5
Experiments 3, 4, and 5

The three experiments reported in this chapter were designed to further explore the results of Experiment 2. With the desire to understand the factors underlying the differential effect of mode of presentation on feature binding performance, the aim was to test what would happen if the encoding conditions of the stimuli were manipulated to be different. Thus, in Experiment 3, the exposure duration of the simultaneously presented stimuli was reduced. In Experiment 4, blank intervals were introduced after every stimulus in the sequential presentation condition. In Experiment 5, pattern masks [visual noise] were used to study the role of spatiotopic representations in iconic memory. The detailed rationale and relevant literature for each of these experiments in presented in this chapter followed in each case by the changes in design and procedures, the results, and discussion.

Nevertheless, in all experiments, in accordance with the review of literature with regard to the importance of locations in feature binding, unchanged locations are expected to yield better performance than random locations. An interaction of locations and mode of presentation is also predicted as locations are expected to play a greater role in simultaneous than sequential presentation.

5.1 EXPERIMENT 3

One of the reasons for simultaneous presentation yielding better performance than sequential presentation in Experiment 2 could be its long presentation time i.e., 1000 ms. This presentation time was kept at 1000 ms in Experiment 2 to equate it with the total presentation time of sequential presentation, where each of the four stimuli were presented for 250 ms.

In Experiment 3, the presentation time of study display in the simultaneous presentation condition was reduced to 250 ms, to make it equal to *one* stimulus of sequential display. Thus, one can say that participants were tested at the other logical extreme, as far as presentation time was concerned. If the superior performance in the simultaneous condition in Experiment 2 is indeed due to the long presentation time, reducing the presentation time of the study display to 250 ms should decrease performance in the simultaneous presentation condition, rendering it lesser than or no different from performance under the sequential presentation condition.

Myriad studies show that longer presentation time generally leads to better performance across a variety of tasks, although there are thresholds for initial liftoff of performance, as well as for when there is no further improvement possible and performance reaches an asymptote [Busey and Loftus, 1994; Loftus and McLean, 1999]. Loftus *et al.* [1985] varied the exposure duration of the stimulus from 62 ms to 1300 ms. The performance curve, when plotted as a function of exposure time, steadily increased, but was level toward the end.

Using sequentially presented stimuli, Potter and Levy [1969] first tested recognition accuracy for series of stimuli with presentation times ranging from 113 ms to 333 ms. Potter [1976] stated that the representation of one stimulus can be compared with another stimulus only after post-processing of the stimulus for several hundred milliseconds. For processing of a natural complex visual scene approximately 100 ms is required [Thorpe *et al.*, 1996]. Standing [1973] suggested that even a new scene is very easy to remember if the presentation time is one second or more. In his studies, with serial presentation of multiple stimuli, recognition accuracy was enhanced with an increase in the time of presentation.

Using simultaneously presented stimuli, Pashler [1988] reported a small yet significant increase in memory for 10 consonants, which were shown for 100, 300, and 500 ms. Liu and Jiang [2005] asked their participants to remember as many objects as possible in images of real life scenes, such as the contents of a refrigerator. They found that an exposure of 250 ms allowed only about one object to be retained in memory, but performance improved with increased exposure duration.

The time-based resource-sharing model [Barrouillet *et al.*, 2004; Barrouillet and Camos, 2007] explains that increasing the duration of exposure of stimuli improves performance because it allows more time for encoding and processing of stimuli in working memory.

Studies specifically testing the effect of duration of stimulus exposure on feature binding in working memory are reviewed in the next few paragraphs. These experiments do generally show greater performance with an increase in stimulus exposure. However, it is difficult to infer an optimum time for which a stimulus is to be presented, given the different kinds of stimuli, different set sizes, and various other variables studied in these experiments.

Karlsen *et al.* [2010] tested the binding performance for spatially and temporally separated features [color and shape] in comparison with bound objects comprising the same features. In an experiment with serial presentation of spatially separated features, two levels of presentation time were used i.e. 250 ms per stimulus and 1000 ms per stimulus. Results revealed significantly better performance with longer presentation time. In another experiment, when the stimuli were presented simultaneously, the presentation time was either 1000 ms or 3000 ms. The effect of presentation time was significant at $p<.058$ with the longer presentation time causing marginally better performance. This research indicated that presentation time is important in processing of objects

Using a different task to test binding, Bays *et al.* [2011] studied the recall precision of binding of color and orientation for simultaneously presented stimuli as a function of presentation time over set sizes 1 to 6. The precision curve, which is the reciprocal of the standard deviation of the error, increased from 0 to 500 ms, but seemed to be constant after that till 1100 ms. Later, Peich *et al.* [2013] used this task to compare the presentation times of 200 ms and 2000 ms [2 seconds] and memory load [1 stimulus or 3 stimuli] to assess the effect of aging on binding of color and orientation. The main effect of presentation time was significant, with performance being worse with the shorter presentation time.

Rhodes *et al.* [2016] manipulated the presentation time to be 900 ms and 2500 ms and tested younger and older adults with binding and uni-feature stimuli. The main effect of the presentation time was significant, with the longer presentation time leading to better memory across age and different types of stimuli.

Brown *et al.* [2017] tested binding performance in younger and older adults. They studied two different presentation times, i.e., 900 ms and 1500 ms, for color only, shape only, and binding stimuli, with both groups. They found that only older people benefit with longer presentation time, and this was irrespective of memory for single feature or binding stimuli. In their second experiment, they compared simultaneous and sequential presentation but used a presentation time of only 1500 ms. In the case of sequential presentation they used 500 ms for each stimulus equating it to the total of 1500 ms for simultaneous presentation of three stimuli. Overall, there were no differences in performance due to mode of presentation, but younger adults performed worse with sequentially presented stimuli specifically in the binding condition.

The current set of experiments are based on Jaswal and Logie [2011], in the sense that they too manipulated locations to be unchanged and random, and tested different modes of presentation, albeit in separate experiments. In each experiment, besides location, they tested the effect of presentation time and study-test intervals on color-shape binding. The presentation times for the study display were 200 ms, 900 ms, and 1500 ms for six stimuli. In the experiments using simultaneous presentation [Experiment 2] and sequential presentation where the display was built up by introducing stimuli one by one [Experiment 3], change detection was significantly worse with exposure durations of 200 ms than 900 ms or 1500 ms. However, there was no difference between 900 ms and 1500 ms in the level of performance. Presumably, 200 ms were insufficient to encode the six stimuli used in their study, but increasing the display duration from 900 to 1500 ms did not yield any significant benefit. In the experiment using sequential presentation, where the previous stimuli disappeared as the next was presented, performance was generally very low and there was no significant effect of time of presentation.

Notice that Jaswal and Logie [2011] had six stimuli, whereas the present research has only four stimuli, which are the same as the upper threshold of working memory capacity. If these four stimuli are easily encoded within 250 ms, there will be no difference in the performance in the simultaneous presentation condition in this experiment as compared to Experiment 2. Otherwise, reducing the time of the study display from 1000 ms to 250 ms is likely to decrease performance in the simultaneous presentation condition as compared to performance in Experiment 2. For sequential presentation, there being no difference from Experiment 2, performance levels similar to Experiment 2 are expected. The concomitant effect of reduced display duration on the interaction of modes of presentation and locations is also of interest.

5.1.1 Design and procedure

The design and procedure remain the same as Experiment 2 except that the study display in the simultaneous presentation condition was shown only for 250 ms.

The experiment was a 2 × 2 factorial design with repeated measures on both factors – mode of presentation [simultaneous vs. sequential] and locations [unchanged vs. random]. Each trial presented four stimuli in the study display. The participant had to remember the bindings between colors and shapes. The stimuli remained on the screen together for simultaneous presentation for 250 ms only. In the sequential presentation condition, every stimulus appeared for 250 ms, with each stimulus being offset with the onset of the next stimulus.

To manipulate locations at two levels – unchanged and random, on half the trials, the test stimuli were presented in exactly the same locations as those in the study display, and on the other half of the trials, the stimuli in the test display appeared in random locations with respect to the study display.

The participant had to detect changes in the binding of color and shape in any stimulus. Whenever a change occurred, it was actually a swap between any two stimuli. Binding change occurred on 50% trials. The dependent variable was accuracy of response, calculated as d prime. Results were analyzed using repeated measures *ANOVA.*

The sequence of events in each trial is depicted in Figure 5.1.

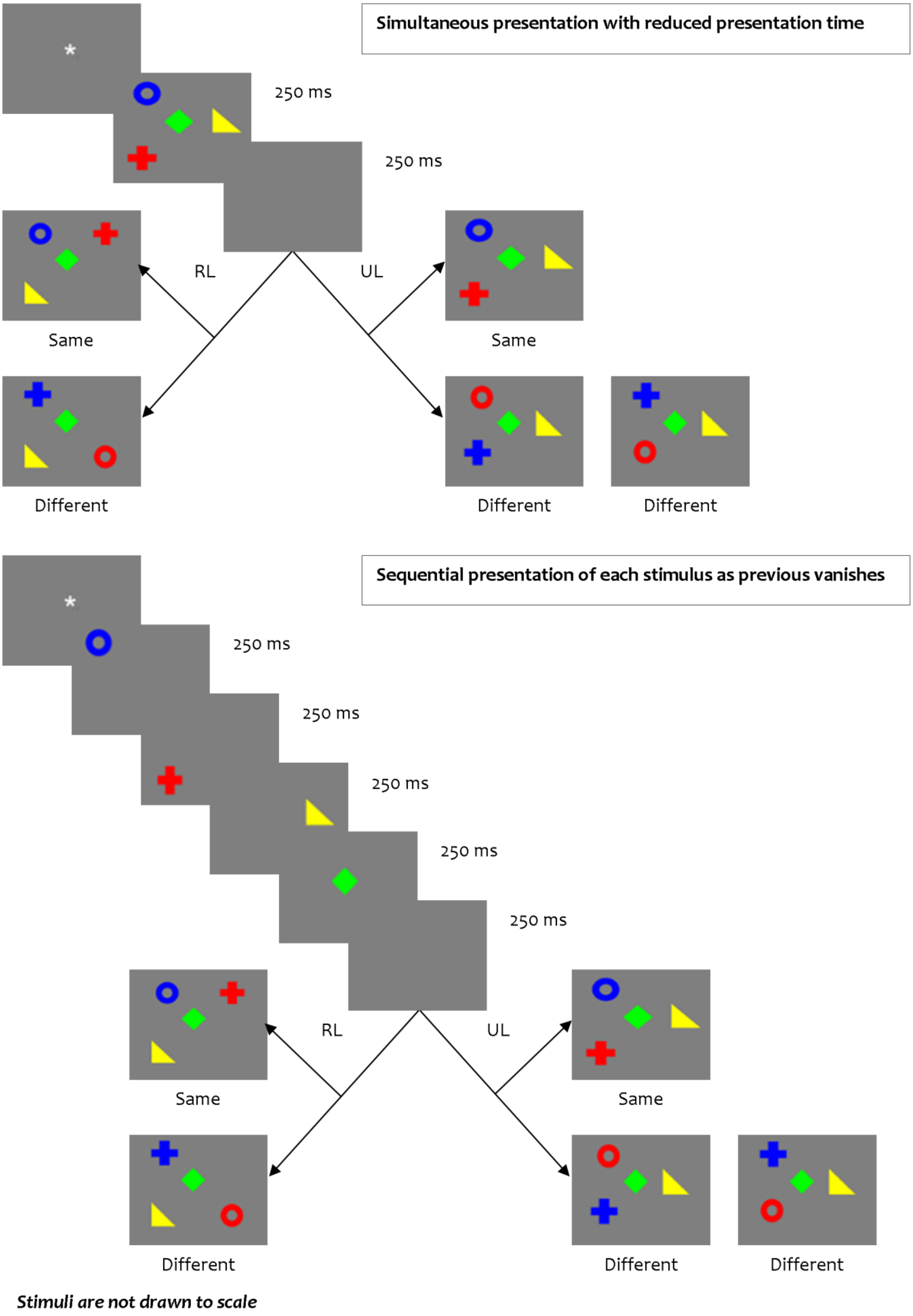

Figure 5.1: Sequence of events in each trial in Experiment 3

5.1.2 Results

Primary Analyses

Mean change detection scores calculated as d primes are shown in Figure 5.2. A repeated measures *ANOVA* revealed the main effect of unchanged and random locations, $F[1,17]=60.598$, $MSE=.237$, $p<.001$, *partial* $\eta^2=.781$, $BF_{10}= 3.984\times10^4$ in that overall performance was reduced when locations were randomly changed from study to test display than when locations were unchanged. The main effect comparing simultaneous and sequential presentation was also significant, $F[1,17]=7.459$, $MSE=.242$, $p<.014$, *partial* $\eta^2=.305$, $BF_{01}=1.226$ with performance being better with simultaneous than sequential presentation. The interaction effect was significant, $F[1,17]=23.061$, $MSE=.381$, $p<.001$, *partial* $\eta^2=.576$, $BF_{10}= 1.760\times10^4$. As depicted in Figure 5.2, there is a significant difference between unchanged and random locations with simultaneous presentation, $t[17]=7.137$ $p<.001$, $d = 1.682$, $BF_{10}= 1.121\times10^4$ but the difference is not significant for sequential presentation $t[17]= 1.406$, $p< 0.178$ ns, $d= 0.331$, $BF_{01}= 1.773$.

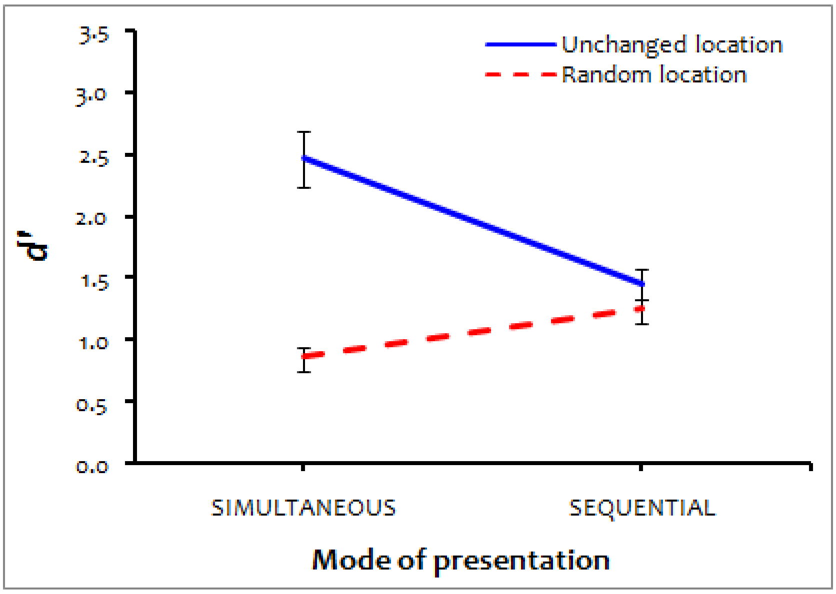

Figure 5.2: Mean d prime scores in Experiment 3

Serial position effects in sequential presentation

The serial position effects in the sequential presentation condition were explored using a 2×4 repeated measures *ANOVA* [location × swaps]. The swaps selected for this analysis were between stimuli shown at serial positions 1 and 4 [showing the joint effect of primacy as well as recency], 1 and 2 [showing only primacy effect], 2 and 3 [items in the middle positions], and 3 and 4 [showing only recency effect].

The main effect of locations was not significant. But the main effect of swaps was significant $F[2.131, 36.134]=10.138$, $MSE=3.181$, $p<.001$, *partial* $\eta^2 =.374$, $BF_{10}=4.453\times10^5$, with Greenhouse-Geisser correction applied. Post-hoc analysis [with Bonferroni adjustment] showed a significant difference between swaps of stimuli at the serial positions 1 and 4, and positions 1 and 2, [$t[17]=3.226$, $p<.030$, $d=.760$, $BF_{10}=9.494$]; at positions 1 and 4, and positions 2 and 3, [$t[17]=4.009$, $p<.005$, $d=.945$, $BF_{10}= 40.566$]; and at positions 2 and 3, and positions 3 and 4 [$t[17]=3.788$, $p<.009$, $d=.893$, $BF_{10}=26.845$]. The interaction effect was not significant. The similar pattern of serial position effects in unchanged and random locations is depicted in Figure 5.3.

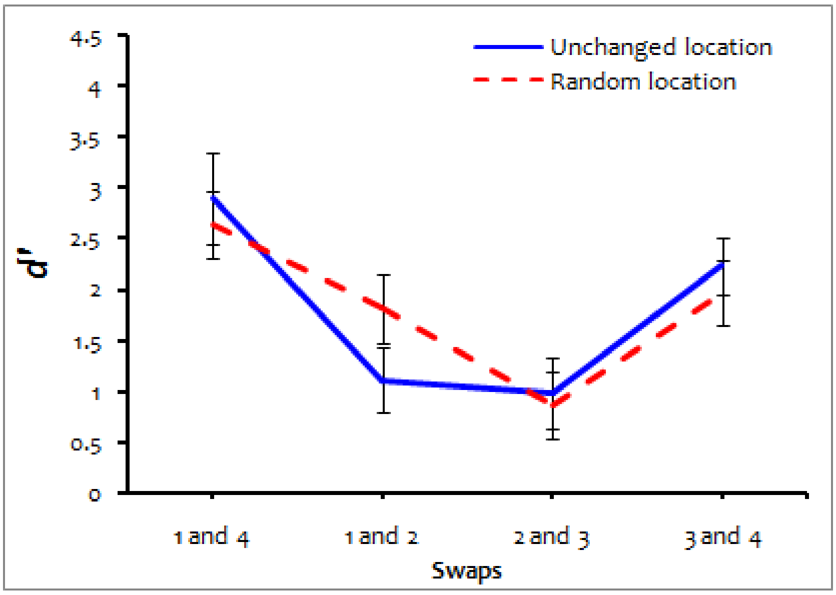

Figure 5.3: Serial position effects in Experiment 3

Comparison of Experiments 2 and 3

A comparison of Experiments 2 and 3 using a three way *ANOVA* with experiments as between participants factor, and mode of presentation and locations as repeated measures, showed that neither the main effect of experiments nor any of its interactions were significant. Bayes factors were computed for each combination of main and interaction effects. A model comprising the three way interaction with all the three main and interaction effects [BF_{10}= 5.608×10^{16}] was compared with a model of three possible main and interaction effects without the three way interaction effect [BF_{10}= 7.173×10^{16}]. The model with a three way interaction fit the data better only by a factor of 1.27:1.

5.1.3 Discussion

The pattern of results obtained in this experiment is the same as that obtained in Experiment 2. The results of this experiment indicate that the presentation time of the study display is not a driving factor in the difference between simultaneous and sequential presentation. In addition, 250 ms are seemingly enough to create a mental representation of the stimuli that can later serve for detection of a change in the test display with respect to the initial stimuli.

Reducing the presentation time of the simultaneous display to a quarter of what it was in Experiment 2 had no effect on the performance of participants. Shorter exposure to the stimuli does not decrease [or increase] the performance of the participants, there being simply no significant difference between Experiments 2 and 3. These results indicate that the presentation time of the study display is not an important factor in the performance of the participants.

5.2 EXPERIMENT 4

Although it seems that better performance with simultaneous presentation is obtained regardless of presentation time, perhaps it is the time given for encoding the stimulus in the sequential condition, which is not enough. Several experimenters have inserted blank intervals after stimulus presentation to aid the process of consolidation. In an early experiment, Erwin [1976] compared three conditions – a blank interval that allowed visual persistence, an immediate mask condition, and a condition where the actual stimulus alternated with a noise mask for the duration that the visual persistence was appraised to last. He found best performance with the blank interval, i.e., the condition, which allowed visual persistence. It was clear that processing of information continues even after the stimulus is no longer present.

Many investigators have studied the process of consolidation, which presumably continues in the blank interval after a stimulus has been presented, using masks to stop the process. The initial assumption was that an immediate mask would destroy the effect of iconic memory, but a delayed one would allow extraction of more information from the icon [Loftus *et al.*, 1985; Loftus *et al.*, 1992]. Vogel *et al.* [2006] used masks at various delays to study the rate of consolidation of colored squares into visual working memory. They found that the rate of consolidation was 50 ms per item and the capacity of visual working memory was limited to about four items. Saults and Cowan [2007] used a similar technique to study working memory capacity across visual and auditory domains.

Another experimental technique that allows the study of the effects of blank intervals, is slowing down the rate of presentation of the stimuli in a sequence. This technique has been recently used in an experiment by Souza and Oberauer [2017] with the effect of increasing the episodic memory of the stimuli presented at a slower rate.

Around the time when the present experiments were being designed, Ricker and Cowan [2014] published their paper tested forgetting in working memory as a function of time. They formulated the experimental conditions comparing simultaneous and sequential conditions such that a blank interval was introduced between the stimuli in the sequential mode. Presumably, this helped in proper encoding of a stimulus, and it made performance in the sequential condition better than the performance in the simultaneous condition. Although they only tested memory for single features, analogously, in the present work, blank intervals were inserted after each stimulus in the sequential presentation condition in Experiment 4, with a view to improving performance in this condition. Presumably, blank intervals aid consolidation or at least protect each stimulus from being overwritten by subsequent stimuli.

5.2.1 Design and procedure

The design and procedure of this experiment was the same as Experiment 2 [and Experiment 3], except two changes. In this experiment, a blank interval of 250 ms was inserted after each stimulus in the sequential presentation condition. Thus, the total time for sequential presentation was 1750 ms, with four stimuli presented for 250 ms each and three blank intervals of 250 ms between the stimuli. [Note that the 250 ms study-test interval anyway followed the last stimulus as per the original design].

The second, related change was an increase in display time for simultaneous presentation to 1750 ms, to equate it with the total presentation time for sequential presentation. Together, the results of Experiments 2 and 3 had already shown that the exposure duration of the simultaneously presented stimuli was not an important factor in the performance of the participants. Thus, it was assumed that increasing the exposure duration of simultaneously presented stimuli to equate it with the total presentation time for the sequential presentation condition would not matter for performance in this condition, and in fact, was necessary to the experimental design.

Other than these two changes, the experiment retained the full factorial 2×2 repeated measures design of the earlier experiments, testing memory for color-shape binding of four stimuli, as a function of simultaneous and sequential modes of presentation, and unchanged and random locations. The sequence of events in each trial is depicted in Figure 5.4,

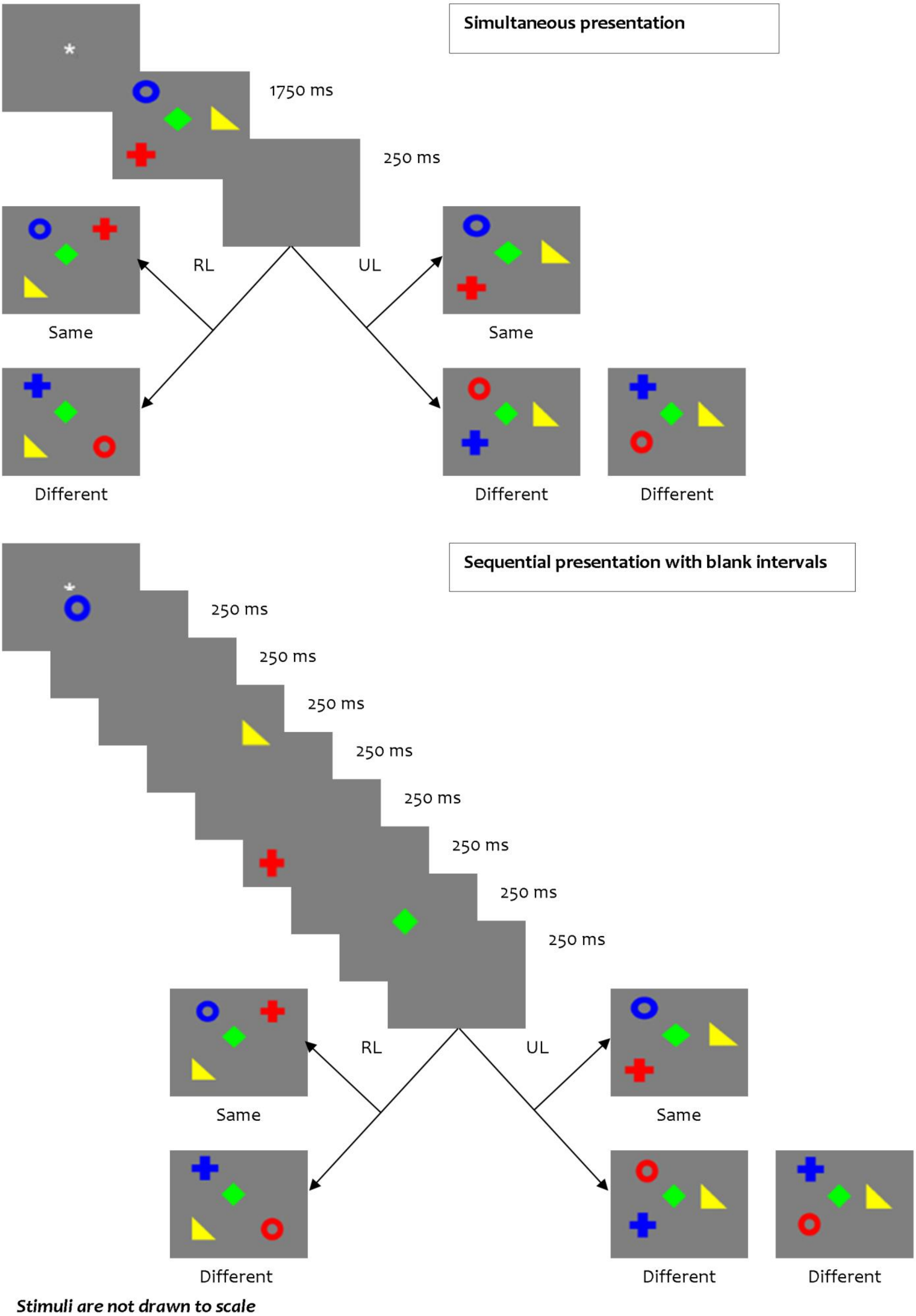

Figure 5.4: Sequence of events in each trial in Experiment 4

5.2.2 Results

Primary Analyses

Mean change detection performance calculated from d primes is shown in the Figure 5.5. A repeated measures *ANOVA* revealed the main effect of unchanged and random locations, $F[1,17]=31.006$, $MSE=.313$, $p<.001$, partial $\eta^2=.646$, $BF_{10}=72.278$ in that overall performance was reduced when locations were randomly changed from study to test display than when locations were unchanged. The main effect of simultaneous and sequential presentation was not significant, $F[1,17] = 3.096$, $MSE=1.085$ $p<.096$ ns, partial $\eta^2=.154$, $BF_{10}=1.47$. Nevertheless, the interaction effect was significant, $F[1,17]=11.826$, $MSE=.372$, $p<.003$, partial $\eta^2=.410$, $BF_{10}= 6.027$. Figure 5.5 clearly depicts that the differential effect of unchanged and random locations is significant in the simultaneous presentation condition, $t[17]=8.438$, $p<.001$, $d = 1.989$, $BF_{10}= 8.765\times10^4$ but not in the sequential presentation condition, $t[17]= 1.026$, $p< 0.319$ ns, $d= .242$ and $BF_{01}= 2.617$.

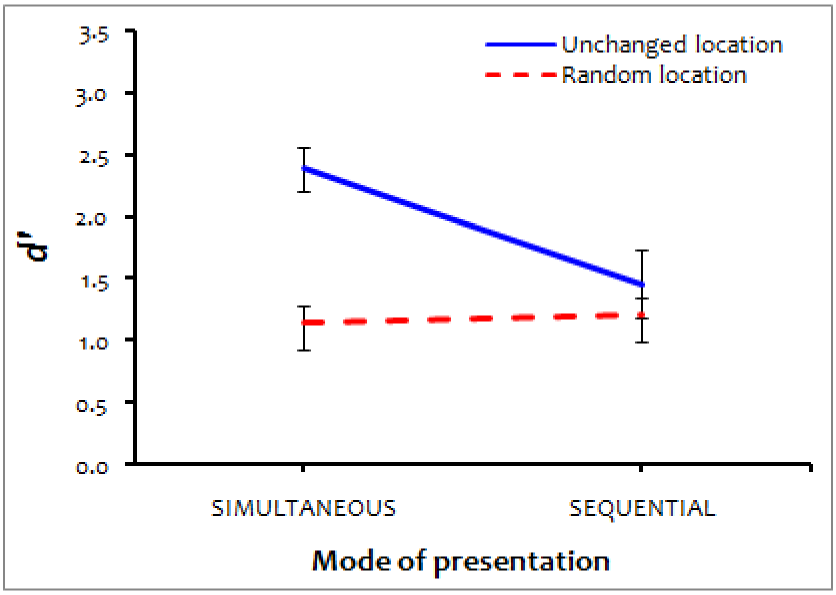

Figure 5.5: Mean d prime scores in Experiment 4

Serial position effects in sequential presentation

The serial position effects in the sequential presentation condition were explored using a 2×4 repeated measures *ANOVA* [location × swaps]. The swaps selected for this analysis were between stimuli at serial positions 1 and 4 [showing the joint effect of primacy as well as recency], 1 and 2 [showing only primacy effect], 2 and 3 [items in the middle positions], and 3 and 4 [showing only the recency effect].

The main effect of locations was not significant. However, the main effect of swaps was significant, $F[3, 51]= 4.453$, $MSE=1.848$, $p < .007$, partial $\eta^2=.169$, $BF_{10}=10.953$. Post-hoc analysis [with Bonferroni adjustment] shows a significant difference between swaps of stimuli at serial positions 1 and 4 and those at positions 2 and 3 [$t[17]=3.216$, $p<.030$, $d=.758$, $BF_{10}=9.333$]. This implies that the joint effect of primacy and recency led to better performance as compared to performance due to swaps of items in the middle positions, thus substantiating the serial position effect. The interaction effect was not significant.

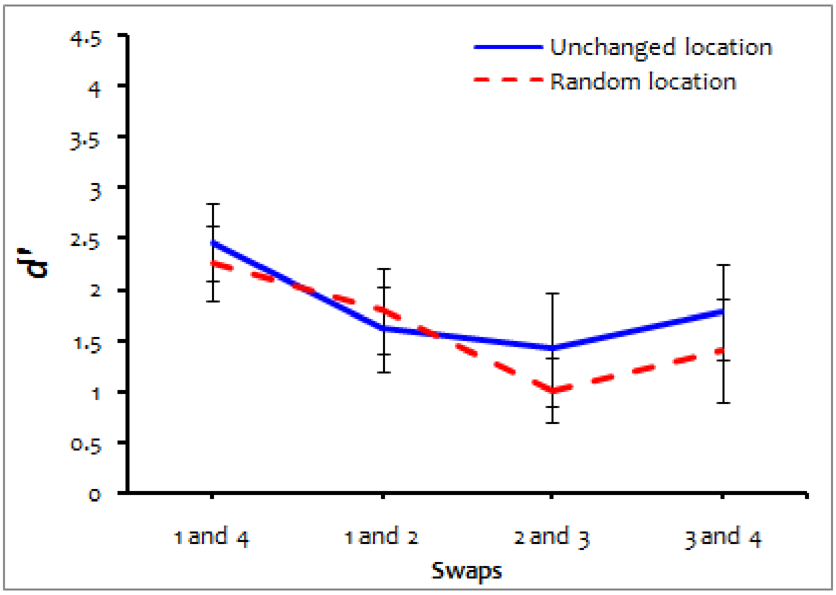

Figure 5.6: Serial position effects in Experiment 4

Comparison of Experiments 2 and 4

A comparison of Experiments 2 and 4 through a three way *ANOVA* showed that neither the main effect of experiments nor any of its interactions were significant. Bayes factors were computed for all the combinations of main and interaction effects. To explore the three way interaction effect, a model comprising the three way interaction effect along with all the main and two way interaction effects [BF_{10}= 2.587×10^{10}] was compared with a model of all main and two way interaction effects only [BF_{10}= 7.445×10^{10}]. The data fit better with the model without the three-way interaction effect by a factor of 2.87:1.

This confirms that there is very little difference between Experiments 2 and 4, the pattern of results being quite similar. Thus, adding blank intervals in the sequential presentation condition did not aid feature binding in any significant way.

5.2.3 Discussion

The main effect of locations and the interaction effect of locations and mode of presentation, both are significant, as might be expected on the basis of the last three experiments. There is nothing new here. What is relatively more informative is that in this experiment there is no significant difference between the two presentation modes. A perusal of data shows that this might be because the overall performance in the simultaneous presentation condition decreased as compared with Experiment 2 [although the decrease does not lead to a significant main effect of experiments in the three-way *ANOVA*]. This might be due to fatigue or boredom with the simultaneously presented stimuli for the long display time of 1750 ms. [This also suggests that there is an optimum presentation time for simultaneous presentation. For the present experiments, this is perhaps close to 1000 ms].The decrease in the performance of the participants in the simultaneous presentation condition particularly in the unchanged locations condition could also be because the participants lost the iconic memory for the study display over the blank period. Alternatively, if the stimuli were already in the visual working memory [with the initial study display being so long], it could be that the participants could not sustain the relational encoding of the multiple stimuli in visual working memory for this long duration. The next experiment will address whether and how far performance in this condition gains from iconic memory.

The performance of the participants with sequential presentation remains virtually the same as in the earlier Experiment 2. Thus, it seems that blank intervals, which yielded better performance with sequential presentation of uni-feature stimuli in the experiment by Ricker and Cowan [2014], conferred no advantage in the present experiment to the multi-feature sequentially presented stimuli for feature binding. Quite likely, in the experiment by Ricker and Cowan [2014] blank intervals prevented subsequent stimuli replacing the earlier ones, and/or enabled better consolidation of the stimuli during the blank interval. Blank intervals may protect uni-feature objects from decay and interference, but apparently have no effect on bindings.

5.3 EXPERIMENT 5

The better performance of participants with simultaneous presentation of stimuli in comparison with sequential presentation found in the previous experiments may also result due to iconic memory of the visual display for simultaneous presentation affording the correct response more easily, especially in the unchanged location condition. Iconic memory preserves the stimulus pattern for some time after it has been presented. It lasts for less than 300 ms, and then information is presumably transferred to visual short term memory [Pashler, 1988; Wheeler and Treisman, 2002]. Masks of different kinds have often been used to wipe out iconic memory [e.g., Becker *et al.*, 2000; Neisser, 1967, Sperling, 1960; Turvey, 1973]. Studies by Loftus *et al.* [1985, 1992] and Phillips [1974] suggest that the icon does not persist beyond the initial 100-300 ms, and in fact, longer the stimulus presentation, shorter the duration for which the icon lasts [Coltheart, 1980].

Thus, to obliterate the effects of iconic memory from performance, it was decided to use a visual noise mask for 250 ms immediately after the study display in all experimental conditions, and explore whether any changes in the pattern of performance would result. Particularly, it was expected that if iconic memory is indeed the reason why simultaneously presented stimuli are better retained with unchanged locations, performance in this condition would reduce as compared to Experiment 2. However, if the stimulus representations are already in visual working memory then they would be immune to the mask and there will be no change in the performance of the participants. This idea is based on experiments by Phillips [1974], who distinguished between sensory storage and VSTM, showing that the former could be masked by visual noise, but the latter was impervious to masking. Indeed masks have often been used at various delays after stimulus presentation to study how far stimuli have been processed or consolidated in visual working memory [e.g., Vogel *et al.*, 2006]. Smithson and Mollon [2006] also concluded from their work that a mask cannot penetrate higher levels of visual analysis and leaves intact conceptual, abstract representations of stimuli.

5.3.1 Design and procedure

The design and procedure remained the same as Experiment 2. The only change was a noise mask introduced in the place of the 250 ms blank display [presented after the study display] for the same duration.

Otherwise, the full factorial 2×2 repeated measures design, analogous to earlier experiments, tested memory for color-shape binding of four stimuli, as a function of simultaneous and sequential modes of presentation, and unchanged and random locations. Figure 5.7 depicts the sequence of events in each trial.

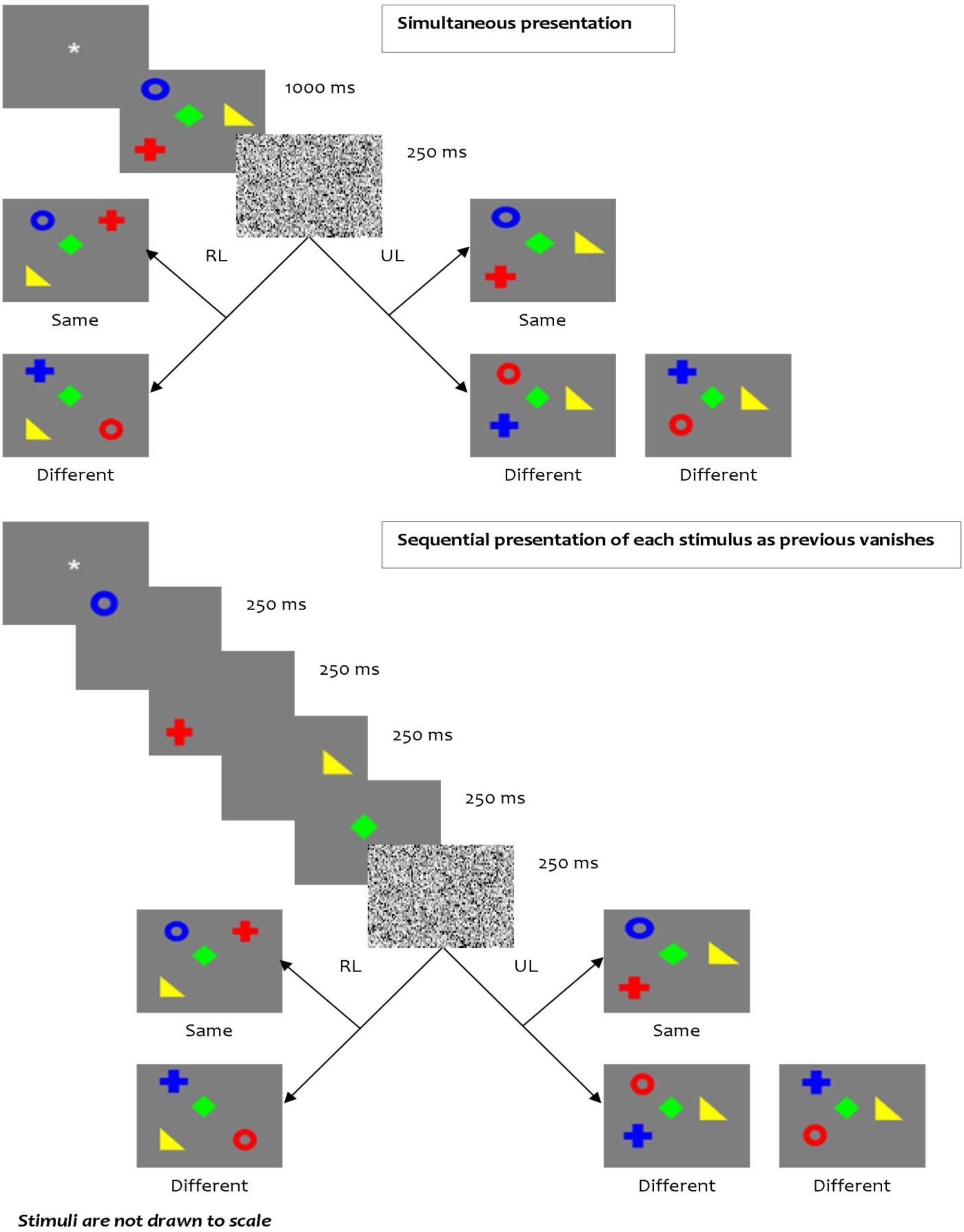

Figure 5.7: Sequence of events in each trial in Experiment 5

5.3.2 Results

Primary Analyses

Mean change detection performance calculated from d primes is shown in the Figure 5.8. A repeated measures *ANOVA* revealed a significant main effect of the mode of presentation, $F[1, 17]=6.949$, $MSE=.260$, $p<.017$, *partial* $\eta^2=.290$, $BF_{01}=1.29$, with simultaneous presentation being better than sequential presentation. The main effect of locations was also significant, $F[1, 17]=43.690$, $MSE=.446$, $p<.001$, *partial* $\eta^2=.720$, $BF_{10}= 4.25\times10^6$ with performance being better with unchanged locations than random locations. The interaction effect was also significant, $F[1, 17]=5.468$, $MSE=.351$, $p<.032$, *partial* $\eta^2=.243$, $BF_{10}=2.80$. The difference due to unchanged and random locations was more with simultaneous presentation [$t[17]=5.761$ $p<.001$, $d=1.358$. $BF_{10}=1043.98$] than sequential presentation [$t[17]=3.981$ $p<.001$, $d=.938$, $BF_{10}=38.52$].

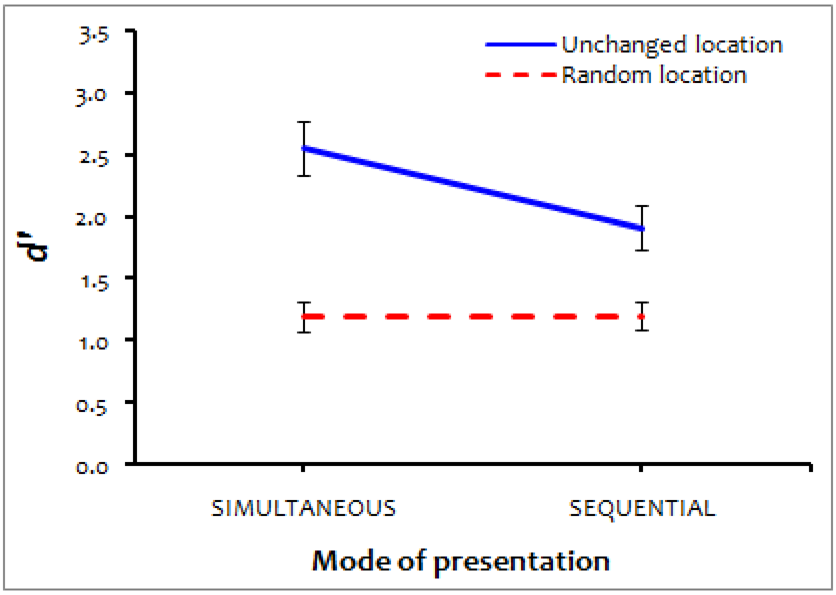

Figure 5.8: Mean d prime scores in Experiment 5

Serial position effects in sequential presentation

The serial position effects in the sequential presentation condition were tested using a 2×4 repeated measures *ANOVA* [location × swaps]. The swaps selected for this analysis were between stimuli shown at serial positions 1 and 4 [showing the joint effect of primacy as well as recency], 1 and 2 [showing only primacy effect], 2 and 3 [items in the middle positions], and 3 and 4 [showing only the recency effect]. As shown in Figure 5.9, only the main effect of locations was significant, $F[1, 17]= 14.124$, $MSE=2.279$, $p< .002$, *partial* $\eta^2=.454$, $BF_{10}=221.277$. The main effect of swaps and the interaction effect were not significant.

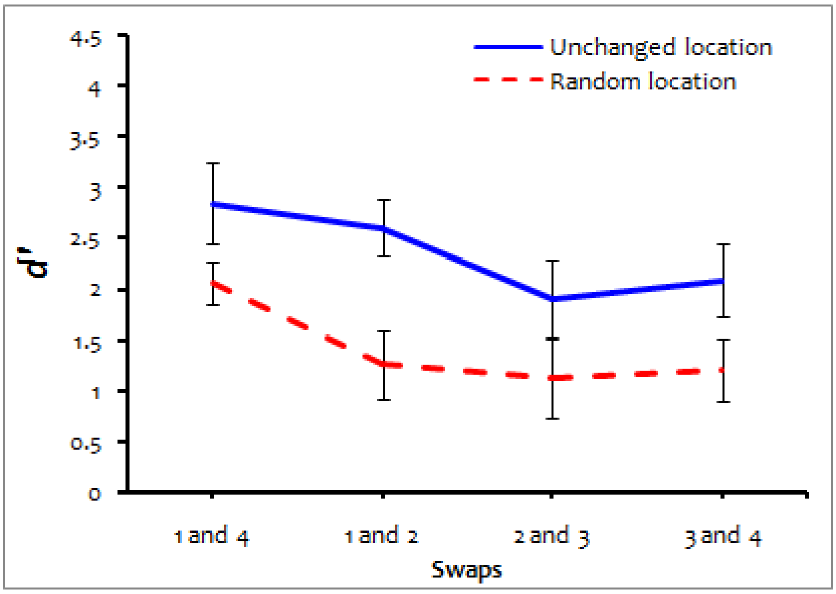

Figure 5.9: Serial position effects in Experiment 5

Comparison of Experiments 2 and 5

The three-way *ANOVA* carried out to compare Experiments 2 and 5 showed that neither the main effect of experiments nor any of the interactions involving experiments were significant. Bayes factors were computed for every combination of main and interaction effects. A model comprising the three-way interaction and all the main and two way interaction effects [BF_{10} = 1.738 × 1018] was compared with the model with only the main and two way interaction effects [BF_{10} = 1.183× 1018]. The data fit better with the model without the three way interaction by a factor of 1.46:1.

5.3.3 Discussion

Visual noise masks were used in this experiment to eradicate the effect of iconic memory in the performance of the participants. Noise masks were used immediately after the presentation of the study display to disrupt the influence of iconic memory. With the idea that the level of performance in the with simultaneous presentation and unchanged locations was higher than the other three conditions in previous experiments primarily because of the advantage accruing to this condition due to a spatiotopic iconic representation, the mask was expected to be most disruptive of performance in this condition in the present experiment. It was of particular interest whether performance in the unchanged locations condition for simultaneously presented stimuli would reduce as compared to Experiment 2. However, there was simply no effect of the mask on the general performance level of the participants or particularly in the condition with simultaneous presentation and unchanged locations. As in Experiment 2, within Experiment 5 also, performance with simultaneous presentation and unchanged locations was significantly superior to performance in the other three conditions.

5.4 COMPARISON OF EXPERIMENTS 2, 3, 4, AND 5

To compare Experiments 2, 3, 4, and 5, a three way *ANOVA* was performed with experiments as the between participants factor and mode of presentation and locations as repeated measures factors. Neither the main effect of experiments nor any interaction of experiments with other factors was significant. Bayes factors were computed for every combination of main and interaction effects. A model comprising the three way interaction and all the main and two way interaction effects [BF_{10}= 2.026×10^{27}] was compared with the model comprising only the main and two way interaction effects [BF_{10}= 7.388×10^{27}]. The data fit better with the model without the three way interaction by a factor of 3.64:1.

Essentially, these analyses confirm what is already intuitively known from the graphs and results; that there is no difference in the pattern of results across Experiments 2, 3, 4, and 5, despite attempts to influence the encoding of stimuli in various ways.

5.5 DISCUSSION OF ALL BEHAVIORAL EXPERIMENTS

This research aimed to compare sequentially presented stimuli with simultaneously presented stimuli, in order to reveal the factors, which lead to differential performance with these two modes of presentation. Previous studies, which compared simultaneous and sequential presentation, have shown mixed results, although in most studies the performance of participants is better with simultaneous presentation. This could be because simultaneous presentation allows participants to remember stimuli in their relative locations and researchers have not removed the confound of simultaneous presentation and locations in their work. In the present research, experiments were particularly designed to disentangle the confound of locations with simultaneous presentation, in view of many theories and studies that have stressed the importance of locations in the process of binding [e.g., Logie, *et al.*, 2011; Schneegans and Bays, 2017; Treisman and Sato, 1990; Treisman and Zhang, 2006; Wolfe, 1994, Udale *et al.*, 2018a].

The results of Experiment 1 show that merely adding a temporal cue, i.e., presenting stimuli one by one to build up the study display, had no differential effect on the performance of the participants as compared to when the stimuli were simultaneously presented. Nevertheless, locations had a significant effect, with performance being significantly better when locations remained the same, than when they were random from study to test. This was true regardless of whether the stimuli were presented simultaneously or sequentially.

However, Experiment 2 showed a significant difference between the two modes of presentation as well as a significant interaction. In this experiment, stimuli were shown in the sequential mode of presentation such that each stimulus was presented with the offset of the previous stimulus. Performance was worse with sequential presentation as compared to simultaneous presentation perhaps because the participants were never able to ‘see’ the stimuli in relation to each other in the sequential presentation condition. Presumably, they were building up a mental representation of the stimuli presented in sequence, as they knew they would be tested with a whole display, having understood the experimental task, and having done many practice trials. However, in building this mental pattern/ representation, it was harder for them to take advantage of the spatial relationship among the stimuli, with sequential presentation such that one stimulus vanished as the next was presented. In Experiment 1, where the study display was gradually built up, they could take advantage of unchanged locations, and put the stimuli in a pattern, and hence the performance is not different in the sequential presentation condition as compared to the simultaneous presentation condition.

Coming back to Experiment 2, encoding the stimuli in a configuration or pattern led to enhanced performance in the simultaneous presentation condition with unchanged locations. However, unchanged locations from study to test did not confer any advantage if the stimuli were sequentially presented. Indeed, for sequentially presented stimuli, performance was statistically not different for unchanged and random locations, indicating that location was simply not a factor in the performance of the participants with sequentially presented stimuli.

These results are in contrast to Pertzov and Husain [2014] who used sequential presentations of four stimuli testing the binding between color and orientation, and compared performance in same and different locations. They showed that there were less errors in the 'different locations' condition. However, the differences in their experimental task as compared to the present one must be noted. In their experiment, same location condition meant presenting the stimuli in exactly the same location one after the other, which does not make location unnecessary to the task, rather it makes locations relevant as a factor creating confusion. In contrast, in the experiments presented in this thesis, the stimuli were presented in different locations, which remain unchanged from study to test. Thus, in this task, locations aid in differentiating the stimuli. In the 'different' locations condition of Pertzov and Husain [2014] the stimuli in the sequence were presented in different locations, and tested by a probe in the center of the screen. In this case too, locations are not irrelevant to the task as the binding of other features [color and orientation in this case] may be addressed through locations, as suggested by feature integration theory [Treisman and Sato, 1990] and more recently by Schneegans and Bays [2017].

Could the relatively long presentation time of 1000 ms for all four stimuli cause better performance because in sequential presentation only 250 ms was given for each stimulus? If this was so, then giving less time to perceive stimuli in the simultaneous condition should decrease performance. However, the results of Experiment 3 showed that this was not the case. Even reducing the presentation time of the simultaneously presented stimuli to 250 ms and thus making it equal to the presentation time of a single stimulus in the sequential condition did not affect the performance of the participants. Probably this is because all stimuli in the simultaneous presentation condition are already encoded, even at 250 ms, and performance has therefore reached an asymptote. Vogel *et al.* [2006] have suggested that about 60 ms are required to encode the first stimulus, followed by 50 ms per stimuli for the rest of them. Although their study was with colored squares [uni-feature objects], in an earlier study, Luck and Vogel [1997] reported that the capacity of visual short term memory is about the same for unifeature and multi-feature objects, which is four objects. There are suggestions that visual working memory capacity is also affected by complexity and resource demand of stimuli [Alvarez and Cavanagh, 2004; Ma *et al.*, 2014]. Yet, the present researcher believes that the four objects used in this work, which are rather simple conjunctions of color and shapes, are well within visual working memory capacity, and so presumably all stimuli in the display could be encoded within 250 ms.

Some researchers have argued that what happens in the maintenance period is as important as initial encoding; and performance is worse with sequential presentation because each stimulus gets overwritten by subsequent stimuli [Allen *et al.*, 2006; Ricker and Cowan, 2014]. Experiment 4 was designed to test whether introducing blank intervals after every stimulus would allow the participant to consolidate its memory and/ or protect it from being overwritten by the next stimulus and hence increase the performance of the participants in the sequential presentation condition. The results did show no significant difference between sequential and simultaneous presentation conditions. However, a perusal of data in order to compare performance in Experiments 2 and 4 revealed that performance did not increase in sequential presentation condition. Rather, it *decreased* in the simultaneous presentation condition with unchanged locations, probably because of the very long presentation time in this condition leading to forgetting. Thus, the blank intervals, which yielded better performance with sequential presentation in the experiment by Ricker and Cowan [2014] conferred no advantage in the sequential presentation condition in the experiment conducted in this research. This might be because the experiments by Ricker and Cowan [2014] were testing memory for unfamiliar shapes, whereas the present researcher was testing feature bindings. Presumably, feature bindings, particularly in the sequential presentation condition, are already represented in the visual short term store beyond iconic memory, and hence do not benefit by the opportunity of consolidation [or protection] given by blank intervals to rather fragile representations of single features.

The idea that feature bindings are represented in visual short-term memory beyond iconic storage is substantiated by Experiment 5, where pattern masks comprising visual noise were used to disrupt iconic memory representations. However, there were no significant differences in the performance of the participants as compared to Experiment 2, substantiating that feature bindings are held in visual working memory and are thus only affected by factors that organize information after basic perceptual processing. Supportive evidence that VSTM representations are immune to masking is offered by several studies [e.g., Phillips, 1974; Sligte *et al.*, 2008; Smithson and Mollon, 2006].

Consequently, one can conclude that the differences between simultaneous and sequential presentation are not due to ostensible perceptual differences, but due to factors and processes that affect the organization of material / stimuli in visual working memory. All manipulations, which could have affected perceptual processing of stimuli, viz., altering the presentation time, inserting blank intervals after each stimulus presented in a sequence, or presenting a noise mask after the stimulus presentation, had no effect on the levels of performance of the participants. So the differential performance in simultaneous and sequential mode of presentation cannot be attributed to factors in perceptual processing. The significant interaction effect obtained in all experiments where stimuli were presented in the sequential condition such that one stimulus vanished as the next appeared, substantiates that location as a feature contributes to making performance better with simultaneous presentation only. The significant advantage of unchanged locations as compared to random locations is clear in the simultaneous presentation condition in all experiments. It is also evident that this advantage accrues only when stimuli can be encoded in relation to each other, being presented together in multiple locations. The term 'vulcanization' used by Vogel *et al.* [2006] aptly describes the role of locations in the creation of bindings, which are strong and resistant to overwriting by subsequent stimuli.

However, in the case of stimuli presented sequentially, locations are simply not relevant to performance as keeping them the same or random, has no effect on the performance of the participants. Perhaps this is because these stimuli are already represented in visual working memory. This idea is further substantiated by Experiments 3, 4, and 5, which show that performance in the sequential presentation condition is immune to manipulations designed to alter the encoding of stimuli such as changes to presentation time, or inserting blank intervals, or using a noise mask immediately after stimulus presentation. Also, performance in the sequential presentation condition could have been worse because participants were generally required to maintain items for a longer duration in this condition. Clearly, this difficulty in 'maintenance' would occur only if the stimuli were already present in visual working memory.

In sum, one may speculate that sequences are encoded or consolidated into visual working memory relatively automatically and perhaps sooner as compared to simultaneously presented stimuli. Analogous to the advantage that sentences have over lists in verbal working memory due to long term knowledge [Allen *et al.*, 2018], perhaps sequences of visual stimuli too benefit from temporal cues which are simply absent in simultaneously presented stimuli. Alternatively, competition among simultaneously presented stimuli may act as a bottleneck and retard the progress of these early visual representations into working memory. This idea is supported by the experimental finding that differences between simultaneous and sequential presentation are evident only at larger set sizes and are not shown with set sizes within working memory capacity [Dent and Smyth, 2006; Igel and Harvey, 1991].

Another explanation could be that participants are using different strategies to process simultaneously and sequentially presented stimuli. Strategic influences have been reported in feature binding tasks. For example, Udale *et al.* [2018b] have argued that participants can use different strategies to encode and process stimuli when required by task demands in the absence of locations being relevant. In fact, they also suggest individual differences among participants in the use of these strategies. Atkinson *et al.* [2018] found that a strategy of focusing on a subset of items was preferred by participants, irrespective of age, and whether a single probe or whole display probe, was used to test binding. This suggests that a strategy that operates within the constraints of working memory capacity limits is the optimal strategy to employ when faced with multidimensional stimuli. Future research might address whether participants are using different strategies to encode and process simultaneous and sequentially presented stimuli, and which are the optimal strategies to use with these two modes of presentation. In fact, much further research is required to explore exactly which factors and processes in visual working memory are relevant for binding sequentially presented stimuli.

These behavioral studies only allow the conclusion that whilst performance with simultaneous presentation relies on location information, performance with sequential presentation is relatively immune to presence/ absence of location information. It is also clear that post-perceptual processes within visual working memory are presumably responsible for the differences in performance due to simultaneous and sequential presentation. In the next chapter, an experiment similar to Experiment 3 is reported, which was carried out in the fMRI environment to study the underlying activation patterns in the four conditions of the experiment in a bid to understand the differences between simultaneous and sequential modes of presentation using a different technique.