.

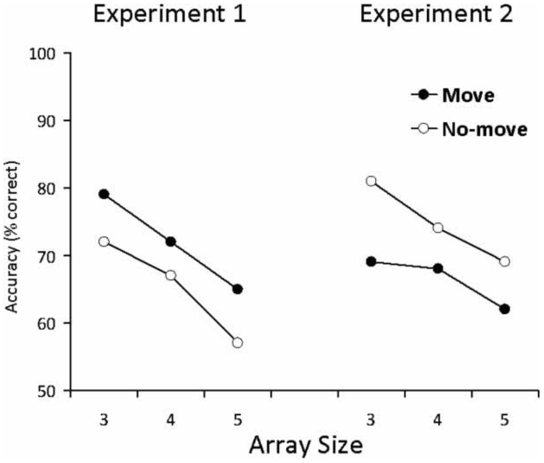

Figure 2. *Recognition accuracy as a function of array size and pointing instruction for Experiments 1 and 2.*

EXPERIMENT 2

In Experiment 1, we replicated the findings of Chum et al. (2007) as participants displayed better memory for the spatial location of objects that they had pointed to during encoding than for objects that they had passively viewed. The only difference between the present results and their results was that we observed advantage for pointed-to objects of array size 5 whereas they observed no difference. This would seem to suggest that spatial working memory is facilitated when object location is encoded via both perceptual and motor codes, relative to a perceptual code only. It is important to note, however, that in this experiment (as in Chum et al.), the requirement to point to versus passively view objects was manipulated within trial. As a consequence, it is difficult to determine whether increased memory for pointed-to objects is solely attributable to these items being encoded in a more spatially based perceptual framework. An equally plausible alternative account is that the requirement to point to only half of the items in a trial (one of the two arrays) leads to an inhibition of motor action for passively viewed objects, which in turn hurts memory for this array. In Experiment 2, we test this possibility by manipulating pointing instruction between blocks. Participants were again presented with two spatial arrays on each trial (three, four, or five squares and three, four, or five circles), which they were required to memorize for a subsequent test, but during the move block, participants were required to touch every item in both arrays, while in the no-move block, participants passively viewed the two arrays.

Method

Participants

A total of 18 undergraduate students from the University of British Columbia underwent individual 60-minute sessions, receiving course credit as remuneration for participating in the study. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment. None of the students had participated in Experiment 1.

Apparatus and procedure

The apparatus and procedure of Experiment 2 were identical to those of Experiment 1 with the exception that pointing was now manipulated between blocks as opposed to within trials. In Experiment 1, participants were required to point to all of the items in one of the two arrays while passively viewing the other. For one block of trials, participants always pointed to the square array, while for the other block of trials, participants always pointed to the circle array. In the present experiment, participants were required to point to all objects in both arrays in one block (move block) while passively viewing all objects in both arrays in the other block (no-move block). As in Experiment 1, memory was only tested for one of the two arrays on each trial. Block order was counterbalanced, with half of the participants completing the point-to block first and the other half completing the passively viewed block first.

Results and discussion

Memory was unaffected by whether the point-to block or the passively viewed block was performed first, so all data were collapsed across that variable. As in Experiment 1, we expected that memory would be affected by array order, the expectation being that memory would be better when memory was tested for the second array presented during study than when it was tested for the first array. As such, the data were initially analysed with a 2 (array order: first or second) × 2 (pointing instruction: move vs. no-move) × 3 (array size: three, four, or five items) ANOVA. Again, there was a main effect of array order, $F(1, 17) = 8.46$, $MSE = 0.03$, $p < .05$, with better memory for arrays that were presented second during the study phase. Array order did not interact with any other variables (all ps $> .36$), however, and therefore all data were collapsed across this variable for subsequent analyses. Mean recognition accuracy as a function of array size and pointing instruction can be found in Figure 2. To determine the effect of pointing on spatial working memory, recognition accuracy was analysed with the 2 (pointing instruction: move or no-move) × 3 (array size: three, four, or five items) ANOVA. There was a main effect of pointing instruction, $F(1, 17) = 17.50$, $MSE = 0.011$, $p < .01$; however, unlike Experiment 1, participants now exhibited better memory for the arrays that they passively viewed than for the arrays that they pointed to. There was also a main effect of array size, $F(2, 34) = 8.76$, $MSE = 0.01$, $p < .01$, with better memory for smaller arrays than for larger arrays. The interaction between pointing instruction and array size approached, but did not reach, conventional levels of significance, $F(2, 34) = 2.54$, $MSE = 0.00$, $p = .09$. Paired sample t tests indicated that participants exhibited superior memory for passively viewed relative to pointed-to arrays for all three array sizes (all ps $< .05$) but that the magnitude of this difference was greater for array size 3 than it was for array sizes 4 and 5, which did not differ. There were no other main effects or interactions.

Comparing the two experiments

The results of Experiment 2 are in direct contrast to the results of Experiment 1. When pointing instruction was blocked rather than manipulated within trial, participants now exhibited poorer memory for pointed-to than for passively viewed arrays. Thus, it is not always the case that spatial working memory is facilitated when object location is encoded via both perceptual and motor codes, relative to a perceptual code only.

A direct comparison of Experiments 1 and 2 is difficult given that in Experiment 1, participants pointed to between 3 and 5 objects on each trial while passively viewing an additional 3–5 objects, whereas in Experiment 2, participants pointed to between 6 and 10 objects on each trial in one block while passively viewing between 6 and 10 objects on each trial in the other block. Despite differences in encoding, however, the memory test in each experiment was the same, with memory being tested for a single array that had either been pointed to or passively viewed. A careful examination of recognition memory for pointed-to arrays relative to passively viewed arrays in the two experiments reveals an interesting pattern of results. In Experiment 1, when pointing instruction was mixed within trial, participants' memory for the pointed-to array was accurate, on average, 72% of the time (64% for array size 5, 72% for array size 4, and 79% for array size 3), whereas in Experiment 2, when pointing instruction was blocked, participants' memory for the pointed-to array was accurate, on average, 66% of the time (62% for array size 5, 68% for array size 4, and 69% for array size 3). Thus, participants displayed superior memory for the pointed-to array when it was paired with a second array that was to be passively viewed. For the passively viewed arrays, however, the opposite pattern of results is observed. In Experiment 1, participants' memory for the passively viewed array was accurate, on average, 65% of the time (57% for array size 5, 67% for array size 4, and 72% for array size 3), whereas in Experiment 2, participants' memory for the passively viewed array was accurate, on average, 75% of the time (69% for array size 5, 74% for array size 4, and 81% for array size 3). These results were confirmed by a 2 (pointing instruction: move vs. no-move) × 2 (experiment: 1 or 2) ANOVA in which there was a significant interaction between pointing instruction and experiment, $F(1,\ 34) = 29.26$, $MSE = 0.00$, $p < .01$.

Taken together, the present results suggest that spatial working memory is not always facilitated when object location is encoded via both perceptual and motor codes, relative to a perceptual code only. Instead, the critical variable appears to be the requirement to select a certain subset of items for additional processing. When participants are required to point to items in one array while passively viewing another, processing of the point-to array is enhanced but processing of the passively viewed array appears to be inhibited, when compared with trials in which all items are pointed to or all items are passively viewed. When no selection is required, however, and participants have to either point to everything or passively view everything, the additional requirement to point to objects actually impairs memory.

EXPERIMENT 3

In Experiment 3, we sought to determine whether the results of Experiment 2 were specific to the paradigm we used, or if pointing to objects in an array would also impair memory relative to passively viewing objects when participants are presented with only a single array to memorize. In the previous experiments, participants were always presented with two arrays of objects to memorize but they did not know which of the two arrays would be tested. Perhaps the additional working-memory load associated with remembering pointing instruction and two separate arrays is responsible for the difference in results between Experiments 1 and 2 and not selection per se. Evidence consistent with this idea comes from Fischer (2001), who has reported substantial differences in performance on Corsi Blocks tasks (a task that also taps spatial working memory) when the number of response alternatives are manipulated. Here, we again manipulate pointing instruction between blocks but present only a single array on each trial to reduce uncertainty as to which items would be tested. Moreover, we include a condition in which array items are presented for 2,000 ms each to give participants additional time to process each item. If pointing to items enhances spatial working memory then the requirement to memorize only one array and additional processing time could lead to enhanced memory for pointed-to items relative to passively viewed items in the present experiment. If, however, selection is key, then we would always expect participants to display superior memory for passively viewed relative to pointed-to arrays in the present experiment.

Method

Participants

A total of 44 undergraduate students from the University of British Columbia underwent individual 60-minute sessions, receiving course credit as remuneration for participating in the study. All students had normal or corrected-to-normal vision and were naïve about the purpose of the experiment. None of the students had participated in any of the previous experiments.

Apparatus and procedure

The experiment, programmed in Visual C++, was individually conducted on a Pentium IV PC with a 19″ touch screen monitors in a room equipped with soft lighting and sound attenuation. Participants were seated approximately 44 cm from the computer screen and made responses by pressing the touch screen in front of them.

The basic procedure was identical to that used in the previous two experiments so we note only the important changes below. All trials consisted of both a study phase, in which a single array of white filled-in squares was presented, and a test phase, in which memory for the location of the squares was tested. In the study phase, participants viewed a single array of squares (which consisted of 5, 7, or 9 squares[2]). For half of all participants, each square was presented sequentially for 1,000 ms, whereas for the other half of participants, each square was presented sequentially for 2,000 ms. In both the 1,000-ms and 2,000-ms display conditions, each subsequent square appeared at the same moment that the previous square disappeared. Participants were instructed to memorize the location of the squares as their memory would be tested at the conclusion of the study phase. Moreover, participants were instructed that they would complete two blocks of trials, and that in one block they were to passively view each square as it was presented (no-move block), whereas in the other block they would be required to tap each square as it appeared (move block). Block order was randomized. For the 1,000-ms display condition, there were 96 trials in each block with 32 trials for each array size. For the 2,000-ms display condition, there were 72 trials in each block with 24 trials for each array size. Thus, in the no-move block, the array was always encoded via a perceptual code, while in the move block, the array was encoded with both a perceptual and motor code.

Immediately following the study phase on each trial, participants' memory was tested for the location of all squares in the just-viewed array. Prior to the test array, a mask containing a random matrix of small black and white squares (with each square subtending 0.4° of visual angle and the entire mask subtending 12°) was presented for 150 ms, at the end of which a test array was presented. In the test array, either all of the squares were presented at the same location at which they had appeared previously, or one of the squares was presented at a new location previously unoccupied by any of the squares in the study array. Participants were required to determine whether

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[2] We initially pilot tested this experiment with array sizes of 3, 5, or 7 objects, but performance was at ceiling for the 3-object arrays, preventing us from making any sort of meaningful comparison between the point-to and passively viewed arrays.

the test array was the same (respond "same") as that presented at test or whether it was different (respond "different"), with one of the squares now appearing at a new location (participants were not required to indicate which of the locations had changed position, only that a change had occurred). Two circles appeared at the bottom of the screen (one marked "S" for same, one marked "D" for different), and participants were asked to tap the appropriate response button. On half of all trials, the test array was the same as the array that had been presented during study, and on the other half of trials, the test array was different. Participants were asked to take as much time as they needed for the memory test though they were encouraged to respond within 5 seconds.

Results and discussion

Memory was unaffected by whether the point-to block or the passively viewed block was performed first so all data were collapsed across that variable. Mean recognition accuracy as a function of array size, display time, and pointing instruction can be found in Figure 3. To determine the effect of pointing on spatial working memory, recognition accuracy was analysed with a 2 (pointing instruction: move or no-move) × 2 (item display time: 1,000 ms vs. 2,000 ms) × 3 (array size: three, four, or five items) ANOVA. There was a main effect of pointing instruction, $F(1, 21) = 15.10$, $MSE = 0.02$, $p < .01$, as participants displayed better memory for passively viewed arrays than for pointed-to arrays, just as in Experiment 2. There was also a main effect of array size, $F(2, 42) = 31.84$, $MSE = 0.01$, $p < .01$, with better memory for smaller arrays than for larger arrays. Finally, there was an interaction between display time and array size, $F(2, 42) = 4.62$, $MSE = 0.01$, $p < .05$, as the effect of array size was reduced with longer display times. There were no other significant main effects or interactions. Critically, in none of the conditions in the present experiment did we observe a memory advantage for pointed-to relative to passively viewed objects. Even with a working-memory load reduction in the present experiment relative to Experiment 2 (given that there was only one array to memorize, fewer overall items to memorize, and up to twice as much time to memorize each location), participants displayed consistently better memory for passively viewed objects.

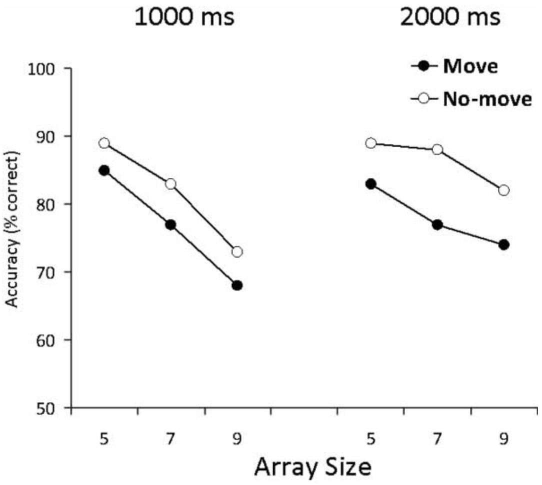

Figure 3. *Recognition accuracy as a function of array size, pointing instruction, and display time (1,000 ms per object or 2,000 ms per object) for Experiment 3.*

GENERAL DISCUSSION

Taken together, the results of the present study suggest that the influence of action on spatial working memory is far less straightforward than it initially appeared. Recently, Chum et al. (2007) provided evidence that pointing to an array of objects enhanced memory relative to passively viewing an array. It was suggested that pointing led to a more "active" processing of object location and that the enhanced memory for pointed-to objects was attributable to these items being encoded in a more spatially based perceptual framework. Given that Chum et al. manipulated pointing instruction within trials, however, it was unclear as to whether the advantage for pointed-to objects reflected enhanced processing of pointed-to objects, decreased or inhibited processing of passively viewed items, or some combination of these factors. In the present Experiment 1, we replicated the basic Chum et al. finding, with memory for pointed-to arrays being superior to memory for passively viewed arrays. In the present Experiment 2, however, we manipulated pointing instruction between blocks, and a very different pattern of results emerged. Memory was now superior for passively viewed arrays relative to pointed-to arrays. Moreover, in comparing the first two experiments, it is clear that the enhanced memory for pointed-to arrays in Experiment 1 is also accompanied by poorer memory for the passively viewed array than when pointing instruction is blocked. This would suggest that the requirement to select a subset of items for additional processing (pointing) leads not only to enhanced memory for the selected objects, but also a decrement in memory for the objects that were not selected for additional processing. In Experiment 3 we replicated Experiment 2 with a slightly different paradigm, which reduced working-memory requirements (by presenting only one array rather than two and increasing display time for each object within the array) but we still observed a consistent advantage for passively viewed arrays relative to pointed-to arrays.

The results of the present experiments are clear. Simply pointing to an object does not, alone, enhance memory for that object and may actually impair memory for objects as the resources required to execute a motor movement may leave fewer resources available to memorize object location. Instead, the critical predictor of how action influences memory appears to be the requirement for selection. When individuals are required to select a subset of items for action, there is a distinct advantage to encoding items in terms of both a perceptual and a motor trace. The enhanced memory for objects that have been selected for action, however, comes at a cost: that being relatively impaired memory for the items not selected for action. In situations where individuals are required to point to or passively view every item on a trial, however, all items are treated equally (there is no requirement to select a subset of items for additional processing), and the requirement to point to objects interferes with the memory process.

It is worth noting that while the present Experiment 1 replicated Chum et al.'s (2007) basic pattern of results, we did not obtain a load-dependent decrease in action-based facilitation. Chum et al. only observed an advantage for pointed-to arrays relative to passively viewed arrays for array sizes of three and four, leading to the suggestion that action-based facilitation effects may be masked or negated with larger array sizes, or that there is a limit to the amount of egocentrically coded spatial information that can be held in spatial working memory. While both of these possibilities are compelling, our failure to replicate the load-dependent finding here calls into question whether such a distinction is necessary as the effect of action on working memory was consistent across all of our arrays.

The finding of enhanced memory for items selected for action and reduced memory for items not selected for action is reminiscent of other selection-based memory effects, such as retrieval-induced forgetting (e.g., M. C. Anderson, E. L. Bjork, & Bjork, 2000; M. C. Anderson, R. A. Bjork, & Bjork, 1994; Dodd, Castel, & Roberts, 2006; MacLeod & Macrae, 2001). In retrieval-induced forgetting studies, participants initially study a series of category–exemplar pairs, which they are to learn for a later memory test. Following study, participants engage in retrieval practice, where they are repeatedly cued to recall half of the items from half of the studied categories. On a later free-recall test, participants display superior memory for items that they have studied and practised recalling but decreased memory for unpractised items from practised categories relative to items from unpractised categories. It has been suggested that retrieval-induced forgetting is an inhibitory effect, wherein the act of correctly recalling an item during retrieval practice necessitates an inhibition of related competitors, making them less accessible at a later time. A similar account could be offered for the results of Chum et al. (2007) as well as the present Experiment 1. Perhaps when participants are required to point to only half of the items in a trial (one of the two arrays), this leads to an inhibition of motor action for passively viewed objects, which in turn hurts memory for the passively viewed array. It is worth noting, however, that while these effects may be conceptually similar, in the present research we believe the influence of action/selection occurs at encoding whereas with retrieval-induced forgetting the critical processing is generally thought to take place during retrieval and/or retrieval practice, an important distinction between the two effects. Further research will be required to determine whether the decrement in memory that is related to selection is attributable to inhibitory processes.

Beyond retrieval-induced forgetting, the present results also seem closely related to studies of spatial short-term memory capacity as assessed by the Corsi Blocks task. The Corsi Blocks task requires participants to reproduce recently perceived visual displays through a series of sequential pointing movements. Though often used as a measure of spatial memory span, there was no initial agreement as to how Corsi Blocks should be used, and, as such, methodological differences across studies have led to confusion as to what, exactly, is being tested and how various critical variables (e.g., visual encoding, maintenance, response selection) are contributing to overall performance (see Fischer, 2001, for a review). Fischer (2001) had participants perform a series of Corsi Blocks tasks while manipulating the duration of encoding intervals, retention intervals, and response alternatives and reported substantial differences in performance as these key variables were systematically altered. Though not identical to the Corsi Blocks task, the present manipulation also points to the importance of task set, selection, and trial type in measuring spatial working memory when participants engage in a motor-driven task relative to a strictly visual task. Taken together, these results further our understanding of spatial working memory and the factors that influence it.

Having determined that the influence of action on working memory is sensitive to contextual manipulations, further research will be required to determine when action is advantageous to the encoding of information and when it is detrimental. For example, had participants in the present study been required to memorize not just the location of items in an array, but also the order in which the items were presented, there is reason to believe that a motor code would facilitate performance in this situation. Logie (1995) has distinguished between visual and spatial components of working memory by proposing an active movement-driven component known as the inner scribe and a static visual component known as the visual cache. Given that our pointing manipulation probably taps into the inner scribe while our passive viewing manipulation is likely to engage only the visual cache, this creates the possibility that quite different memory representations are being formed, and the effectiveness of the representation will be a function of task type. If participants were required to track the order in which objects were presented, or track moving objects on a screen, a distinct advantage may again arise for pointing over passively viewing materials, because the inner scribe would be central to each task. The issue at hand, therefore, is larger than whether a manipulation is run in a mixed or blocked fashion and instead more relevant to the type of processing engaged and how performance is affected, reminiscent of the classic transfer-appropriate processing phenomenon in memory for verbal materials (e.g., Morris, Bransford, & Franks, 1977).

In conclusion, the present study suggests a complex interaction between action and working memory. When individuals select a subset of items in a display for additional processing, the act of pointing to those items enhances memory relative to the other items that are only passively viewed. Though this would seem to suggest that the act of encoding items with both a perceptual and a motor trace leads to superior memory relative to encoding items via a perceptual trace only, the results of our Experiments 2 and 3 show this not to be the case. When participants are required to point to or passively view all items in a display, memory is actually superior for the passively viewed item. The critical variable here seems to be that of selection, such that when a subset of items requires selection for additional processing, processing of the selected (e.g., pointed-to) items is enhanced while processing of the nonselected items is reduced. When no selection is required, and all items are treated equally, however, the additional resources required to engage motor activity may be seen as interfering with one's ability to memorize object location or, alternatively, a qualitatively different type of representation may be formed at encoding, the effectiveness of which may be dependent on task type. In any case, a useful analogy here would be that of a university student studying for an exam, who has decided to highlight key passages of text to which they will devote greater attention. A student who is able to effectively use this technique would select key passages for additional processing, and their memory for these passages should be subsequently enhanced, while their memory for material that has not been highlighted would be poor. Not all students are able to effectively use this technique, however, as students who are unable to determine what is important will just highlight everything they read. Unfortunately, the mere act of highlighting does not ensure that material will be committed to memory, meaning that the student has wasted valuable time and resources highlighting every passage in the text when they could have simply dedicated that same time/resources reading and memorizing the material. In the former example, highlighting would be incredibly helpful, whereas in the latter, it is hurtful. The influence of action on memory seems to play out in a similar manner, as it is only beneficial in an appropriate context, and action alone does not guarantee any processing benefit.

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