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Research report

Why do people remember dynamic images better than static images?

Background

The visual world is intrinsically dynamic, and being able to process dynamic information is critical for successful interaction with the environment. Evidence suggests that the cognitive system can use dynamic cues to aid performance in tasks such as identification and categorization (e.g., Cutting, 1986; Lamberts, 2004), even when visual information is degraded (e.g., Johansson, 1973; Pollick et al., 2002). Dynamic information also facilitates the learning and recognition of faces (e.g., Lander & Bruce, 2003; O'Toole, Roark, & Abdi, 2002). These results suggest that dynamic information is an intrinsic part of memory representations. However, surprisingly little is known about the role of dynamic information in long-term memory. Visual memory research has focused primarily on how people remember static stimuli (e.g. Lamberts, Brockdorff, & Heit, 2002; Standing, 1973). Only recently have researchers begun to address the impact of dynamic information on encoding and retrieval processes.

In one of the first studies comparing memory for dynamic and static pictures, Goldstein, Chance, Hoisington, and Buescher (1982) found better recognition if pictures were presented in dynamic mode at study and at test. Encoding times for moving and static pictures, however, were not matched in Goldstein et al.'s (1982) study. More recently, Matthews, Benjamin and Osborne (2007) carried out two old-new recognition memory experiments featuring complex dynamic stimuli, but without the presentation time confound. Their results showed that moving pictures (film clips presented at 25 frames per second) were remembered better than multi-static pictures (clips presented at a rate of 2 frames per second) and better than static pictures (a single frame from the clip). Although the Matthews et al. (2007) study thus demonstrated a *dynamic superiority effect*, many questions about the nature, the extent and the origins of this effect remain unanswered. Some of these questions have been addressed in the current project.

Objectives

The primary aims of the research were (i) to confirm that the recognition advantage for dynamic images is robust, (ii) to explore reasons why dynamic images are recognized better than multi-static or static images, and (iii) to develop a formal theory of recognition memory that can account for recognition of dynamic images. We believe that we have achieved these objectives.

To achieve aims (i) and (ii), we have carried out a series of six experiments. The experiments we carried out do not correspond exactly to those outlined in the proposal. We covered all the hypotheses (and more), but did so in a slightly different way than originally planned. The reason for the deviation is that the results from our initial experiments suggested promising new directions, which we decided to pursue, and led us to abandon one particular line of enquiry. Experiments 1 and 2 in this report correspond to the proposed Experiments 1 and 4 (*Orthogonal Manipulation and Response Criterion*). Proposed Experiment 3 (*Depth of Encoding*) was not carried out, because a between-experiment comparison (on the data from Experiments 1 and 2 in this report) allowed us to test the depth of encoding hypothesis in a powerful manner, and showed that there was no effect – it seemed pointless to pursue the issue further. Planned Experiment 2 (*Retention Interval*) is covered entirely by the two experiments reported here as Experiments 3 and 4. These two experiments tested retention interval effects in two different ways, in addition to a number of other effects (which were not part of the original proposal, but emerged as highly relevant in the course of the project). The proposed Experiment 5 was carried out, and corresponds to Experiment 5 in this report. We are still finalising the collection of additional control data for this experiment, but we provide a preliminary analysis of the key results. Finally, Experiment 6 in this report was an additional, unplanned experiment, in which we tested two specific explanations for the dynamic superiority effect, which we had not anticipated at the time of writing the proposal.

The results of the experiments confirmed the robustness of the dynamic superiority effect. We found that the effect was preserved under incidental encoding conditions (Experiment 1), under retrieval conditions that emphasise the use of recollection (Experiment 2), and regardless of depth of encoding (comparison between Experiment 1, which used shallow encoding, and Experiment 2, which used deep encoding). Moreover, the dynamic superiority effect was found regardless of the presence of faces in the scenes and with low levels of attention at encoding (Experiment 6). The magnitude of the effect, however, was modulated by several factors, which provide important indications about the origins of the effect. The effect was reduced when there was a mismatch between study and test presentation modes (study-test congruency effect, Experiments 1, 2, 4, and 6). The dynamic advantage was also reduced when the recognition test required recognition of scene details, possibly because encoding the additional information present in moving scenes may reduce attention paid to details of the scene (Experiments 3 and 4). We found preliminary evidence that the memory advantage for dynamic stimuli is preserved even when movement is only implied in static stimuli (Experiment 5), and we showed that disrupting attention at encoding reduced the magnitude of the dynamic superiority effect (Experiment 6).

To achieve aim (iii), we have developed a formal model of recognition memory that can handle dynamic information, by adding the representation scheme for events developed by Lamberts (2004) to the instance model of recognition memory from Brockdorff and Lamberts (2000). The model correctly predicts key aspects of the results, including the general dynamic superiority effect and the encoding-retrieval congruence effect.

Methods and Results

Because there were six separate experiments in this project, we present the Methods and Results together for each experiment.

Experiment 1: Study-Test Congruence

The Matthews et al. (2007) study used matching study and test presentation modes: Moving scenes at study were probed with moving scenes at test and static scenes at study were probed with static scenes at test. This design could not indicate whether the memory effect for moving scenes was caused by an advantage at encoding, an advantage at retrieval, or a combination of both (e.g., Kent & Lamberts, 2008). In Experiment 1, we investigated the role of encoding and retrieval factors (and their interaction) in the dynamic superiority effect, by orthogonally manipulating mode of presentation at encoding and at test. In addition, study instructions (intentional vs. incidental encoding) were manipulated between participants.

72 students were tested individually. The stimuli consisted of 540 video clips. The clips were silent and presented in black and white. They all featured people moving and interacting with each other. Each clip was presented for 3 s. Three presentation modes were used: Moving, multi-static, and static. Moving stimuli were constructed by playing 75 frames (25 per second). Multi-static stimuli were constructed by presenting five frames for 600 ms each. The static stimuli consisted of a single frame.

The participants first took part in a study phase in which they observed a sequence of 270 clips (90 moving, 90 multi-static and 90 static, all intermixed). In the incidental encoding condition, participants were told to look for a woman in the scene. In the intentional encoding condition, participants were also informed about the subsequent memory test. Participants returned three days later for the test phase. The test consisted of 540 trials. Half of the test trials contained a *new* clip (i.e., a clip not seen in the study phase, in any presentation mode), whereas the other test trials contained an *old* clip (i.e., a clip presented in the study phase, possibly in a different presentation mode). Equal numbers of clips were presented in each mode (static, multi-static and dynamic). The design thus crossed presentation mode at study (moving, multi-static, and static) with presentation mode at test. For each test clip, participants rated on a 6-point scale (from "definitely old" to "definitely new") whether or not the clip had been presented in the study phase. Participants were told that presentation mode was irrelevant for their decision.

Recognition accuracy was computed with d_a, which is a multi-point sensitivity measure (Macmillan & Creelman, 2005). Sensitivity was estimated for each participant in each condition by fitting a maximum-likelihood unequal-variance Gaussian model to ROC curves (see Buratto & Lamberts, 2008). Figure 1 shows an overview of the results. Sensitivity was higher for moving stimuli than for multi-static stimuli, which in turn yielded significantly higher sensitivity than static stimuli. The intermediate performance in the multi-static condition suggests that the amount of information available at encoding plays a role in memory for moving pictures. There was also a significant main effect of test mode. Sensitivity was lowest when static scenes were presented at test. Importantly, there was also a reliable study-test congruency effect, as a strong interaction between study and test presentation modes. For each study mode, performance was best if the test mode matched the study mode.

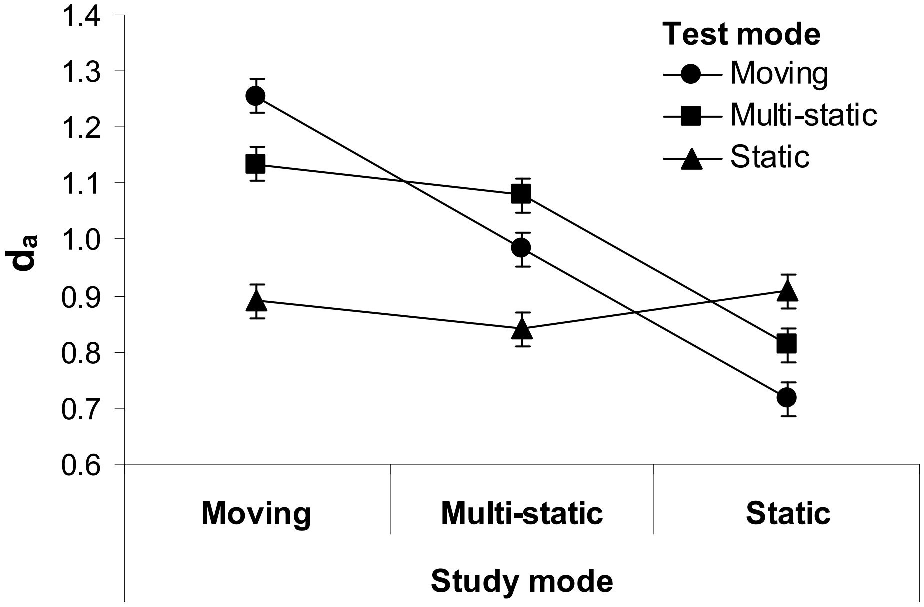

Figure 1. Mean discriminability as a function of study and test modes, Experiment 1. Bars are standard errors adjusted for within-subject designs (Masson & Loftus, 2003).

Experiment 1 thus replicated the dynamic superiority effect. In addition, the main effects of study mode and test mode in Experiment 1 suggest that the amount of information present at encoding and retrieval played a role in subsequent memory performance. More importantly, Experiment 1 showed that the dynamic superiority effect was modulated by the congruency between study and test conditions. The study-test congruence effect provides strong evidence that the dynamic status of studied clips is retained in long-term memory representations. Priming studies with faces had already suggested that dynamic information is stored automatically (Lander & Bruce, 2004), and our data extend these findings to a broader class of stimuli. Neither the dynamic superiority effect nor the congruency effect depended on the intention to memorise at encoding, suggesting that both effects emerge from representations that are constructed on the basis of spontaneous processing of complex visual stimuli.

Experiment 2: Study-Test Congruence and Response Criterion

In Experiment 2, test instructions (inclusion vs. exclusion) were manipulated between participants. Whereas the standard task in Experiment 1 required the participants to ignore presentation mode in deciding whether an image is old or new (inclusion instructions), in Experiment 2 a condition was added in which participants should classify as new previously studied scenes tested in a different presentation mode (exclusion condition). The exclusion instructions should induce recall-to-reject processing at test (Rotello, Macmillan, & Van Tassel, 2000). 72 students took part. The materials and study procedure were similar to those in Experiment 1, except that deep encoding instructions were given in both the inclusion and exclusion conditions.

The results from the *inclusion condition* are shown in the left panel of Figure 2. Sensitivity was higher for moving than for multi-static clips, which in turn exceeded sensitivity for static clips. In contrast with the results from Experiment 1, there was no main effect of test mode. There was, however, a congruency effect similar to that in Experiment 1. The dynamic superiority effect was significant in the inclusion condition: Sensitivity was higher in the moving/moving condition than in the multi-static/multi-static and static/static conditions.

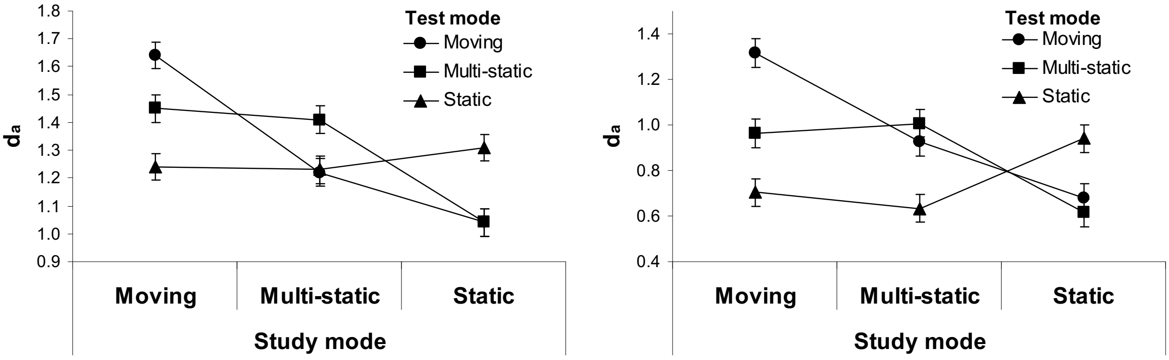

Figure 2. Discriminability as a function of study and test modes (left: *inclusion condition*; right, *exclusion condition*).

In the *exclusion condition* (right side of Figure 2), scenes studied in the moving mode were better recognised than scenes studied in the other modes. Again, there was a significant interaction between the study and test presentation modes. The participants were often unable to reject pseudo-targets as instructed. Instead, the responses showed a congruency effect that was quite similar to that in the inclusion condition (and in Experiment 1), suggesting that the test instructions did not substantially alter the nature of the congruency effect.

Experiment 3: Retention interval and lure similarity (I)

Experiment 3 addressed questions about the perceptual specificity of event representations after different retention intervals. We also manipulated the similarity of studied scenes (*targets*) to unstudied test scenes (*lures*). The hypothesis was that paying attention to the extra information available in moving scenes may improve memory for the general theme of the scene but could possibly impair memory for perceptual details of the scene. We addressed this issue by using test lures that were similar to target scenes so that participants would have to remember details of the studied scene to give a correct response.

120 students participated. Stimuli consisted of 480 video clips, 240 of which were presented at study (half in moving mode and half in static mode). Another set of 120 clips was presented in the test phase as similar lures (60 clips) and related lures (60 clips). Similar lures had the same people and background to a clip presented in the study phase but differed in the action depicted. Related clips featured some of the people present in a studied clip but different in background and action. The remaining set of 120 clips (two from each film) was presented in the test phase as unrelated lures. Presentation mode (moving or static) and scene type at test (target, similar lure, related lure, or unrelated lure) were manipulated within participants, whereas

retention interval (90 min, 1 day, or. 14 days) was manipulated between participants. In the study phase, participants were presented with 240 clips (120 moving and 120 static, all intermixed). The test phase consisted of 120 *old* and 240 *new* clips. Of the *new* clips, 60 were *similar*, 60 were *related* and 120 were *unrelated.* Similar and related new clips were presented in the same mode as the corresponding studied clip. Unrelated clips were randomly presented as moving or static. Presentation modes were always matched at study and test.

The results showed higher sensitivity d_a for moving than for static scenes. Retention interval had a main effect; sensitivity was lower after 14 days. Sensitivity d_a was lower for similar than for related lures, which, in turn, was lower than d_a for the unrelated lures. More importantly, the decrease in discriminability with increasing target-lure similarity was more pronounced for moving scenes than for static scenes.

The analysis of proportions of "old" responses revealed a main effect of scene type, with more "old" responses to targets than to similar lures, more to similar lures than to related lures, and more to related lures than to unrelated lures (see Figure 3). Similar and related lures were incorrectly recognised as "old" more frequently when the scenes were moving than when they were static. Crucially, the fact that false alarms to unrelated lures did not differ between moving and static scenes suggests that there was no overall bias to say "old" more often to moving than to static scenes.

Experiment 3 thus showed that the dynamic superiority effect is reduced when recognition requires memory for scene detail and that false alarms to similar lures are higher when the lures are moving than when they are static, suggesting that the dynamic superiority effect is largely due to increased retention of scene gist.

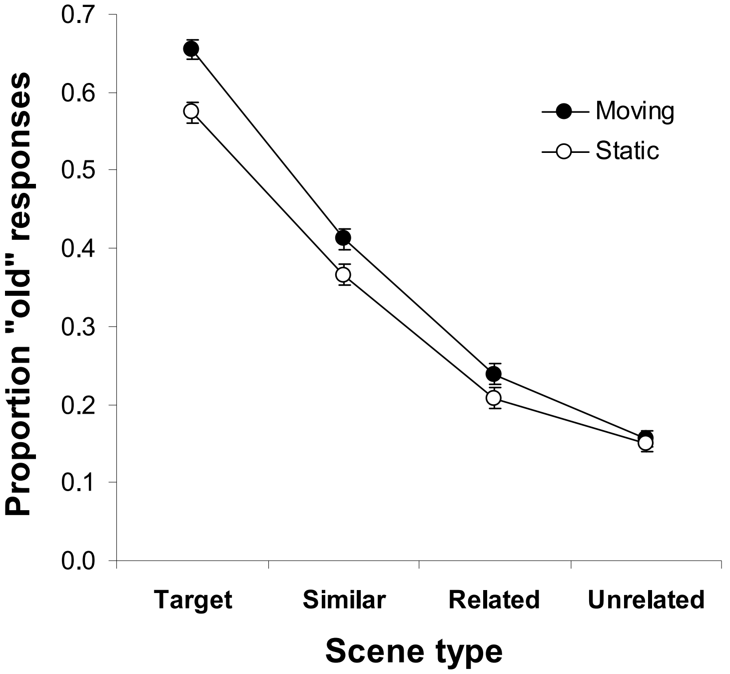

Figure 3. Proportion of "old" responses as a function of scene type (collapsed across retention intervals) and presentation mode. Hits are "old" responses to *targets* and false alarms are "old" responses to *similar*, *related* and *unrelated* lures. Error bars represent standard error of the means.

Experiment 4: Retention interval and lure similarity (II)

This experiment investigated whether the dynamic superiority effect is based on better memory for scene gist or better memory for both gist and perceptual details, using a paradigm developed by Bartlett, Gernsbacher and Till (1987). Participants studied moving and static scenes at different points in time and carried out a final recognition test involving all previously studied items. Test scenes were either studied scenes, mirror-reversed versions of studied scenes or unrelated, unstudied scenes.

30 students participated, and the stimuli were 600 video clips. Recognition decisions were carried out in two steps. First, participants made an old-new decision; they were explicitly instructed to respond “old” to original and mirror-reversed versions of studied scenes. Because old-new decisions could be based on thematic familiarity, performance on this task provided a measure of memory for scene gist. For those scenes judged “old”, participants completed a second step in which they indicated whether the orientation was reversed or not. Correct “reversed” responses depend crucially on memory for scene detail (i.e., orientation), whereas correct “same” responses may also be produced by recognition of scene gist. We also manipulated retention interval: Scenes were studied 7 days, 1 day or 90 minutes prior to the single recognition test session. Finally, we varied the movement congruence. Study mode (moving vs. static), test mode (moving vs. static), retention interval (90 min vs. 1 day vs. 7 days) and scene type [*same* (target) vs. *reversed* (mirror-reversed lure) vs. *unrelated* lure] were all manipulated within participants.

Focusing first on the decision to call a stimulus “old” or “new”, we replicated the findings of previous experiments: Memory was better for moving stimuli, but this was modulated by a marked movement congruency effect. More importantly, these effects were not affected by retention interval, suggesting that dynamic representations stored in memory were not reduced to a common static representation over the course of 7 days (Homa & Viera, 1988). Memory was also better for *same* scenes than for *reversed* scenes, suggesting that left-right orientation was automatically encoded at study as an additional feature in the memory trace. The effect of orientation did not depend on retention interval, indicating that the recognition advantage for *same* relative to *reversed* scenes was mainly driven by memory for scene gist (Bartlett et al., 1987). The effects of orientation and movement remained the same when we considered only data from the congruent conditions (i.e., study moving/test moving and study static/test static). The results from the two congruent conditions, collapsed over retention interval, are shown in Figure 4 (a).

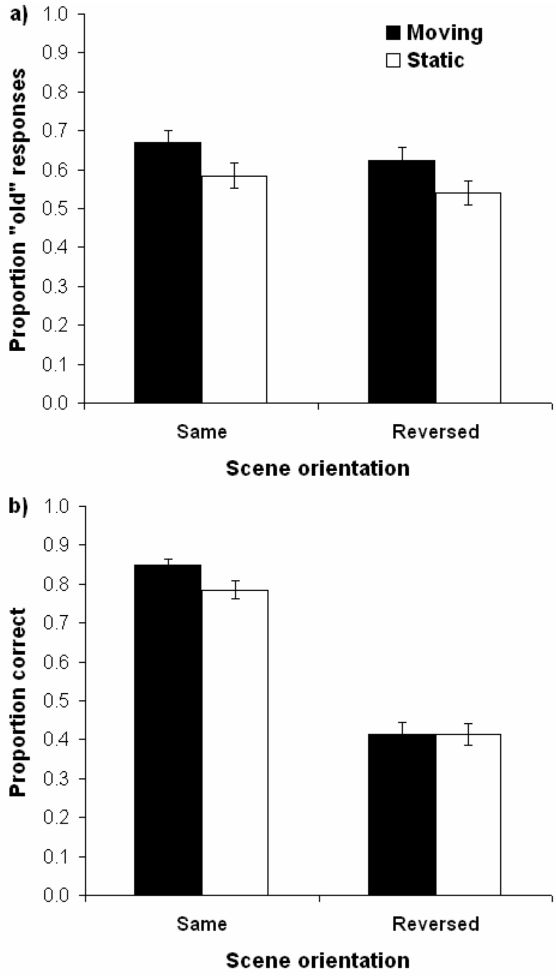

Figure 4. Performance in the old-new task (upper panel) and same-reversed task (lower panel). Data are for congruent conditions, collapsed over retention interval.

We then looked at orientation judgments for those items judged “old” (again using only those data from the congruent conditions). The results, collapsed over retention interval, are shown in Figure 4 (b). As reported elsewhere (e.g., Bartlett et al., 1987), accuracy was higher for *same* than for *reversed* stimuli, and correct “reversed” decisions were more negatively affected by increased retention interval, consistent with the idea that these decisions tap memory for the details of a scene (Gardiner & Java, 1991). Crucially, the memory advantage for moving over static images was present for *same* scenes but not present for *reversed* scenes. Figure 5 (b) illustrates these results (collapsed across retention intervals). The fact that the dynamic superiority effect persisted in the condition where memory for both scene gist and perceptual detail are likely to contribute to performance (i.e., *same* scenes) but disappeared in the condition where memory for detail was critical (i.e., *reversed* scenes) suggests that the dynamic superiority effect is generally driven by superior memory for scene gist. The results of Experiment 4 therefore confirm and extend the results of Experiment 3. Taken together, the results of Experiments 3 and 4 suggest that moving images improve long-term memory by preferentially aiding recognition of scene gist.

Experiment 5: Implied Motion

The aim of Experiment 5 was to investigate whether *implied* motion is enough to produce a long-term memory benefit. Imaging work has demonstrated that similar areas in the brain are activated when participants observe moving pictures as when they observe static pictures that imply motion (e.g., Kourtzi and Kanwisher, 2000). This suggests the intriguing possibility that static pictures with implied motion alone might elicit a long-term memory advantage, similar to that normally found with moving pictures. To test this possibility, we conducted an experiment to compare recognition memory performance for pictures with high levels of implied motion relative to pictures with low levels of implied motion.

We first carried out a norming study with 72 participants, to produce a set of static stimuli with known implied motion status. 40 students participated in the main study. The main experiment employed a 2 (mode: implied motion vs. no implied motion) × 2 (scene type: target vs. lure) within-participant design. Participants took part in a study phase where they were presented with a sequence of 92 stills (46 with implied motion and 46 without implied motion) in random order. The recognition test phase (held 24 hours later) comprised 184 trials, mixing targets and lures.

The main result was an interaction in the proportion of "old" responses between mode (implied motion or not) and picture type (target or lure) (see Figure 5). This result suggests that motion implicit in a static picture may be sufficient to produce the dynamic advantage. Although the main experiment has been completed, we are still running an additional control condition (*N* = 40), which is important for ruling out the possibility that the implied motion pictures used were somehow more distinctive than the no implied motion pictures.

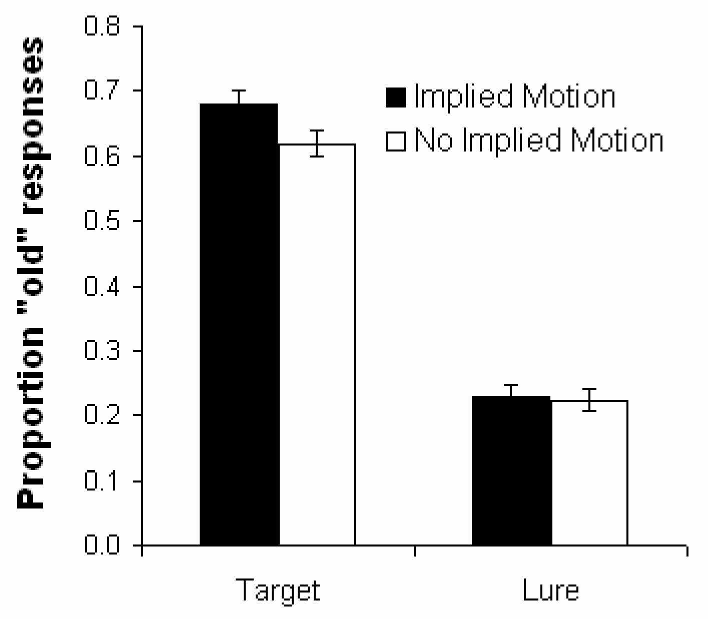

Figure 5. Proportion of "old" responses as a function of mode (implied motion vs. no implied motion) and picture type (target vs. lure).

Experiment 6: Faces and Divided attention

The dynamic scenes used thus far featured unfamiliar film characters interacting with each other. Stimuli thus contained a mixture of rigid and non-rigid face motion. Because it is known that moving faces may be recognized better than static faces (O'Toole, Roark, & Abdi, 2002), the dynamic advantage we found may have simply been a consequence of having faces in our stimuli. To investigate this possibility, we presented participants with clips showing either visible faces (people interacting) or no visible faces (hands manipulating objects). As a secondary manipulation, we varied levels of attention at study (using a load task), to test whether the dynamic superiority effect depends on the differential allocation of attention to moving and static stimuli.

Sixty students participated in the study. The experiment employed a 2 (clip type: faces vs. hands) × 2 (study mode: moving vs. static) × 2 (test mode: moving vs. static) × 2 (attention: full vs. divided) mixed design. In the divided attention study condition, participants looked at the clips and, at the same time, performed an auditory load task (involving tone comparisons). The test procedure followed the standard recognition-memory test protocol.

The dynamic superiority effect was significant, and did not depend on clip type or attention (if anything, the effect was slightly smaller for face clips than for hands clips). Sensitivity was higher in the congruent moving condition than in the congruent static condition, and was higher in the full attention condition than in the divided attention condition. Importantly, however, there was no interaction between attention and congruence condition (see Figure 6). Response times in the secondary task were faster with static pictures than with moving pictures, which suggests that moving scenes may attract more attention than static scenes.

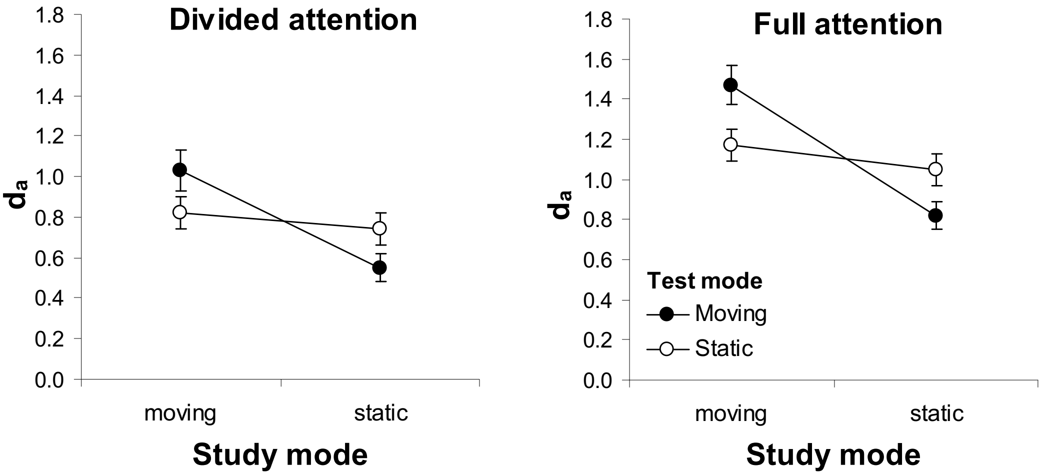

*Figure 6. D*iscriminability as a function of study and test modes (collapsed across face and hand clips).

Experiment 6 ruled out the possibility that the dynamic superiority effect is simply a special case of the memory advantage for moving faces. Differential allocation of attention to moving scenes relative to static scenes may help explain why dynamic images are better remembered than static ones.

Modelling

The model that we constructed to explain the data on memory for static and dynamic stimuli assumes that the likelihood of positive recognition is a function of the total similarity of the current stimulus to the traces stored in memory. The model correctly predicts the general dynamic superiority effect without any parametric variation, because it assumes that old-new judgments about dynamic stimuli involve an integration of similarity information over a time-extended trajectory in representation space (Lamberts, 2004). Because it is based on a large number of samples, this integration process produces greater discriminability than a process based on single-point representations (which would apply to static stimuli). The model predicts generally intermediate performance for multi-static stimuli, because recognition of those stimuli involves a more limited integration process (over a smaller number of samples). The model also correctly predicts the encoding-retrieval congruence effects that we observed. We are currently extending the model to encompass other data sets (including those obtained with point-light stimuli and biological motion), and we expect that this will yield a comprehensive account of memory for dynamic stimuli.

Activities

Results from the project were presented at colloquia at the MRC Cognition and Brain Sciences Unit in Cambridge (December 2008) and at Swansea University (February 2009). They were also reported at the Experimental Psychology Society meeting in Leicester (April 2009).

Outputs

The results of Experiments 1 and 2 were accepted for publication in the *Quarterly Journal of Experimental Psychology* (Buratto, Matthews, & Lamberts, in press). The results of Experiments 3 and 4 have been submitted for publication to the *Journal of Experimental Psychology: Learning, Memory and Cognition* (L.G. Buratto, W. J. Matthews, & K. Lamberts, submitted). A manuscript which contains Experiment 6 has been submitted to *Psychonomic Bulletin and Review* (L. G. Buratto, W. J. Matthews, & K. Lamberts, submitted). Two further manuscripts are in preparation. One reports Experiment 5 (including the additional control data), and the other will present the formal model of recognition memory for dynamic and static objects.

Impacts

The results have not yet been applied outside the academic community. However, there is potential for educational and forensic applications. In education, the results add to previous findings showing that animation of materials can improve learning (e.g., Park & Gittelman, 1995; Taylor, Pountney, & Baskett, 2008). Our results also point to the importance of testing in a mode that is congruent with study. Relevant to forensic issues, Experiment 3 showed that the proportion of false alarms to similar lures is higher when lures are moving than when they are static. This suggests that, although memory for scenes is generally improved when the test involves moving stimuli, recognition of perceptual details may be less reliable when participants are tested with moving scenes.

Future Research Priorities

The present research project was fruitful in opening several possible avenues for future research. The implied motion results (Experiment 5), although still preliminary, suggest that static stimuli that elicit a sense of movement can also improve long-term memory. It would be interesting to further explore the reasons behind this memory advantage. One possibility is that the implied actions embedded in implied-motion pictures attract and sustain attention.

Another outstanding issue is to determine more precisely the locus of the gist/detail differences found in Experiments 3 and 4. In particular, it would be important to explore the hypothesis that differential allocation of attention to moving and static stimuli can explain both the dynamic superiority effect and its attenuation when memory for scene detail is required. In this respect, measurement of eye movements may prove informative. First, it is important to determine whether or not a particular object or person in the scene has been fixated at study, as fixation is crucial for subsequent memory performance (Nelson & Loftus, 1980). Second, eye movements may clarify the differential distribution of attention in moving scenes compared to static scenes. It has recently been shown that the areas looked at in a complex scene can differ qualitatively depending on whether participants are instructed to memorize the scene or to find an object within it (Castelhano, Mack, & Henderson, 2009).

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