MEMORY FOR LUMINANCE:

AN EXPLORATION OF A BIAS IN JUDGEMENTS OF DISCRETE CHANGES IN LUMINANCE

By

JAMES CUYLER BREHAUT, B.A.

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AUTHOR: James Cuyler Brehaut
B.A. (Honours) (Mount Allison University)

SUPERVISOR: Dr. S.P. Tipper

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Abstract

The series of nine experiments in this thesis describes an exploration of what we believe to be a new empirical effect for luminance judgements. The basic effect is that judgements about discrete changes in luminance are biased in the direction of previous luminances. Along with an introductory chapter and a final chapter discussing overall conclusions, the nine experiments are arranged into three chapters, each of which addresses an hypothetical explanation of the effect.

In Chapter 2, the relationship between the luminance bias and representational momentum (RM) was examined. Experiment 1 demonstrated the basic RM effect using a common RM paradigm (E.g. Freyd & Finke, 1984), and showed that when subjects in a comparable experiment made luminance judgements, they showed data opposite to that predicted by the RM hypothesis. Experiment 2 showed that this qualitatively different pattern of data was not the result of time course differences. Experiment 3 showed that the effect of a manipulation which reduces or eliminates RM has a very different effect on the luminance task. We conclude from these experiments that RM may not act on the dimension of luminance change, that this finding is important in light of current debates as to the function of RM, and that the luminance effect is worthy of further study in its own right.

In Chapter 3, we examined whether the luminance bias might be explained by either of two mechanisms which are argued to be the result of processes early in the visual system, namely the "ramp aftereffect" first reported by Antis (1967), and constancy. Because the ramp aftereffect is known not to transfer across retinal locations, Experiments 4 and 5 tested whether the luminance bias under investigation here does so. It does. Experiment 6 asked whether the size of the bias changes for dark items on a light background, as opposed to light items on a dark background, a manipulation which results in more robust lightness constancy (Jacobsen & Gilchrist, 1988b). It does not. We conclude that the luminance bias is not the result of these early perceptual mechanisms.

In Chapter 4, we asked whether the bias for luminance judgements is better characterized as stemming from the first item in the display, the most recent item in the display, or some average of all the displays. Experiments 7 and 8 manipulate the first and most recent items while holding the average luminance of the displays constant. Experiment 9 manipulated the average luminance of the displays, while holding the most recent item constant. The results suggest that the luminance bias is affected by the average luminance of the displays. This finding puts a constraint on potential models of this luminance bias.

The final chapter in the thesis discusses the conclusions to be drawn from the nine experiments. It argues that these findings suggest that representational momentum can only be observed for a subset of dimensions of change, contrary to current theory. It speculates on the physiological underpinnings of both RM and the luminance bias. It suggests that the luminance bias is better characterized as a memorial rather than a perceptual effect. Finally, it speculates on the possible adaptive value of this effect.

Dedication

I want to dedicate this work to my Dad. When he was alive, I always thought that our differences outweighed our similarities. This never diminished our love for each other, but simply meant that we spent our time thinking about and doing different things. As the years progress, though, I am continually reminded of our similarities - favorite melodies of his that are now mine, personality traits I see developing in myself, the times I compliment myself by thinking that I have his hands. It seems that it is the similarities that last, and I am glad of it.

Because learning has become so important to me, I like to think of the things that he taught me. Appreciation of music, of course. Canoeing. How to strip a log, and why you might want to. But when I think more about it, I think of him always having a new project going, always reading about it, always wanting to talk about what he had learned about his current interest. And I think that by example he helped instill in me that same interest in learning new things; it doesn't really matter what.

This work is dedicated to the memory of

John William (Bill) Brehaut

(1924 - 1991)

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My family continues to be supportive of me, no matter what I do; this is a luxury many don't have, for whatever reason, and I always try to remind myself of the fact. They are also an incentive for me; anything that I do, I am doing it at least partly to make Mom proud of me. You'd think you'd outgrow that.

Finally, I want to thank Dafna, for sticking with me all this time despite the odds, and generally for being who she is. Believe me, there is nothing more rewarding about this PhD than the fact that it means we get to start out together... in the SAME CITY, no less. Thanks, honey.

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Chapter 4 - Memory mechanisms

Chapter 1 - Introduction to the thesis

Overall Introduction

This thesis describes the discovery and exploration of a bias in memory for the luminance of stimuli. Because this bias is relevant to current issues in the literature on the representational momentum effect (e.g. Freyd & Finke, 1984), and because it was discovered in the context of thinking about these issues, we first examine the literature on representational momentum in some detail. This is the goal of Chapter 1. Chapter 2 describes attempts to address these issues empirically. In the process of addressing these issues, we discovered a new bias in memory for luminance decisions, one that we believed warranted further research independent of the considerations regarding representational momentum. Chapter 3 outlines attempts to relate this bias to other luminance-related effects, specifically the ramp aftereffect (Anstis, 1967) and brightness constancy. In Chapter 4 we specify the nature of the luminance bias more precisely, by testing several candidate mechanisms that could give rise to the effect. Finally, Chapter 5 discusses the conclusions to be drawn from Chapters 2-4. We argue that the results place important restrictions on models of RM, that the luminance effect is better characterized as memorial rather than perceptual, and speculates on the utility of this phenomenon, both as an empirical tool and an adaptive mechanism.

Theories of Perceptual Representation

The problem of how, and in what form, visual information is represented in the human visual system is of fundamental importance to the study of both visual perception and visual cognition. One approach in studying the problem is to examine how static two-dimensional retinal images may be parsed, converted into three-dimensional percepts, then stored for later retrieval. This approach had been the most common one until the early 1980's (for a review, see Pinker, 1985).

One traditional problem with this approach is that it fails to consider, except perhaps in a post hoc way, that the visual world is dynamic; that motion is an important part of virtually all aspects of our visual experience. This was part of the motivation behind the work of Gibson (1979) and his ecological approach to visual perception. His thesis that aspects of the visual world, or affordances, could be perceived directly from the optic flow was predicated on the fact that information coming into the eye was complex and dynamic. He argued that this dynamic information could be used directly by the visual system, without the added step of information being compared to internal perceptual representations.

Marr (1982) argued that this Gibsonian emphasis on extracting the invariants of the dynamic visual array was correct. However, Marr also believed that the Gibsonian approach underestimated the complexity of the process of extracting those invariants. It was this process of invariant extraction that Marr believed had been overlooked, and much of his final work was devoted to developing a computational theory of the extraction process. The work of Marr (1982) was therefore, at least in part, an attempt to incorporate into a representation-based, information-processing framework the Gibsonian emphasis on the dynamic nature of the visual world, and the importance of the information in the dynamic visual array.

More recently, another approach to the problem of information representation has emerged. This new approach may be seen as similar to that of Marr's, in that emphasis is placed on the importance of both perceptual representations, and the information to be gleaned from the dynamic visual array (Shepard, 1984; Freyd, 1987, 1992, 1993). However, in contrast to Marr's model, this perspective argues that perceptual representations are themselves dynamic, and not static representations of a dynamic world. The dimension of time is an inherent part of these dynamic representations; it is "mandatory, necessary, and unavoidable" (Freyd, 1993). This new emphasis on dynamic mental representations represents an important new perspective in the study of visual perception and cognition, and therefore deserves discussion and investigation.

Much of the evidence that has been offered to support the theory of dynamic representations comes from work examining a phenomenon known as representational momentum (RM). Given its status as the flagship methodology of this new approach to perceptual representation, it is important to examine the boundary conditions of representational momentum, to test the generality of the dynamic representation hypothesis. One of the purposes of Chapter 2 is to show one of these boundary conditions, and to speculate on its ramifications for the theory of dynamic representations.

Representational momentum

The representational momentum (RM) effect is a systematic distortion in the memory for the final position of an object in the direction implied by a set of inducing displays. In a typical RM paradigm, there are three sequential presentations of a rectangle, each differing from the last by a fixed amount of rotation about its center. After presentation of these "inducing displays", a fourth display, the "probe", is presented. The task for the subject is to decide whether or not the probe is in the same position as the final inducing display. Forward probes, ones that are displaced further than this "Same" position along the implied path of rotation, elicit increased RTs and error rates relative to Backwards probes, ones that are displaced less far than the Same position. This representational momentum effect is a robust one, typically observed in almost all subjects with 100-200 ms reaction time (RT) differences and 10-30% error rate differences (Freyd & Finke, 1984).

The RM effect has been demonstrated under a wide variety of conditions. It has been shown for rotational motion, where the effect seems to be roughly analogous to physical motion, changing predictably with implied velocity and acceleration of the inducing displays (Freyd & Finke, 1985; Finke, Freyd, & Shyi, 1986). It has been shown for horizontal and vertical motion of a target (Hubbard & Bharucha, 1988; Hubbard, 1990). Complex motion of pattern elements can also elicit RM-like effects (Finke, Freyd, & Shyi, 1986; Finke & Shyi, 1988). A series of experiments by Kelly and Freyd (1987) suggests that RM can be observed for any change that preserves target identities across inducing displays, including changes in size, motion for objects whose internal markings change without disrupting target identity, and gradual but not radical shape changes. A momentum effect has even been found in the auditory domain for changes in pitch (Kelly & Freyd, 1987; Freyd, Kelly, & DeKay, 1990).

The varied circumstances under which RM is observed has led to strong claims about the nature of the underlying mechanism. Kelly and Freyd (1987), for example, argued that because RM has been demonstrated for dimensions of change for which the application of the physical momentum analogy is not appropriate, such as pitch change, RM must reflect some "abstract" representation of the physical laws of motion. In a review of the RM literature, Freyd (1987) stated she " would expect to find representational momentum for any dimension of continuous change, but not discontinuous change...that can be mentally represented." (p.435) In a similar vein, Freyd, Kelly and DeKay (1990) stated that if this mechanism is an intrinsic component of the perceptual system, "momentum effects should be found for any dimension of continuous change." (p.1116)

Does RM occur for change not correlated with motion?

There are a wide variety of conditions under which RM can be observed. If at least some of these dimensions of change are not reliably correlated with motion in the real world, then RM probably reflects a mechanism more general than one dealing only with motion (Freyd,1987; Kelly & Freyd,1987; Finke & Freyd,1989). Kelly and Freyd (1987), as well as demonstrating RM for pitch, showed that RM occurs for a wide variety of visual changes that at the outset might seem uncorrelated with motion of objects in the real world. For example, in a task where subjects were asked to make judgements about the width of rectangular stimuli, a rectangle that decreased or increased in width but not height across inducing displays gave rise to a momentum effect. Because such change is not commonly viewed, this finding could be construed as RM for a dimension of change not correlated with motion in the real world.

However, there are a number of reasons why such a conclusion might not be accepted without further consideration. First, the RM result was far smaller than is typical for more conventional RM displays. Typically, RM experiments result in significant effects for both directions of change (clockwise or counterclockwise motion), for both RTs and error rates. In this experiment, while the effect was significant overall with respect to errors, it was not significant when the data were analyzed separately for each direction of change (width increasing or decreasing), nor was there a significant effect for RTs. It is possible that this considerably smaller effect resulted from some residual extrapolation of motion from this display. One such explanation was acknowledged by the authors, in that phenomenologically these displays could have been interpreted as a parallel projection of an object rotating about the vertical axis in depth.

Given alternative explanations for the above experiment, then, the conclusion that RM is a general enough phenomenon to extend to change not correlated with motion would be on rather weak footing if it were not the case that RM occurs for auditory pitch change as well (Kelly & Freyd, 1987; Freyd, Kelly, & DeKay, 1990). Indeed, Kelly and Freyd (1987) argued that "the fact that momentum effects were obtained with changes in pitch...seriously brings into question the proposition that representational momentum can occur only with transformations that specify changes in spatial location..." (p.396). Note, however, that this conclusion assumes that pitch change is not reliably correlated with physical motion in the real world.

This premise needs further verification. In fact, we know that pitch change is in many circumstances correlated with motion. This is known as the Doppler effect. As a source of sound moves, wavelengths in front of the source are shortened, while wavelengths behind the source are lengthened. These changes result in a rise in the pitch of a sound as it approaches the listener, and a decrease in pitch as it moves away.

Kelly and Freyd (1987) offer two reasons why the Doppler pitch change argument is not a strong argument for pitch change being a cue to motion. First, they argue that Doppler effects are the result of fast-moving sound sources, such as trains, planes, cars, etc. These are sources to which we have been exposed only very recently, in evolutionary terms. Thus, they argue that evidence for RM for pitch change is probably not due to these evolutionarily recent Doppler effects, because the evolution of such mechanisms would have taken thousands, not tens, of years. Second, they point out that pitch change is often not correlated with motion. Human speech, for example, can cover a wide range of pitch, while the speaker may not be moving relative to the listener.

It is simply not true that only evolutionarily recent phenomena give rise to the Doppler effect. Listening to a flock of geese or a cawing crow as they fly overhead will demonstrate the point. More importantly from an evolutionary perspective, there are (and presumably were) predators in nature that move very quickly. Use of any source of sensory information by prey to avoid an oncoming predator would be adaptive. The Doppler effect is one such source.

Kelly and Freyd's (1987) second reason for doubting the importance of the Doppler effect as a cue to motion is that pitch change need not be correlated with motion. However, there are few, if any, cues to motion that are unambiguous in the real world. A more appropriate question might be whether the Doppler effect can be used by listeners to accurately predict a position in space. There is some evidence to suggest that this is the case. Rosenblum, Carello, and Pastore (1987) asked subjects to imagine facing a street with traffic flowing in either direction. They were then presented with auditory stimuli resembling the sound of the two-tone European ambulance sirens. These stimuli were varied such that the Doppler pitch shift, amplitude change, and/or interaural time differences implied a specific point at which the ambulance passed by. The task of the subject was to indicate that point. Subjects were able to do this task quite accurately. More importantly, even when only the Doppler cue implied motion of the object, people still carried out the task accurately, although somewhat less so than when all three cues were available. While subjects in this experiment were making judgements about a point in time rather than a position in space, the result does imply that Doppler information can be used to locate consistently moving objects in space. Note that this predicts that consistent changes in Doppler shift, interaural time difference, and amplitude should all result in RM for spatial judgements. These experiments have not yet been carried out.

In summary, we are arguing that the conclusion that RM occurs for dimensions of change not associated with motion in the real world may be premature. We have attempted to evaluate the notion that RM does occur for such dimensions in a number of ways. First, we examined the results that suggest RM occurs for spatial changes not correlated with real-world motion, and argued that motion could indeed have been extrapolated from those displays. Second, we addressed the argument that RM occurs for pitch change, and argued that perhaps this dimension, too, can be a reliable cue to motion in the real world. If we accept these arguments, then the notion that RM occurs for dimensions not correlated with motion in the real world remains untested. The next step is therefore to choose a non-motion-correlated dimension of change and examine whether RM can be found for that dimension.

Does RM occur for luminance decisions?

RM for changes in luminance has been explicitly predicted in the literature. Freyd et al (1990) predict that RM should be evident " for any dimension affording continuous transformation, including, in the visual domain: rotation, translation, change in illumination..." (p.1108). Luminance change can vary continuously. It can be correlated with motion in depth; objects as they approach will often appear increasingly bright. On the other hand, moving objects may travel through any number of ambient illuminations, changing the physical luminance of the object. These sorts of luminance changes would not be meaningfully correlated with consistent motion. The dimension of luminance change is therefore similar to dimensions of change that exhibit RM (e.g. pitch change), in that in the real world it may or may not be correlated with the motion of an object.

There are reasons to believe that luminance change could be a more stringent test of the "RM for non-motion-correlated change" hypothesis, however. One such reason is that RM for luminance change might actually be maladaptive. A major function of the visual system is to maintain constant perceived brightness of objects in the face of changing illumination. As an object moves from a darker to a lighter illumination, the amount of light reflected from its surface will increase; brightness constancy ensures that this change will not be interpreted as a change in brightness. An extrapolative process such as RM would seem to work against this process. This reason alone makes it less plausible that RM would be a strong factor for luminance change.

Second, and more importantly, there is no evidence in the literature of which we are aware to suggest that luminance change alone can be used as a cue to motion. While atmospheric perspective is a cue to depth that presumably could be used to track an approaching object, this cue involves changes in the colour and clarity of the object as well as its brightness. We know of no evidence suggesting that luminance alone can be used by the observer as a cue to motion. This differentiates luminance from pitch change, which clearly can be used as a cue to motion, as indicated by the work of Rosenblum, Carello, and Pastore (1987).

An RM task requiring luminance decisions will thus allow us to test more stringently the hypothesis that RM should be found for non-motion-correlated dimensions of change. If RM reflects a general phenomenon, then displays of discrete incremental luminance steps should result in a distortion of memory in the direction of luminance change implied by the inducing displays. On the other hand, if RM is limited to dimensions that are sufficiently correlated with motion to be used as a cue to motion, we might expect to see no RM for luminance decisions. Chapter 2 addresses these issues empirically.

Chapter 2 - Representational momentum experiments

Introduction

As discussed in Chapter 1, the representational momentum effect is both robust and applicable to many different tasks; impressively consistent effects have been demonstrated under a wide variety of conditions and methodologies. This wide applicability has become a cornerstone of the discussion about what the effect means. One argument suggests that the mechanism underlying RM is fundamental to the way we encode all information; this argument is based to a great extent on the generality of the RM phenomenon (Freyd, 1987; 1992). Because the observation of generality is crucial to the theoretical discussion surrounding RM, it is important to test the boundary conditions of the effect, to determine if there are important exceptions to the RM rule.

Experiments 1-3 in this chapter begin that process, by examining whether a RM effect for luminance change is observed. If the RM phenomenon reflects a mechanism that is fundamental to all information processing, as argued by Freyd (1987), then one should be able to observe a RM effect for luminance change. On the other hand, if RM reflects a mechanism that exerts its effects only on a subset of incoming information, such as ones specifically correlated with motion in the real world, one might expect there to be no RM effects for luminance change.

Experiment 1 looked for an RM effect for luminance under conditions as similar as possible to a situation that has been effective in eliciting RM effects for many dimensions of change. Experiment 1A is a replication of the original Freyd and Finke (1984) rotation momentum paradigm. Experiment 1B shows that when subjects are asked to make luminance judgements in a task similar to Experiment 1A, there is a robust displacement in the direction opposite to that predicted in the RM literature; Backward probes had longer RTs and greater error rates than did Forward probes. Experiment 2 addresses whether the different results could be attributable to similar processes with different time courses. Experiment 3 asks whether a manipulation that eliminates RM for orientation change similarly alters the luminance effect, and shows that the differing results from Experiments 1A and 1B were not the result of subtle display differences.

Experiment 1A - Replication of Orientation RM

Introduction

In order to examine issues of when RM might or might not appear, it is important to ensure that the effect in its original form is both replicable and robust. Experiment 1A was a replication of Freyd and Finke (1984) Experiment 1. As such, the methodological parameters described in this experiment are identical to those of Freyd and Finke (1984) unless otherwise specified. Figure 1 depicts a typical trial. Subjects were presented with three inducing displays that together implied rotation in a certain direction. They were then presented with one of three types of Probe Orientation: Same, Forward, and Backward. If the results of the original experiment are to be replicated, we expected to find longer RTs and greater error rates when responding to the Forward probes relative to the Backward probes.

Figure 1 about here

Method

Subjects

Subjects in this experiment were 12 undergraduate students (7 female) taken from an introductory Psychology course at McMaster University. They participated in the experiment to fulfil a course requirement. In this as in all of the experiments in this thesis, subjects were naive to the purpose of this experiment, and had never participated in any similar experiment.[1]

Design

Following the design of Freyd and Finke (1984), half the time subjects were presented with trials where the probe was the same as the third inducing display (Same trials), and on the other half with probes that were different from the third inducing display (Different trials). Subjects were informed of this Same/Different ratio. While we are mainly interested in the comparison of two kinds of Different trials, Forward and Backward, the Same/Different ratio of trials was necessary to prevent subjects from tending to respond "Different" on trials when they were uncertain. The design of the experiment was therefore a 2 x 2 repeated measures design. The first factor of Direction had two levels: Clockwise and Counterclockwise rotation. The second factor of Probe Orientation had two levels: Same and Different. On half of the Different trials, the orientation of the probe was in the Forward direction, and on the other half in the Backward direction.

Stimuli

Stimuli in this experiment consisted of arrangements of five collinear circles as depicted in Figure 1. Each of the constituent circles had a radius of 20 pixels horizontally, and 15 vertically. This correction for distortion due to aspect ratio was necessary because pixels on a computer screen are higher than they are wide, by a factor of 4:3. Subjects were seated approximately 75 cm from the computer screen. The entire object in the upright position, therefore, was 20 pixels wide (1.55 cm), or about 1.1° of visual angle, and 75 pixels long (7.7 cm), or about 5.6°.

The choice of stimulus was somewhat different from that of Freyd and Finke (1984), who used simple rectangles. This choice was inspired by the problems of presenting a smooth rectangle on a PC computer screen. Presenting such displays resulted in jagged borders when the rectangle was presented in orientations other than 0°(vertical) or 90°(horizontal). This jaggedness changed with orientation and thus introduced a confound with the independent variable of probe orientation. A series of circles was chosen to avoid this problem, because a circle presented anywhere has the same jaggedness of edge, while a series of five of them provides the long axis necessary for orientation judgements.

Procedure

In this, as in all experiments in this thesis, subjects were tested individually. Subjects were seated in a room lit by a single 100 watt incandescent bulb. Instructions were given orally. They were told that while fixating on the central cross, they should press the space bar on the keyboard to start the trial. They were further told that they would see three presentations of an object, one after another, at different orientations. They were instructed to keep their eyes on the center of the object. Immediately after the third presentation, there would be a fourth, and they were to decide whether or not that fourth object was at the same orientation as the third. If it was, they would press the marked "S" key on the keyboard (actually the "R" on the keyboard); if it was different, they would press the marked "D" key (the "O" key on the keyboard).

Each trial proceeded in the following manner. A fixation cross marked the place where the subjects were to look at the beginning of a trial. A blank screen was presented for 257 ms after the subject pressed the space bar until the first inducing display appeared. It remained on the screen for 257 ms, after which there was an ISI of 257 ms. This presentation rate was continued for the second and third inducing displays, until the target appeared and remained on the screen until the subject's response. After response, the fixation cross reappeared.[2]

For Clockwise trials, the three inducing displays were presented at 6°, 26°, and 46° from vertical. For Counterclockwise trials, they were presented at 86°, 66°, and 46°. For the fourth (probe) display, the Same orientation for both directions was 46°, while the Different orientations were ± 8° from that point, at 54° and 38°. These choices were similar, but not identical, to those of Freyd and Finke (1984), who used 17° increments for inducing displays and 7° increments from Same for the probes. Pilot data suggested that our choices provided the most reliable effects given our stimuli.

The experimenter demonstrated the task for the first few trials of the practice session. Subjects were asked to place their index fingers on the Same and Different keys, while resting a thumb on the space bar. After the demonstration, subjects were reminded that the differences between the third and fourth presentations would be very slight; they would have to watch carefully for any difference. They were told that half of the trials would require a 'Same' response, while half would require a 'Different' response. They were reminded that deviations from the Same orientation could be in either direction. Finally, they were asked to respond as quickly as they could while still maintaining accuracy.

There were 32 trials in the practice session, and 240 trials in the test session. Each session had equal numbers of Same and Different trials, and in each the number of Different trials was equally divided into Forward and Backward conditions. Thus, in the test session there were 120 Same trials, 60 Forward trials, and 60 Backward trials. Half of the trials in each condition were presented in Clockwise motion, half in Counterclockwise motion.

At the end of the practice session, subjects were given overall accuracy feedback, and reminded of the requirements to respond quickly and accurately. At the end of each set of 60 trials, subjects rested for approximately 30 seconds. They were also told that they could rest any time during the experiment by waiting before they pressed the space bar to initiate the next trial. They were given feedback and debriefed at the end of the experiment.

Analysis

RTs and error rates in this experiment were analyzed with a 2 x 2 repeated measures ANOVA. Each analysis had two factors. The first factor of Orientation Direction had 2 levels: Clockwise and Counterclockwise. The second factor of Probe Orientation had two levels: Forward and Backward. This comparison of Forward and Backward trials (rather than Same vs. Different) was judged to be the measure of interest for several reasons. First, this comparison is the one typically carried out in the literature (e.g. Freyd & Finke, 1984). Both conditions involved making the same overt response. Both conditions had the same number of trials overall. Further, the RM hypothesis states that subjects should have more trouble Forward (in the form of longer RT's and larger error rates), because these orientations should be compatible with their distorted memory of the orientation of the item. This deficit should be relative to an orientation that is similarly distorted from Same, but not in the direction implied by the inducing displays. Hence, the Forward/Backward comparison was considered the important comparison for present purposes.

Results

Mean RTs for correct trials were collected for each subject, averaged for each subject according to condition, and then averaged across subjects. In the original study, Freyd and Finke (1984) also discounted any trials for which RTs were greater than 2 seconds. In our experiment, these trials accounted for less than 2% of total correct trials, and had no appreciable effect on the data when removed. In the analyses reported here, they are included.

Mean response times and error percentages are reported in Figure 3A. Because the comparison of primary interest was between Forward and Backward trials, data from the Same trials were excluded from analysis, although they are shown in Figure 3A for the interest of the reader. RTs and errors were analyzed separately using 2 x 2 repeated measures analyses of variance (ANOVAs). ANOVAs were performed on Forward vs. Backward conditions, and the two directions of motion, Clockwise and Counterclockwise. The data show a clear replication of RM. Analysis of the RT data showed that there was a significant effect of Probe Orientation $\underline{F}(1,11) = 8.42$,MSe = 9269.28, p=.014; response to the Forward condition took significantly longer than to the Backward condition. Neither the effect of Direction nor the interaction reached significance ($F < 1.0$ in both cases).

Analysis of the error data supported the RT data. There was a significant effect of Probe Orientation, $\underline{F}(1,11) = 23.33$, MSe = 24.02, $p < .001$, showing that there were more errors for the Forward condition than the Backward condition. There was an effect of Direction in the error data, $\underline{F}(1,11) = 5.99$, MSe = 3.56, p = .032; more errors were made in the Clockwise than the Counterclockwise direction (Means of 15.4% and 17.4%, respectively). Since direction of rotation is typically run between subjects in the literature, there has been little examination of such directional asymmetries. This result is not corroborated by other experiments in this thesis. The Probe Orientation x Direction interaction did not reach significance, $\underline{F} < 1$. In summary, then, we have successfully replicated the typical RM effect with this methodology; greater error rates and longer RTs to the Forward probes relative to the Backward probes suggest that subjects have a more difficult time with probes further in the direction implied by the inducing displays.

Experiment 1B - Luminance Decisions

Introduction

Having established that the RM effect for orientation is replicable with our displays, in this experiment we tested whether RM could be observed for a non-motion-correlated dimension of change, namely luminance change. The same objects were used as in

Experiment 1A, with the exception that instead of changing in orientation (Clockwise or Counterclockwise), the objects remained upright and changed in luminance (Figure 2). Objects could either start light and get progressively darker (the Start Light condition), or vice versa (Start Dark condition). The task for the subject was to decide whether the probe was the same brightness as the third inducing display. If RM holds true for the dimension of luminance change, probes further along the path of luminance change should be more difficult than those less far along. In contrast, if RM is specific to motion systems, then it should not be observed for luminance decisions. In such a situation, we would expect there to be no significant difference between the Forward and Backward conditions for either of our dependent variables.

Figure 2 about here

Method

Subjects in this experiment were 12 undergraduates (7 female) from a first year psychology course participating individually for course credit. The design of this experiment was modelled on Experiment 1A. The experiment had a 2 x 2 repeated measures design. The first factor, Direction of Luminance change, had 2 levels: Start Light and Start Dark. The second factor of Probe Luminance had 2 conditions, Same and Different. As before, half of the Different trials showed probes that were further in the direction implied by inducing displays relative to the third inducing display (Forward condition), while the other half were in the opposite direction (Backward trials). It was the comparison between the Forward and the Backward trials that was the important comparison.

The procedure for this experiment was as similar as possible to that in Experiment 1. The stimuli are shown in Figure 2. Instead of changing in orientation these stimuli remained upright and changed in luminance from one inducing display to another. Different shades of gray were created by allowing all three of the phosphor guns to fire equally at one of 64 levels of intensity. This allowed for 64 different shades of gray from which to choose our displays. Inducing display gun values were set at 63,51, and 39 for the Darker direction, and 15, 27, and 39 for the Lighter direction. Probe settings were 27, 39 and 51. These settings were chosen to use almost the entire range of luminance change available to us, and to provide readily distinguishable inducing display steps and relatively difficult probe steps (See Appendix A for the luminances used in the three experiments). As Appendix 1 makes evident, the inducing display increments and probe display differences from Same were not constant log luminance differences in Experiment 1. For Experiments 2 and 3 we attempted to make the log luminance increments more similar, given the constraints of the 64 levels of grey with which we had to work.

Note, too, that because no attempt was made to determine what luminance change is psychologically equivalent to an orientation change of a particular size, any attempt to compare the magnitude of effect size between the two tasks is impossible. However, as we will show, the data show a qualitative rather than a quantitative difference between the two tasks. This suggests that the different patterns of data between the orientation and luminance tasks are not the result of psychological scaling differences.

There again were 32 practice trials, and 240 test trials.

Results

As before, Same data were not included in the analysis, but are included in the figures for the interest of the reader. Mean RTs and errors are shown in Figure 3B. Both were analyzed with 2 x 2 repeated measures ANOVAs. Analysis showed a pattern of data opposite to that predicted by the RM hypothesis. Looking first at the RT data, there was an effect of Condition, $F(1,11) = 60.02$, $MSe = 3791.5$, $p < .001$; subjects took longer to respond to the

Backward condition relative to the Forward condition. There was no significant effect of Direction, F(1,11) = 1.5, MSe = 3373.2, p = .24, nor was there a significant interaction, F < 1 .

Analysis of the error data also revealed a significant effect of Condition, F(1,11) = 43.34, MSe = 16.1,p < .001; subjects made more errors to the Backward condition than the Forward condition. There was no effect of Direction, F(1,11)= 2.28, MSe = 13.91, p = .16, and no significant interaction, F(1,11) = 2.34, MSe = 28.9, p =.15.

Figure 3 about here

Discussion of Experiment 1

In Experiment 1A, we replicated the results originally reported by Freyd and Finke (1984). The effects of Probe Orientation were somewhat smaller than those reported in the original study (79 ms and 22.3% errors vs. 216 ms and 37.5% error rate in the original study). The smaller effect reported here may be attributable to procedural differences. In particular, Finke and Shyi (1988) reported that RM is stronger when only one direction of motion is presented to a given subject. However, we chose to manipulate direction within subjects in order to insure that strategies by subjects could not magnify the effect. For example, exposing the subjects to the same direction of motion, with only three possible probe orientations throughout the session, could result in subjects developing a strategy of recognizing each probe display and responding the way they did last time to that display. With both directions intermixed, it is at least less likely such a strategy might be used. Regardless, significant RM for orientation judgements was demonstrated.

On the other hand, the results from Experiment 1B were directly opposite to those predicted by the RM hypothesis. Subjects were slower and more prone to error in making judgements about a luminance shifted backwards from Same than about a luminance that was farther in the direction implied by the inducing displays. Note that this backwards shift in the response distribution occurred for both luminance change directions, which discounts any explanation of the shift based on bias to respond Same to one sort of probe over another. This shift was not the result of any speed/accuracy tradeoff, since it was observed both in RTs and errors. The effect is robust; 100% of subjects showed it, both in RTs and errors. These data question the generality of RM as it has been proposed in the literature. If no effect for luminance change had resulted from the displays in Experiment 1B, we might have considered the possibility that the luminance changes were not large enough to produce psychological change similar to that of the orientation manipulation. However, the fact that the results are opposite to that predicted by the RM hypothesis makes such scaling concerns unlikely. There seems to be a mechanism at work here that is distinct from that which gives rise to RM.

Note that in spite of our rather liberal use of the phrase "luminance judgements" throughout these experiments, because we did not maintain constant contrast for these stimuli, we cannot be certain whether subjects were making their decisions on the absolute luminance of the stimuli, or with respect to contrast with the background. It has been shown that contrast is in many cases a more important dimension to the visual system than is absolute luminance (Gilchrist, 1988). In these experiments, however, the two are confounded. This confound was introduced because the control available to us with the computer screen did not allow us to examine these effects separately. This issue is not a concern in our discussion of RM; the data imply an important constraint on theories of RM, whether the effect is due to luminance or contrast. Rather, the issue speaks to the mechanism underlying the new effect. Future research separating absolute luminance of the stimulus from its contrast to the background could shed further light on this new phenomenon.

Experiment 2 - Time course manipulations

Introduction

In Experiment 1, we showed initial evidence that luminance decisions may not exhibit an RM effect; rather, they seem to result in an effect opposite to that of RM. If this new effect is robust, it calls into question the idea that RM should occur for any dimension of change. However, before we can make strong conclusions about this issue, we should show that the new effect is replicable, and further that it does not stem from artifacts of the particular methodology used in Experiment 1.

In Experiment 2, we introduced a new methodology to further explore this luminance shift and its relationship to RM. Freyd and Johnson (1987) showed that the size of the RM effect increased linearly as the time between offset of the third inducing display and onset of the probe (the retention interval, or RI) varied from 10 to 90 milliseconds. Experiment 2A attempted to replicate this finding.

Experiment 2B asked whether a similar result could be shown for luminance decisions. Perhaps RM for luminance exists, but simply has a much faster time course than RM for orientation change. If so, RM may simply have peaked and died away by the time the probe appeared 257 ms after the offset of the third inducing display. If that is the case, probing the luminance displays at very short retention intervals should result in a Forward shift of responses for the luminance task. If there were never any RM to be observed, we might predict only an increasingly large negative shift with increasing retention intervals. This prediction stems from the argument that negative shifts like this one are caused by memorial confusion between the third inducing display and the probe; this confusion likely would increase with retention interval. This increased confusion would presumeably result from increased noise introduced between the two stimuli to be compared. Note that this argument assumes that perceptual (as opposed to memorial) processes cannot develop along time courses as long as those in question. We address this issue further in Chapter 5.

In Experiment 2C, we attempted to determine whether or not the backwards luminance displacement can best be characterized as perceptual or memorial. As Hubbard (1993, 1995) argued, if an effect is perceptual, the effect should eventually decrease as the retention interval increases. If the effect is some form of memorial confusion, then it should if anything increase as the retention interval increases. We tested this hypothesis by measuring the backwards effect with longer ISIs of approximately 100-800 ms.

Methodological changes

In this experiment, we introduced a new methodology based on the work of Freyd and Johnson (1987). This new methodology was different in several ways from Experiment 1. For example, in Experiment 1B the Backwards luminance probe was identical to the second inducing display. It may be that a specific confusion occurred between these two displays, overriding an underlying RM effect for luminance. In Experiments 2B and 2C, nine different probe luminances were used, all of which were distinguishable from the second inducing display (as determined by pilot testing). Both inducing and probe luminances were adjusted to provide more similar log luminance differences between adjacent luminances (see Appendix 1).

Following the example of Freyd and Johnson (1987), the dependent measure in this experiment was the number of Same responses to each probe condition. The plotting of Same responses rather than percent correct was necessitated by use of nine different probe displays. Different probes that were nearest to being the same were very difficult to distinguish from Same probes; Different probes that were farthest from being the same were very easy to distinguish from Same probes. Because we wanted to plot a distribution of responses across the nine probe displays, plotting correct/ incorrect would have resulted in a W-shaped response function, while plotting "Same" responses results in a simpler parabolic distribution.

Reaction times were not collected in this procedure, again following the example of Freyd and Johnson (1987). Because the number of incorrect Same responses to the more extreme probes was very small, very few reaction times would be included in the analysis for these probes, yielding unstable reaction time measures. In addition, measuring Same responses may be a more sensitive measure using this procedure. Kelly and Freyd (1987) reported highly significant RM when number of Same responses was the dependent variable, but no effect for RTs.

Figure 4 shows the relationship between the inducing displays and the probes for the orientation stimuli of Experiment 2A. Probe 5 was identical to the third inducing display while the other probes were increasingly removed from Same, yet still distinguishable from the second inducing display orientations. If there is no evidence of any RM displacement, the number of Same responses should be largest at probe five, then fall away symmetrically on either side of Same. Displacements were measured by a shift in the distribution of Same responses in one direction or another. This method also insures that a smaller percentage of trials are considered filler trials, because the Same trials (which are typically not analyzed) now account for 11% rather than 50% of total trials.

Figure 4 about here

In this experiment we also varied the interval of time between the third inducing display and the probe. By varying this "retention interval", Freyd and Johnson (1987) probed the RM effect at different points as it developed over time. Experiment 2A is a partial replication of their results. Experiment 2B shows that the Luminance task does not give rise to RM even at very short retention intervals. Experiment 2C shows that the backwards shift for luminance judgements continues to increase over longer retention intervals.

Experiment 2A - Orientation task

In order to examine the time course of this new effect, we must first test whether our methods produce similar results to those reported in the literature. In this experiment, we replicated the results of Freyd and Johnson (1987). They showed that the amount of displacement induced by typical RM displays increased in a relatively linear fashion as the amount of time between offset of the third inducing display and onset of the probe increased from 10 to 90 milliseconds. The design of our study was identical to that of the original Freyd and Johnson (1987) study. Inducing displays were presented at 6°, 23° and 40° (Clockwise motion), or 74°, 57° and 40° (Counterclockwise motion). There were nine possible probe positions, only one of which was truly the Same. The other eight probe positions differed from the Same position by 2°,4°,6°or 8° in either direction. The dependent variable was the number of Same responses to each of the probe positions.

Method

Subjects

Twenty undergraduate students from a McMaster University introductory Psychology class (12 female) participated in the experiment to fulfil a course requirement. There was an increase in N for this study relative to the last because there were fewer observations per probe position in this study relative to Experiment 1, and because the variable of direction of inducing display change was run between subjects. This increase was in accordance with the Freyd and Johnson (1987) study.

Stimuli

As in Experiment 1, the same stimuli consisting of five collinear circles were used in Experiment 2. Inducing display orientations in this experiment were presented at 6°, 23°, and

40° for subjects viewing Clockwise motion, and at 74°, 57° and 40° for those viewing Counterclockwise motion. Ten subjects viewed rotation in each direction, as was the case in the original study (Freyd & Johnson,1987, Experiment 1). The probe could appear at the same orientation as the third inducing display (40°), or at ± 2°,4°,6°, or 8° from Same (see Figure 4).

There were 81 trial types (9 probe orientations x 9 retention intervals) that were presented equally often in the practice and test sessions (1 each in the practice session, 3 times in the test session). This was in accordance with the original study.

Procedure

Subjects were given a set of instructions that were almost identical to the ones given to subjects in Experiment 1, with the exception that they were not told that the number of Same and Different responses was the same. They were given a general strategy that if the probe looked even slightly different, they should respond 'Different'.

A typical trial is illustrated in Figure 4. Subjects initiated the trial by pressing the start key on a response box. Two hundred fifty-seven ms after this, the first inducing display was presented for 257 ms, after which there was an interstimulus interval of 257 ms. The second inducing display came on and remained for 257 ms, after which there was another ISI of 257 ms. The third inducing display then came on for 257 ms after which there was a retention interval determined by the trial condition. Freyd and Johnson (1987) used 9 intervals from 10 to 90 ms in 10 ms increments. However, since this experiment was run on a PC, we were limited by the refresh rate of our 70 Hz monitor; therefore, retention intervals had to be some multiple of 14.3 ms. Intervals in this experiment ranged from 14.3 to 128.7 ms. The probe stayed on the screen until the subjects had made their response. Responses were made by pressing either the 'Same' or 'Different' key on a response box.

The practice session consisted of 81 trials presented in random order, while the test session consisted of three sets of 81 trials each. At the end of each set of trials, subjects rested for at least 30 seconds before they were allowed to proceed. The session took about 20 minutes to complete.

Results

In this and in subsequent experiments, the term "shift" will be used to denote a shift in the distribution of Same responses away from the probe labelled as Same. Positive shift estimates indicate shifts in the Forward direction, and negative shift estimates indicate shifts in the Backwards direction. The number of same responses averaged across subjects and retention intervals is shown in Figure 5A. All twenty subjects showed a skew in the distribution of Same responses in the direction predicted by the RM hypothesis.

In accordance with previous research (Freyd & Finke,1985; Freyd & Johnson, 1987), the distribution of Same responses for each subject collapsed across retention intervals was subjected to a quadratic regression, and a measure of the amount of shift for each subject was determined by solving for the peak of that fitted parabola. The range of fit varied from .4 to .87 of the variance accounted for by the best fitting parabola, which is similar to the results of the original study. Mean positive shift estimates indicate response distribution shifts in the direction implied by the inducing displays (i.e.beyond Same), while negative shift estimates indicate shifts in the direction opposite to that implied by the inducing displays (i.e.behind Same). The range of response distribution shift varied from + 0.285° to + 5.615°. Mean shift across ten subjects for the clockwise direction was + 1.46°; for counterclockwise motion it was + 1.49°. This was not a significant difference t(18) = 0.052, ns., suggesting the amount of shift was not greater for one direction than the other.

An important result from the Freyd and Johnson (1987) paper was the generally linear increase of the size of estimated shift as retention interval increased. We collapsed our data across the 20 subjects, yielding a single distribution for each of the retention intervals, and a separate estimate of shift was computed for each collapsed distribution, using the procedure described above. The data are shown in Figure 5B. For purposes of comparison, we have included the data from Freyd and Johnson (1987) Experiment 1. There is an increase in shift with retention interval. Linear regression suggests that the best fitting line explains 86.3% of the variance. While this figure is lower than the 96% reported in the original study, it should be noted that the slightly different time courses between the two studies meant that the final retention interval was outside of the range of the original study (129 ms vs. 90 ms). It is this final point that deviates from linearity to the greatest extent. Without this final point, the linear regression explains a greater amount of the variance (R^2= .943). The best fitting regression lines for the two studies are remarkably similar (Y = .107+.017X in our study, Y=.070 + .019X in the original). We have thus replicated the original Freyd and Johnson (1987) study quite successfully, showing that the amount of RM observed increases in a linear fashion with length of the retention interval. This serves as a replication of the impressively clean result reported by Freyd and Johnson (1987), indicating that the development of RM for orientation change over the time course discussed is robust and replicable.

Figure 5 about here

Experiment 2B - Short time course, luminance task

If RM reflects a general mechanism, there should be some Forward shift for luminance judgements. This hypothesis was not supported in Experiment 1. It may be, however, that while there was a forward shift for luminance at very short retention intervals, it may have peaked, died away, and then turned negative by the time we probed it with the target at 257 ms ISI. Freyd and Johnson (1987) report that the forward shift for orientation judgements will die away and turn negative if the retention interval is extended long enough (i.e., greater than 1 s). If the results from Experiment 2A overlooked RM with a shorter time course, with this more sensitive methodology we should be able to see a forward shift for luminance judgements at very short retention intervals.

Method

Subjects

There were again 20 undergraduate students from McMaster University (14 female) participating in the experiment as part of an introductory psychology course requirement.

Design

The design was the same as in Experiment 2A. Half of the subjects saw dark objects that got progressively lighter (Start Dark condition), while the other half initially saw light objects that got progressively darker (Start Light condition).

Stimuli

In this experiment, there were 9 probe luminances: Same, ± 4.7, 8.7, 13, and 17.5 cd/m^2. There were also nine retention intervals, ranging from 14.3 ms to 128.7 ms in steps of 14.3 ms, as in Experiment 2A. If RM for luminance has a shorter time course, then we would expect RM for short retention intervals that should gradually die away with increasing retention interval. If there is no RM to be observed, we may expect to see only a Backwards shift as retention interval increases.

Procedure

Objects like those in Experiment 2A were presented upright for 257 ms with 257 ms

ISIs. Each presentation was a different level of grey that differed from the last in luminance by approximately the same log luminance distances, although we deviated from this somewhat at the higher luminances. As well, the difference between each successive target in terms of log luminance was kept as similar as possible. (See Appendix A for the luminance and log luminance readings for all the stimuli in this experiment.)

In all other respects, the procedure was the same as that in Experiment 2A. Eighty-one trial types (9 probe luminances x 9 retention intervals) were again presented equally often in the practice and test sessions (1 each in practice, 3 times each in test).

Results

As in Experiment 2A, Same responses for each probe averaged across retention intervals from each subject were submitted to a quadratic regression, and an estimate of the amount of shift derived for each. Overall fits ranged from .519 to .947 of the variance accounted for by the best fitting parabola. Negative shift estimates refer to shifts in the Backwards direction. Shift ranged from 1.13 to -4.87 cd/m2, for an overall mean shift of -1.12 cd/m^2. This shift did not differ for the two directions of luminance change; the mean shift of the Start Light condition was -1.66 cd/m^2, while the mean of the Start Dark condition was -0.57 cd/m^2, $t(18) = 1.45$, $MSe = 2.84$, $p > 0.1$. However, the effect was significantly different from 0 for the StartLight condition, $t(9) = 2.517$, $p. < .05$, but not for the StartDark condition, $t(9) = 1.62$, ns.

The number of Same responses averaged across subjects and retention intervals are reported in Figure 6A. While only 13/20 subjects showed a Backwards shift overall, across subjects the distributions were shifted in the backwards direction even for the very short retention intervals. This observation was supported when the data were collapsed across subjects and an overall estimate derived for each retention interval. As may be seen from

Figure 6B, at no retention interval does the shift estimate exceed 0, indicating a shift in the Forward direction. Thus, even with retention intervals as small as we could generate, we found no sign of a positive shift, suggesting that the shorter time course hypothesis cannot explain the absence of RM. As in Experiment 2A, we computed the best fitting regression line for these shift estimates. The best fitting line was given by $Y = -0.463 - 0.0071X$ ($R^2 = 0.47$); the negative slope of the line supports the idea that if anything the data show an increase of shift with retention interval.

Figure 6 about here

Experiment 2C - Longer time course

Is the backwards luminance shift perceptual or memorial in nature? The data from Experiment 2B suggest that for very short retention intervals there is no positive shift. Indeed, if anything, there seems to be a slight negative shift even at the shortest retention interval. There was some indication that the shift increased with length of the retention interval. If this shift were due to some perceptual confusion between inducing displays and probe, one might expect it to decrease as the time to process the inducing displays (the retention interval) is increased. On the other hand, if the shift stems from a failure of memory for the inducing displays, one might expect the effect to increase with retention interval (see Hubbard, 1995 for an elaboration of this point with respect to RM). This experiment tested these hypotheses. Retention intervals were extended out to almost 800 ms, rather than the 128 ms maximum in Experiment 2B.

Method

Twenty subjects, 16 female, participated in the experiment for course credit. The only difference in this experiment from Experiment 2B was the range of retention intervals, which now varied from 85.8 ms to 772.2 ms in nine steps of 85.8 ms.

Results

Shift estimates for each subject ranged from -.39 to -8.28 cd/m^2; i.e.in every case, subjects responded "Same" more often to Backward than Forward probes. Range of fit for these subjects was .556 to .904 of the variance accounted for by the best fitting parabola. All subjects showed an overall negative shift in this experiment. Overall mean shift was -3.1 cd/m^2. Again, the amount of shift did not differ between the two directions, $t(18) = 1.24$, $p > 0.1$. The effect was significant for both directions (9/9 subjects in both cases; significant by sign test).

The number of Same responses averaged across subjects and retention intervals are shown in Figure 7A, and clearly show a marked skew in the negative direction. Figure 7B shows the estimated shift for each retention interval. The data show that there was some increase in the magnitude of the Backwards shift with retention interval. As in Experiment 2A, we computed the best fitting regression line for these shift estimates. The best fitting line was given by $Y = -1.62 - 0.016X$ ($R^2 = 0.665$); the negative slope of the line suggests that shift either remains the same or increases with retention interval, but does not decrease.

Figure 7 about here

Discussion of Experiment 2

This set of experiments again demonstrates the robustness of both RM and the backwards luminance shift. Experiment 2A replicated the results of Freyd and Johnson (1987) in showing that RM for orientation judgements increases in a linear fashion at retention intervals less than 100 ms. Experiment 2B showed that RM for luminance was not eluding us because of a very short time course; even at the shortest retention interval, the observed effect was in the

Backwards direction. Experiment 2C showed that this backwards shift continues to increase with increases in retention interval, at least out to retention intervals of over 800 ms. This is another aspect of the luminance shift that differentiates it from RM. Freyd and Johnson (1987) reported that RM peaks at approximately 300 ms and then steadily declines. The fact that luminance decisions resulted in Backward shifts, as opposed to exhibiting a Forward shift for shorter retention intervals, further supports the idea that RM is not a factor for luminance decisions.

Note, too, that the data are not consistent with the notion of an underlying forward RM effect overshadowed by a stronger backward shift. If this were the case, we might have found a period in the measured time course in which the shift was positive, or at least less negative, corresponding to the rise and decay of the overshadowed RM. The data seem to imply a single mechanism resulting in a negative shift for luminance decisions. That the shift increases with increasing RI suggests a memorial rather than a perceptual locus for this mechanism.

The overall shift in the Backwards direction for luminance decisions was greater in Experiment 2C than it was in Experiment 2B (nine of nine retention intervals, significant by sign test). Because the only difference between the designs of the two experiments was in the retention intervals used, it is likely that the greater shift was due to the longer retention intervals in Experiment 2C. Hubbard (1995) argued that displacements such as RM that continue to increase with increasing retention interval are likely the result of a memory process. Whereas perceptual confusions are more likely to be resolved as more time is allowed for processing, the argument goes, memorial confusions are likely only to increase as the amount of time between the two items to be compared is increased. Given this argument, one might be tempted to conclude that this Luminance Backwards shift is memorial rather than perceptual in nature. However, given that some perceptual effects such as dark adaptation have very long time courses, it would be unwise to conclude that this effect is memorial without further consideration. We further address these issues in Chapters 4 and 5.

This distinction between perceptual and memorial effects allows us to make predictions about how other manipulations common to the RM literature would affect the negative shift. The 2-1-3 manipulation is an interesting case. Freyd and Finke (1984) showed that when the first two inducing displays were reversed in order, RM for orientation judgements disappeared. Presumably this was because a consistent motion was no longer implied by the inducing displays. If we employ the same manipulation with luminance displays, we might expect that if the shift were the result of a perceptual confusion between the two most recent displays before the probe, it would decrease with 2-1-3 presentations, because the second event is now more discriminable from the third display. However, if the shift is the result of a failure of memory for the inducing displays, one might expect no difference between a 1-2-3 display and a 2-1-3 display for luminance judgements.

Experiment 3: 2-1-3 manipulation

Introduction

In this experiment, we examined whether changing the order of the first two inducing displays would affect performance on the luminance task. Freyd and Finke (1984) showed that when the order of the first two displays was reversed so as to interfere with the consistent motion implied by the inducing displays, RM for orientation judgements disappeared. We replicated this methodology, and extended it by examining whether this manipulation would affect performance in the luminance task. Experiment 3A attempted to replicate Freyd and Finke (1984), comparing performance from a group of subjects who viewed consistent orientation change to one in which the first and second displays were presented in reverse order (hence the term 2-1-3 manipulation). Experiment 3B examined the effects of the same manipulation on luminance change for two new groups of subjects. We also attempted to rule out the possibility that subtle display differences might have produced the luminance shift, by presenting the same stimuli to two sets of subjects, one basing their decisions on orientation, the other on luminance.

Method

Subjects

These were 32 undergraduates from an introductory Psychology course, participating as part of a course requirement. None had ever participated in a similar experiment, and all were naive to the purpose of the experiment.

Design

Four groups of 8 subjects were presented with stimuli that changed both in luminance and in orientation, as in Figure 8. Two groups were asked to attend to Orientation (Experiment 3A), while the other two groups were asked to attend to the Luminance of the object (Experiment 3B). One group in each experiment was presented with an inducing display implying a consistent change along the attended dimension (the 1-2-3 groups), while the other group in each experiment saw the first two displays reversed (the 2-1-3 groups).

Stimuli

Each of the subjects in Experiment 3A saw 50 practice trials and 500 test trials. During the test session each subject saw the 500 trials in different random orders. All stimuli varied in both orientation and luminance. During each trial eight subjects saw Orientation (the attended dimension), vary according to the typical 1-2-3 RM procedure, while eight saw it vary 2-1-3. The unattended dimension (i.e. Luminance in this experiment) always varied 1-2-3. In Experiment

3B, the attended dimension was Luminance, and the unattended dimension Orientation. Eight subjects therefore saw a 1-2-3 luminance inducing display, while eight saw a 2-1-3 inducing display. The unattended dimension of Orientation was varied 1-2-3.

There were two possible directions of inducing displays for luminance (Start Dark and Start Light), and two possible directions of inducing display (Clockwise and Counterclockwise) for orientation, each presented on half of the trials. There were 5 possible probe orientations (34°,37°, 40°[Same], 43°,46°), and 5 possible probe luminances (see Appendix A). Five repetitions of each type of trial resulted in 2 x 2 x 5 x 5 x 5 = 500 trials per subject.

Five probe displays were used in this experiment, rather than the nine used in Experiment 2. This number of probes has been shown to provide useful estimates of response distribution shift, while decreasing the number of trials needed for a fully randomized design (Freyd and Finke,1985). The overall design of the experiment, therefore, had two between subjects factors: Attend Orientation/Luminance and 1-2-3 / 2-1-3 display. The within-subjects factors were Orientation Direction (Clockwise and Counterclockwise), Luminance Direction (Start Dark and Start Light), Probe Orientation, and Probe Luminance. As before, the dependent measure was the number of Same responses to the various probes.

Figure 8 about here

Procedure

Figure 8 shows a typical trial. After fixating on the central cross, subjects initiated the trial by pressing a start key on a response box. Two hundred fifty-seven ms after the keypress, the first inducing display was presented for 257 ms, followed by a 157 ms ISI. Pilot data suggested that this shorter ISI resulted in more robust effects with this methodology. This presentation rate was continued until the presentation of the probe, which remained on until the subject made a Same / Different decision. Subjects were given the same instructions as in Experiment 2, with the addition that they were specifically told that the changes in the unattended dimension (Orientation or Luminance) were irrelevant and that they should concentrate on the attended dimension. These subjects were also asked to respond conservatively; that is, they were told that if the probe seemed to change even slightly, they should respond "Different". The experiment lasted between 35-45 minutes.

Results - Experiment 3A: Orientation data

The data for this experiment showed the typical RM effect for the 1-2-3 trials, and a somewhat surprising reverse shift for the 2-1-3 data. Unattended luminance factors affected performance very little. We support these conclusions with the following analyses.

The number of Same responses from the two Orientation groups were first submitted to a 2 x 2 x 2 Mixed design ANOVA[3]. The factor of Type of Display (2-1-3 or 1-2-3) was manipulated between subjects. The other two repeated measures were Direction of Luminance change (Darker and Lighter) and Direction of Orientation Change (Clockwise and Counterclockwise). Note that if previous results are to be replicated, and Same responses are equivalent for both directions or Orientation change, there should be no effect of Orientation Direction with respect to the number of Same responses. Because subjects are not paying attention to Luminance change, we would predict no effect of Luminance Direction, nor would we expect it to interact with any other variable. Finally, if the results of Freyd and Finke (1984) are to be replicated, we expect no main effect or interaction with the factor of Type of Display.

The results generally bore out these predictions. There was one unexpected main effect of Luminance Direction, $\underline{F}(1,14) = 4.74, MSe = 42.85, p=.047$. This indicates that there were more Same responses to the Start Dark direction than the Start Light direction (means of

58% and 55.4%, respectively). The small difference between means, and the fact that a comparable effect of the unattended dimension was not found in Experiment 3B lead one to wonder whether this might be a spurious result. Further research will have to address this question. No other main effect or interaction was significant.

To test the effects of the manipulation on shifts in the distribution, analysis of shift estimates were subsequently carried out. Response distributions for both groups according to Orientation Direction and Probe Orientation are presented in Figure 9. If there were no shift, the response distributions for both Orientation Directions would lie directly on top of one another, symmetrically around Same. We predicted that for the 1-2-3 group there would be a significant shift away from Same, while for the 2-1-3 group there would be no such effect.

Figure 9 about here

To determine whether this shift is larger in one direction or another, or for one group or another, we need a more direct measure of the shift of these response distributions. As described in Experiment 2, Freyd and Finke (1985) addressed this question by fitting a parabolic regression to the data from each subject and computing the derivative of the regression equation to find the peak, to show that a significant number of these peaks were not centered on Same. Because we were replicating the results of Freyd and Johnson (1987), we employed that method in Experiment 2A. However, this method is not only time consuming, but involves imperfect regression fits. In some cases, these fits were not very impressive, given the fact that probes furthest from Same sometimes received almost no Same responses. This tended to flatten the tails of the response distribution, decreasing the fit of the best fitting parabola overall.

A simpler and more direct manner (Munger & Cooper,1993) involves taking an average of the difference of Same responses to corresponding probes either side of the Same probe. This was the method employed here. Assume A,B,C,D, and E refer to the five probes, with C being the Same probe. An estimate of the amount of shift (S) in the response distribution is given by

1) $S = [(E-A)+(D-B)]/2$.

After finding the value of S for each subject and for each condition, we can submit these shift estimates to analysis. We submitted them to a 2 (Type of Display) x 2 (Luminance Direction) x 2 (Orientation Direction) Mixed design ANOVA. The effect of the unattended dimension of Luminance Direction was not significant, $F(1,14) < 1$, nor did it enter into an interaction with any other variable ($F < 1$ in all cases). The unattended dimension of Luminance Direction thus seemed to have very little effect on response shift for this task. Interestingly, there was no main effect associated either with Group, or the attended dimension of Orientation Direction ($F < 1$ in both cases). However, there was a highly significant Group x Orientation Direction interaction, $F(1,14) = 82.93$, $MSe = 45.51$, $p < .001$. The reason for this interaction, and the lack of a main effect of the attended dimension of Orientation Direction, can be clearly seen by looking at Figure 9. The 2-1-3 group not only showed no RM, but instead showed a Backwards effect equal in size to the RM effect of the 1-2-3 group. A post hoc Neuman Keuls test showed that the two groups differed at both Orientation directions ($p < .001$ in both cases). Further, the means for the 1-2-3 Forward condition and the 2-1-3 Backward condition did not differ, nor did the 1-2-3 Backward condition and the 2-1-3 Forward condition means. This is consistent with the notion that the manipulation of Type of Display (1-2-3 vs. 2-1-3) resulted in roughly equal but opposite effects.

While the crossover interaction was not predicted, it is not a new finding in the literature. Freyd and Finke (1984) also showed a slight negative shift using the 2-1-3 manipulation, although the effect was not significant. This effect may be similar to the periodic motion effects of Verfaillie and D'Ydewalle (1991). They showed that when subjects view periodic motion of objects, they show forward shift in their judgements when probed during the period, but backward shift when probed at the end of a period, at the point where the object changed direction. Over the course of trials, the 2-1-3 displays in this experiment could be interpreted as an object moving back and forth periodically, which may account for the reverse shift found for these trials.

In summary, the 1-2-3 group showed the typical RM, a forward shift in the distribution of Same responses. The 2-1-3 group showed the opposite, a backward shift in responses. While this reversal was not predicted, it is not without precedent in the literature, and probably stems from the periodic changes in direction of the displays within a trial. The effect of the unattended dimension of Luminance Direction did not affect shift estimates.

Results - Experiment 3B: Luminance data

Data from this experiment again showed a significant Backwards shift for luminance decisions. Unattended orientation dimensions affected the data very little. In addition, the 2-1-3 manipulation did not affect the size of the backwards shift. We support these conclusions first with a 2 (Group) x 2 (Luminance Direction) x 2 (Orientation Direction) mixed design ANOVA on the overall number of Same responses, which resulted in no significant main effects or interactions. Note that the effect of the unattended dimension, which was marginally significant in Experiment 3A, was not significant here $\underline{F}(1,14) = 1.71$, $MSe = 16.84$, $p > .20$.

Response distributions for both groups according to Luminance Direction and Probe Luminance are presented in Figure 10. Note that if there were no shift, then the response distributions for both Luminance Directions would lie directly on top of one another, symmetrically around Same. We submitted the shift estimates to a 2 (Group) x 2 (Luminance Direction) x 2 (Orientation Direction) mixed design ANOVA. The effect of the unattended dimension of Orientation Direction was not significant (F < 1), nor did it enter into any interactions (p > .2 in all cases). This suggests that the unattended dimension again seemed to have very little effect on response shift, as was the case in Experiment 3A. There was a highly significant effect of the attended dimension of Luminance Direction, F(1,14) = 211.5, MSe = 32.9, p < .001). This indicates that this variable results in a shift in one direction for StartLight trials, and in a different direction for StartDark trials, as can be seen in Figure 10. Finally, there was a significant effect of Type of Display, F(1,14) = 7,27, MSe = 49.98, p = .017). Examination of the average shifts (9.37 for the 1-2-3 group, 11.66 for the 2-1-3 group) indicates that there was actually **more** shift from the 2-1-3 group than the 1-2-3 group, contrary to the prediction of the RM hypothesis, which predicted that the 2-1-3 manipulation should decrease the amount of shift observed for that group.

In summary, when subjects attended to the luminance of the object, the 1-2-3 group showed the negative luminance shift. In contrast to Experiment 3A, however, the 2-1-3 group did not show a decreased or opposite shift to the 1-2-3 group, but rather a larger shift. The unattended dimension of Orientation Direction did not affect shift estimates.

Discussion of Experiment 3

Results from these experiments make a number of points. First, we have shown that the surprising backwards shift for luminance decisions reported in Experiment 1B was not due to any subtle display differences between Experiments 1A and 1B. The Attend Orientation 1-2-3 group and the Attend Luminance 1-2-3 group saw exactly the same 500 trials; the only difference was the dimension of change to which the subjects were told to attend. This attentional manipulation nevertheless led to shifts in different directions, as is clear by examining Figures 9 and 10.

Second, the data suggest that the forward shift for orientation judgements and the backwards shift for luminance judgements are subserved by separate mechanisms. A coherent direction of implied change is essential for a forward RM shift, but unnecessary for the backward luminance shift. The unattended direction change variable never interacted with the attended dimension. Since a common underlying mechanism would have resulted in complex interactions between attended and unattended dimensions, perhaps these two types of shift are subserved by two separate mechanisms. The possible nature of these mechanisms is taken up in the general discussion.[4]

Finally, the data may be seen to support the idea that the luminance shift is more likely memorial than perceptual. If the luminance shift were the result of some perceptual confusion between similar things, we might have expected this 2-1-3 manipulation to decrease it, since the event immediately preceding the final inducing display was more salient in the 2-1-3 condition. On the other hand, if the shift were due to some general central tendency mechanism, as proposed by Freyd and Johnson (1987), or some memorial confusion involving the display as a whole, we might predict no effect of the 2-1-3 manipulation. Experiment 3 shows that this manipulation increased the size of the distribution shift.

Discussion

Taken together, the data reported in these experiments suggest that the mechanism underlying RM may not act on the dimension of luminance change. Experiment 1 showed that in a task made as similar as possible to the original RM task of Freyd and Finke (1984), subjects making luminance rather than orientation decisions showed a shift opposite to that predicted by RM. This backward luminance shift is not the result of speed/accuracy tradeoff, as it is present in both RTs and errors. Experiment 2 corrected for a possible confound in Experiment 1, that the Different probes were identical to the second inducing displays. When this confound was removed, a robust luminance shift remained. This luminance shift withstood changes in methodology, including changes in luminance steps, changes in retention interval, whether the direction of change was run between or within subjects, and various methods of measuring the size of the effect. Experiment 2 also demonstrated that the luminance shift held for a wide variety of retention intervals, suggesting that an RM effect for luminance was not missed as the result of its time course being shorter. In general, the luminance shift increased with increasing retention interval. Finally, Experiment 3 showed both RM for orientation and the (backward) luminance shift with the same stimulus displays, by manipulating which domain of change (orientation or luminance) subjects were told to attend while making their decisions. The two effects were further dissociated by showing that the 2-1-3 manipulation, which flips the RM effect, only increases the luminance shift.

The Function of RM

The data reported here challenge the notion that RM reflects an abstract, general mechanism that applies to any dimension of change. Not only have we failed to show RM for luminance decisions, but we have shown that such decisions result in a response distribution distortion opposite to that predicted by the RM hypothesis. In light of this evidence, we believe it may be worthwhile to re-evaluate the theoretical underpinnings of RM.

The notion that RM reflects a general perceptual process stems from a particular theoretical perspective as to the function that RM serves. This perspective has been laid out persuasively in the literature (see especially Freyd, 1987). From this perspective, information about potential change, or transition states, is held to be as important to the perceiver as information about steady states. For example, recognition of handwriting is affected by knowledge of the method used to produce that handwriting (Freyd, 1983a). Static pictures of moving objects will result in a representation that can continue the motion (Freyd, 1983b). These data imply that information about changes between states are important for the system. RM is purported to reflect a general mechanism that, at least in part, is involved with the representation of these transition states. In general, the assertion is that some, if not all representations in the brain are inherently dynamic, with the dimension of time inextricably represented (Freyd, 1987;1992).

We agree that there are dynamic representations, and that the importance of transition states to the visual system argues against the widely held assumption that all representations are essentially static pieces of stored information. However, the idea that transition states are important to the visual system is a separate issue from whether such transitions are represented for all dimensions of change, regardless of whether or not the dimension is correlated with motion in the real world. Freyd (1993) distinguishes between the idea that RM is the result of internalizations of regularities in the real world, and the idea that it reflects a fundamental aspect of representation in general. In the former case, one might expect RM to be specific to dimensions of change for which such representations would be advantageous. From the latter perspective, the effect would be an unavoidable aspect of representation, and thus would occur for any dimension of change. This latter perspective is clearly the one espoused by Freyd (1987,1993), but the experiments described in this chapter argue against it. We believe that this finding is not inconsistent with many of the ideas about dynamic mental representations that have been discussed, such as the notion that dynamic representations are an adaptive aspect of some anticipatory computations (Freyd, 1992;1993); what it does indicate is that it may be more parsimonious, and more fruitful, to think of RM as reflecting a more specifically motion-based mechanism. In short, these findings are consistent with the hypothesis that dynamic mental representations are likely limited to situations where motion is involved, and are likely not an unavoidable aspect of all representation.

The Nature of the Luminance shift

When subjects are asked to make a judgement about the relative luminance between a probe and the third inducing display, the distribution of Same responses is shifted in the direction of the earlier inducing displays. It is clear that there remains much to be learned about the nature of the backwards shift for luminance decisions. We have suggested that it may be the result of memorial processes, but we have no direct evidence to show this. It may be that this is the result of incorporating consistencies about the perceptual world into our representational system much as has been hypothesized for RM and other judgement shifts. Alternatively, it may simply be some default behaviour to extract the central tendency of stimuli, as suggested by Freyd and Johnson, (1987). Based on the data presented here, our idea that it is the result of a memorial process represents little more than speculation. Before we discuss why we think it may have a memorial component, we outline some possible alternative explanations.

One possibility is that the luminance shift is simply the result of pupillary changes. The argument might be made as follows. ISIs during which the screen is dark would result in an increase in pupil size. When the next stimulus then briefly appeared, this increase in pupil size might result in increased light entering the eye, resulting in a perception of that object as being brighter than had there been no ISI. Perceived brightness of that briefly presented object would then be compared to a probe that remained on the screen for as long as the subject wished. Matching these two stimuli might then result in a pattern of data such as those reported here.

This explanation might be plausible if we were examining only one dimension of luminance change. However, this hypothesis predicts that when the stimuli get progressively lighter (the Start Dark Condition), a forward shift would result, instead of the observed backward shift. In addition, note that this explanation predicts that the shift should disappear with no ISI. Note too that it predicts that when the background is brighter than the objects, the opposite shift should occur. These issues are addressed in later chapters. To anticipate, data indicate that the backward luminance shift remains with a white background. These data make the pupillary explanation of the luminance shift unlikely.

Another possibility is that the backwards luminance shift reported here is similar to a retinal phenomenon known as the ramp aftereffect, first reported by Anstis (1967). Subjects were presented with a stimulus that varied in luminance according to a temporal ramp. For example, one such display might gradually increase in luminance over two log units in the space of one second, after which it would immediately return to the initial dark luminance. A common adaptation period involved 30 of these one-second ramps. At the end of this adaptation period, a grey test stimulus replaced the inducing display. Subjects reported a robust luminance change aftereffect; the physically unchanging test stimulus appeared to decrease in brightness for a period of 1 to 8 seconds after adaptation.

Is it possible that the backwards shift in Same responses here is due to the same mechanism that underlies Anstis's ramp aftereffect? Certainly both involve response shifts in the direction of previous stimuli. However, certain differences in methodology lead one to doubt this hypothesis. Clearly, our displays involve far more discrete changes in luminance than is the case in most studies examining the ramp aftereffect, but there is no a priori reason why that should preclude visual adaptation. Anstis (1967) reported that the aftereffect could be observed after only 1 ramp cycle, while generally the effect is stronger with increasing length of the adaptation period. It may be that our discrete displays give rise to some form of ramp aftereffect.

We see three main points that argue against this hypothesis. First, the two luminance directions were tested within subjects in Experiments 1 and 3. In a ramp aftereffect study, randomization of trials is a method commonly used to control for carryover between one direction of adaptation and another (e.g. Anstis & Harris,1987). Often, each trial is separated by a break as long as five minutes to reduce this effect. Trial presentation in the current methodology involves random presentation of both luminance directions, with the interval between response and the start of the next trial being rarely more than two seconds. It seems unlikely that such a methodology could result in robust aftereffects. Second, Experiment 3 suggests that luminance change in a consistent direction is not required to produce the backwards shift, since a 2-1-3 display involved two directions of luminance change among the three static inducing displays. One would be forced to argue that the single change in luminance from the second to the third inducing display was enough adaptation to produce this robust shift. This may be the case, but it does stretch what is normally meant by the term 'adaptation'. Finally, the Anstis ramp aftereffect does not transfer between retinal locations, implying an early perceptual locus. Chapter 3 addresses the issue of whether the effect under investigation here also transfers across retinal locations.

We therefore believe that initial evidence argues against an early perceptual explanation of this luminance effect. To a certain degree, further specification of this shift as either perceptual or memorial will depend on where one draws the line between perception and memory. However, inasmuch as perceptual processes are believed to have relatively short time courses, while memorial ones have longer time courses, the luminance shift described here may be seen to fall under the latter heading.

Hubbard (1995) addressed the perceptual/memorial issue with respect to RM. He argued that RM might be considered memorial in nature because the magnitude of RM increases with retention interval for very short intervals. The logic was that if the effect were solely perceptual, longer retention intervals would allow the system more time to disambiguate the inducing displays, thus decreasing rather than increasing the effect. If the effect were memorial, an increasingly weak trace of the third inducing display would result from an increasing retention interval, thus increasing the effect.

The data from Experiment 3 do not indicate that the magnitude of the luminance shift deteriorates with an increase in retention interval; if anything, it continues to increase. Given the above logic, this may be seen to imply a memorial rather than a perceptual mechanism. Taken together, data from Experiments 2 and 3 seem to imply a memorial component to this task. Chapter 4 addresses this issue more directly.

In summary, these three experiments had two main foci. First, the project began as an attempt to find out whether RM could be seen for changes in the luminance of an object. Despite many attempts, we have never seen such an effect. We have argued that this restriction on the generality of RM has important implications for theoretical accounts of RM. In particular, we argue that RM might more fruitfully be considered a phenomenon relevant only to dimensions of change correlated with motion in the real world. This may allow us new insights into the implementation of the RM mechanism in the physiology of the visual system.

Second, we have discovered an interesting new empirical effect, where subjects asked to make judgements about the luminance of two objects will show a bias in the direction of previously presented luminances. We have demonstrated the robustness of this shift, and clearly distinguished it from RM. We have suggested that it may be a memorial rather than a perceptual effect, although this remains to be more rigorously verified. Chapters 3 and 4 examine the nature of this luminance effect itself in more detail.

Chapter 3 - Ramp aftereffect and constancy

Introduction

In Chapters 1 and 2 we argued that examination of people's behaviour in making luminance judgements could constrain possible models of RM specifically, and notions of information representation more generally. In Chapters 3 and 4 we leave considerations specific to RM behind, and examine aspects of the newly discovered luminance effect, in the hopes of gaining information about the way in which luminance and related types of information are represented.

Consider a situation in which an artist attempts to re-create on canvas a particular scene from memory. If the painting is to be a faithful representation of the scene, information about the colour and luminance of areas within the scene must be accurately represented in memory. Studies in the psychological literature examining memory for colour and luminance information have been relatively rare, but what studies there are suggest that such information is subject to substantial error when memory judgements are required of subjects (Newhall, Burnham, & Clark, 1957; Uchikawa & Ikeda, 1986). It may be that systematic investigation of the errors associated with memory for colour and luminance could shed light on the role such information plays in the visual system. In Chapter 2 we reported a new error in memory for luminance judgements. Chapters 3 and 4 attempt to further specify the error and its implications for the study of the visual system in general.

Attempts to further specify the nature of this effect should accomplish at least two goals. First, such research should specify the relationship between this effect and others already in the literature that might be related. Chapter 3 begins this process, by examining the relationship between our effect and two phenomena about which more is known; specifically, the ramp aftereffect (Experiments 4 and 5) and lightness constancy (Experiment 6). Second, such research should map out the parameters of the effect in order to develop a theory about its nature and function, with an eye to discovering its physiological substrates. This was the goal of Chapter 4.

Section 1 - Ramp aftereffect

As suggested in the discussion of Chapter 2, the ramp aftereffect first reported by Anstis (1967) might seem to have a common cause with the luminance shift reported in Chapter 2, because both result in a response shift in the direction of previously presented stimuli. One way to examine whether the two effects stem from similar processes is to test whether they function at the same level of the visual system. This section reports two experiments to that end.

Anstis (1967) outlined the basic parameters of the ramp aftereffect. Subjects were presented with a stimulus that varied in luminance according to a temporal ramp. For example, one such display might gradually increase in luminance over two log units in the space of one second, after which it would immediately return to the original darker starting luminance. A common adaptation period involved thirty of these one second ramps. At the end of this adaptation period, a grey test stimulus replaced the inducing display. Subjects reported a robust luminance change aftereffect; the physically unchanging test stimulus appeared to decrease in brightness for a period of 1 to 8 seconds after adaptation. While not pupillary in nature, since the effect was maintained with artificial pupils, this ramp aftereffect was said to be the result of a mechanism very early in the visual system. Opposite effects could be created in adjacent areas of the retina using checkerboard adaptation displays. The effect did not transfer between eyes, and thus Anstis (1967) concluded that the effect was "retinal rather than central" (p. 711) in nature.

Since this first report of the ramp aftereffect, further work has specified its underlying mechanism. Anstis (1979) showed that the ramp aftereffect may be generated by at least two different components. Subjects were adapted to a spot of constant luminance surrounded by a background that increased in luminance according to a ramp. After adaptation, not only did the surround show an aftereffect, but the central spot also showed a ramp aftereffect in the opposite direction to the surround. Anstis (1979) showed that increases in surround luminance during adaptation resulted in decreases in the luminance of the central spot by simultaneous contrast. In addition, the apparent dimming of the surround during the test period due to the ramp aftereffect itself was shown to spatially induce the brightening of the central dot. Each mechanism was shown to result in an aftereffect of the dot when the other was held constant. These results suggest that there are probably multiple sources of this effect, including simultaneous contrast and adaptation (Anstis, 1986; Anstis & Harris, 1987).

Further work has implicated the on- and off- channels of the transient ganglion cells as the source of these aftereffects. Anstis and Harris (1987) examined changes with spatial frequency in the aftereffect across different retinal eccentricities, using different checkerboard ramp adaptation displays. They noticed that as the size of the squares decreased (or as the spatial frequency increased) in the adaptation display, not only did the vividness of the aftereffect decrease, but so too did the range of eccentricity over which the aftereffect could be induced. This led to the hypothesis that the range of eccentricity over which the aftereffect appeared might be determined by the size of the receptive fields for the cells underlying the aftereffect.

The authors employed two clever manipulations in their attempt to infer the size of these retinal receptive fields. In one experiment, they showed subjects a phase-scrambled checkerboard display for which each check varied according to a ramp while the display as a whole remained a constant luminance. In another experiment, they used a "snowfall" display for which each check was either black or white, while the entire display effectively varied according to a ramp. For the phase-scrambled display, only check sizes of no larger than a threshold size would result in an aftereffect, as a single check would need to fall on a single receptive field in order to experience the ramp. For the snowfall display, only check sizes no smaller than a threshold size would result in an aftereffect, as several checks need to fall on a receptive field to experience the ramp. By varying the size of the checks making up these displays, and observing whether the display resulted in an aftereffect, the authors concluded that the best estimate of the receptive field size for the cells underlying the aftereffect was 9 arcmin. They argued that this relatively coarse spatial grain was consistent with an underlying transient system, which has high temporal and low spatial resolution.

Further evidence to support the transient channel hypothesis was shown by Cavanagh and Anstis (1986). Subjects were presented with moving sawtooth gratings. Anstis (1986) showed that the perceived brightness of the overall grating depends upon the direction of motion of that grating, due to selective adaptation of the same brightening or dimming detectors affected by the ramp aftereffect. Cavanagh and Anstis (1991) showed that this direction-dependent brightness change was increased as the overall luminance of the grating was increased, suggesting that light adaptation is required to produce the effect. Further evidence suggested that temporal information alone, as opposed to the temporal and spatial change information afforded by drifting gratings, was enough to support the brightness change. Both findings support the notion that the transient system underlies these phenomena.

Cavanagh and Anstis (1991) explained these results by suggesting that this brightness change, and by association the ramp aftereffect, resulted from an inability of the off-response transient cells to reflect the fast portion of the ramp. For example, a particular sawtooth grating might consist of a series of ramps that gradually increase in brightness to the left of the peak, then gradually decrease in brightness to the right of the peak. As that grating travels from left to right across a particular receptor, the receptor will increase firing, but then not be able to decrease its firing rate fast enough to reflect the fast decrease in brightness to the right of the peak. This results in a percept of a relatively bright grating. On the other hand, a grating that had the fast part of the ramp as brightening results in a percept of a relatively dark grating. They supported this hypothesis by showing that symmetrical ramp periods showed very little brightness change, while increasingly asymmetrical ones increased the change.

The mechanism underlying the ramp aftereffect is therefore quite well understood. It does not transfer interocularly, or across retinal locations. It seems largely to be governed by the transient system, involving relatively large receptive fields and requiring light adaptation and temporal change to show the effect. More specifically, it seems to be governed by a non-linearity in response between on- and off- center transient detectors, caused when extremely asymmetric ramps render one channel unable to fully reflect the sudden change in luminance. Is it possible that the shift reported in these current experiments is a result of the same mechanism? Anstis (1967) reported that a prolonged adaptation period is not necessary to produce the effect; a single ramp cycle is sufficient. While the adaptation displays approximate a continuous change in luminance, typically they are composed of a number of discrete luminances presented in succession. It is conceivable that a more obviously discrete adaptation would produce an effect, albeit a smaller one. In this case, over a series of trials, adaptation for luminance change would be induced, even with such discrete luminance changes. If the same transient mechanism is proposed to underlie this effect, we should be able to show that it shares similar properties to the original ramp aftereffect. Experiments 4 and 5 addressed this issue, by examining whether the backwards response shift shares an important attribute of the ramp aftereffect, namely retinal specificity.

Experiment 4 - Is the effect retinotopic? Alternating sides

Introduction

Is it possible that the Backwards shift in Same responses shown in Experiments 1-3 is due to the same mechanism that underlies Anstis's ramp aftereffect? Certainly they predict similar shifts in the response distribution. Over a series of trials, it could be that our discrete stimuli could have resulted in a relatively weak ramp aftereffect. However, certain differences in methodology lead one to question this hypothesis. Clearly, displays from Experiments 1-3 involve far more discrete changes in luminance than is the case in most studies examining the ramp aftereffect, but there is no reason a priori why that should preclude visual adaptation. For example, informal evidence suggests that some luminance adaptation can occur very quickly, on the order of 25 ms (Zaidi, pers. comm., 1994). Anstis (1967) reported that the aftereffect could be seen after only 1 ramp cycle, while generally the effect is stronger with increasing length of the adaptation period. If we assume that our displays are giving rise to a weak ramp aftereffect it might predict that the effect should increase as the experiment progresses. However, when we examined the effect by block, we found no differences in the size of the negative shift.

Random presentation of the two Luminance Direction conditions presents another problem for this hypothesis. In a ramp aftereffect study, randomization of different adaptation directions is a method commonly used to control for carryover between 1 direction of adaptation and another (e.g. Anstis and Harris, 1987). Typically, each trial is separated by a break of five minutes, to reduce this effect. Trial presentation in the current methodology involves random presentation of two Luminance Directions, with a response - stimulus interval rarely more than two seconds. It seems unlikely that such a methodology could result in robust aftereffects.

Finally, Experiment 3 suggests that luminance change in a consistent direction is not required to produce the backwards shift, since the 2-1-3 displays involved two directions of luminance change among the three static inducing displays. One would be forced to argue that the single change in luminance from the second to the third inducing display caused enough adaptation to produce this robust effect. While rapid luminance adaptation is a possibility, it would be surprising it such adaptation resulted in a response distribution shift of this magnitude.

Despite these reservations, we sought to test the relationship between Anstis' ramp aftereffect and the response shift reported here. As discussed in the introduction to this section, there is now substantial evidence that the ramp aftereffect is an early perceptual phenomenon, and is retinally specific. This experiment tested whether the luminance shift reported in Chapter 2 would survive if inducing displays and test displays were presented to different parts of the retina. Subjects were asked to maintain fixation to a central cross, while each inducing stimulus and the test stimulus alternated 3° to the left and right of fixation (see Figure 11). We chose this method rather than one in which all inducing displays were on one side of fixation, and the probe on the opposite side of fixation, because pilot data suggested that eye movements were more likely with that method. The fact that only a single item (the probe) was presented to one side of fixation seemed to result in an orienting saccade to that new location that was difficult for a few subjects to suppress. On the other hand, regular alternation between either side seemed to result in a decreased likelihood that subjects would consciously try to track the display with eye movements. Furthermore, the alternation of displays seemed to reduce the likelihood of saccades to the new probe location. Eye movements were monitored by the experimenter for one-half of the subjects. If this backwards shift is subserved by the same mechanism as the ramp aftereffect, we would clearly predict no shift. However, if the mechanism underlying this shift is more central than that of the ramp aftereffect, we might still expect to show a backwards response shift with this type of display. Furthermore, these data will help to begin to pinpoint the locus of this misrepresentation of luminance information. If the luminance shift survives across retinal locations, it suggests that the locus of the error is more central than the retina.

Method

Subjects

Subjects in this experiment were 16 McMaster undergraduates (11 female), who participated in the experiment as part of a course requirement.

Design

Subjects were tested with stimuli similar to those in Experiment 3. In addition to the factors of Luminance Direction and Probe Luminance, a third factor of eye monitoring was included. Half of the subjects were watched throughout the experiment to ensure that they maintained eye fixation while half were only monitored for the duration of the practice session. As a result, this was a 2 (Eye Monitor condition) x 2 (Luminance Direction) x 5 (Probe Luminance) mixed factor design. The factor of Eye Monitoring condition (Monitor/No Monitor) was run between subjects, while the others were repeated measures.

Procedure

Phase 1 - Eye Monitoring pretest

Subjects were run in a brief eye monitoring pretest, in order to ensure the experimenter could reliably detect eye movements. They were asked to fixate on a cross in the center of the screen. On some trials, an asterisk would be presented to the left or right of fixation. If that occurred, they were told to move their eyes to that location, and then move their eyes back to the center when the asterisk disappeared. They were also told that on some trials nothing would appear; in that event they were simply to maintain fixation.

The experimenter positioned himself beside the computer monitor about 3 feet from the subject. The experimenter initiated a trial by pressing the space bar on the computer keyboard. On one third of the trials, the asterisk appeared approximately 3 degrees to the right of fixation for 1 second. One third of trials involved an asterisk appearing 3 degrees to the left of fixation. On one third of trials nothing appeared, and subjects kept their eyes on the central cross. Two seconds after pressing the space bar, a tone sounded; this told the experimenter to make his response about the motion of the subject's eyes on that trial. There were 21 trials in the pretest, lasting about 1 minute in all. Trial order was determined randomly. This phase was carried out by all subjects in both conditions.

Phase 2 - Main Experiment

Figure 11 shows a typical trial in this experiment. Subjects were reminded to maintain fixation throughout the trial. They initiated the trial by pressing the start key on the response box. Two hundred fifty-seven ms after that keypress, the first inducing display appeared upright 3° to the left of fixation for 257 ms, followed by a 157 ms ISI. The second inducing display appeared to the right of fixation for the same amount of time. The third inducing display then appeared 3 degrees to the left of fixation, in the same place as the first inducing display, again for the same amount of time. Finally, the probe appeared to the right of fixation, in the same place as the second inducing display, and remained on the screen until subjects made their response. The fixation cross flashed on and off synchronized with the onset of each display. This was done in order to help subjects maintain eye fixation throughout the trial, rather than have their eyes automatically drawn away from a stationary fixation to the sudden onset of a display in the periphery.

After presentation of the stimuli, subjects were asked to make same/different responses on the response box as before. In the Monitor condition, the experimenter then keyed in whether the subject's eyes had left fixation at any point during that trial. As before, there was a practice session of 50 trials. During this period, eye movements were monitored for subjects in both Monitor and No Monitor conditions. During this practice session they were told immediately each time their eyes moved, and reminded to remain fixated on the central cross. The subjects then carried out a 500 trial test session (2 Luminance Directions x 5 Probe Luminances x 50 repetitions). Subjects' eyes were monitored in the test session only for subjects in the Monitor condition.

Results

Experimenter accuracy in monitoring the three kinds of eye movements (movements to the left, to the right, or no movement) during Phase 1 of the experiment was 96%. Note that this accuracy rating was for detecting a single eye movement of 3 degrees. During Phase 2, in order for a subject to have maintained the stimulus on the same part of the retina for the entire trial by moving his eyes back and forth, he would have had to make 1 eye movement of 3 degrees and 3 eye movements of 6 degrees. It was apparent to the experimenter that this simply did not happen. In general, once subjects had finished the practice session of Phase 2, they were adept at maintaining fixation, and showed little inclination to change their strategy as the experiment progressed. Detectable eye movements of any sort were very rare; the overall number of trials flagged during the test phase because of some form of eye movement was 0.85%. Analyses were affected very little by whether or not these trials were thrown out; as a result, they are included in the following analyses.

As was the case in Experiment 3, we first tested for biases in overall Same responding, and then examined shifts in response distributions by analyzing the shift estimates. The Same responses were first submitted to a 2 x 2 mixed design ANOVA. As was the case in Experiment 3, we did not include the factor of Probe Luminance in the analysis (See Note 3). The factor of Eye Monitor Condition (Monitor/No Monitor) was a between subjects factor. Luminance Direction (Start Light / Start Dark) was a within subjects factor. Mean number of Same responses across all subjects are shown in Figure 12.

Examining the main effects first, there was no significant effect of Monitoring condition

F(1,14) = 2.69, MSe = 128.53, p = .12; overall number of Same responses were not different for the two groups of subjects. There was an unexpected effect of Luminance Direction F(1,14) = 6.18, MSe = 204.41, p = .026; there were somewhat more Same responses in the Start Light direction than in the Start Dark direction (Means of 47.2% vs. 42.2%, respectively). This indicates that there was a tendency to respond "Same" more often for Start Dark trials than Start Light trials. This bias has been reported elsewhere, where subjects show a bias to respond as if darker stimuli were the same as a comparison stimulus when the two stimuli are presented successively (Uchikawa & Ikeda, 1986). However, the effect is small, (means of 47.2% and 42.2%, respectively) and not of primary importance here. This effect is discussed in more detail in the chapter discussion. The interaction was non-significant.

Analyses of the shift estimates were carried out, as described in Experiment 3. We first analyzed the data with a 2 (Eye Monitor condition) x 2 (Luminance Direction) mixed design ANOVA. Because the two Luminance Directions predicted shifts in the opposite directions, the sign of the Start Dark data was changed to make the data comparable. With respect to shift estimates, there was no main effect of Eye Monitor condition, F(1,14) = 2.17, MSe = 36.74, p = .16, no main effect of Luminance Direction, F(1,14) = 1.99, MSe = 220.35, p = .18, and no interaction F(1,14) = 1.38, MSe = 220.35, p = .26.

Further analyses took the form of t-tests to see whether shift estimates for each Luminance direction differed significantly from 0. All t-tests are two-tailed dependent sample tests. Since the factor of Eye Monitor condition had little effect on the data, we collapsed across this factor, and tested overall whether shift estimates for the Start Light and the Start Dark trials differed significantly from 0. Estimates for the two directions were made equivalent with respect to sign, i.e. positive values indicate shifts in the predicted (Backwards) direction. Both Luminance Directions resulted in a significant shift in the predicted direction t(15) = 2.94, S.E. = 3.06, p < .01 (Mean shift estimate of 9.0) for the Start Light direction; t(15) = 4.382, S.E. = 2.68, p < .01 (Mean shift estimate of -11.75) for the Start Dark direction.

Discussion

It was clear that subjects did not adopt the strategy of keeping all the displays in the same retinal position by moving their eyes back and forth to the left and right of fixation. Certainly the subjects in the Eye Monitor condition did not do so; if the subjects in the No Monitor condition did so, we might have expected to see a stronger shift than that seen in the Monitor condition. This was not the case. The few subjects that reported attempting to follow the stimuli with their eyes found the task so difficult that they quickly reverted back to the suggested strategy of fixation on the central cross. In addition, every subject was asked during the debriefing how successful they had been in maintaining fixation, and every subject reported good success with that aspect of the task. It therefore seems likely that subjects were successful at maintaining fixation, insuring that the inducing displays and the probe were presented to two different areas of the retina.

In general, the results from this experiment support the notion that the Backwards shift from these types of displays is not limited to cases where the inducing displays are at the same retinal location as the probe. This result clearly distinguishes it from the adaptation effect introduced by Anstis (1967), which is retinotopic. However, in an effort to provide subjects with a task that could be easily monitored for eye movements, it is possible we may have introduced a confound into the experiment. Because the stimuli alternated sides, from left to right of fixation, it was always the case that the second inducing display and the probe were in the same retinal location. Perhaps this discrete overlap of displays could invoke the same mechanism underlying the Anstis (1967) ramp aftereffect. This clearly would require positing a form of "adaptation" of a different form than one currently accepted, because adaptation usually implies a process with a time course of seconds or minutes. However, recent evidence (Zaidi, pers. comm., 1994) suggests that adaptation for luminance can be an extremely rapid process, on the order of 25 ms.

Experiment 5 attempted to replicate the finding that the backwards shift crosses retinal locations. In addition, it addressed this possible confound of overlap between the second and fourth displays by using a display in which none of the displays fell on the same retinal location. If the effect survives this manipulation, then we may conclude that the effect is driven by a mechanism other than the one that drives the Anstis ramp aftereffect, and further, that the effect is not the result of rapid local luminance adaptation.

Experiment 5 - Is the effect retinotopic? Four locations

Introduction

The purpose of Experiment 4 was to determine whether the backwards response shift is limited to situations where the inducing displays and the probe are presented to the same part of the retina. If this were the case, it would imply that the cause is early in the visual system, as is the case with the ramp aftereffect. The results from Experiment 4 indicate that the effect does transfer across retinal locations, implying a more central locus. However, it is still possible that a retinally specific mechanism could have led to the pattern of data found in Experiment 4. Because the stimuli alternated to the left and right of fixation, the probe was presented to the same retinal location as the second inducing display. If the effect we are studying were due to some retinal interaction between the probe stimulus and previous displays, we might still expect a backwards shift with those displays, albeit perhaps a reduced one.

It was for this reason that we ran Experiment 5. If the effect is the result of overlap between the stimuli, then a display in which there is no retinal overlap throughout the trial should not produce the effect. However, if the effect is not retinally specific and has a more central locus, one should still be able to demonstrate a backwards shift with such a display.

Method

Subjects in this experiment were 12 McMaster undergraduates (6 female), drawn from the Introductory Psychology subject pool. The design of this experiment was a 2 x 5 repeated measures design, the two factors being Luminance Direction and Probe Luminance. Note that the simpler design compared to Experiment 4 is the result of our decision not to monitor eye movements.

Eye Monitoring

Because eye movements were so rare in Experiment 4, we decided to not monitor eye movements in the test session of this experiment. For the practice session, subjects were given identical instructions as in Experiment 4. Subjects were to maintain fixation on the central throughout the course of the trial. The experimenter monitored subjects' eyes for the duration of the practice session, informing them when their eyes had moved. Subjects were reminded to maintain eye fixation periodically throughout the test session. During the debriefing at the end of the experiments, subjects were also asked how successful they had been in maintaining fixation throughout the experiment.

Stimuli and Procedure

The stimuli for this experiment were the same as the last, with the exception of the location of presentation of the inducing stimuli. Instead of presenting successive displays to alternating sides of fixation, stimuli were presented in four predictable locations at equal distances from fixation, as shown in Figure 13. The centers of all four displays were 3° from the center of the fixation cross. The first inducing display always was presented to the left of fixation, at an orientation of 0° (vertical). The second inducing display appeared at 90° (horizontal) above fixation. The third appeared at to the right of fixation at 0°, while the probe appeared below fixation at 90°.

In all other respects, the procedure for this experiment was the same as that of the No Monitor condition of Experiment 4.

Results

Subjects reported having no great difficulty maintaining eye fixation after the monitored 50 trial practice session. The experimenter also found that after the first few trials, subjects reported that maintaining fixation was the easiest way of completing the task, and after that were disinclined to change their strategy.

Initial analysis took the form of a t-test, to test whether there were more Same responses to either the Start Light or the Start Dark condition. There was an unexpected effect, $t(11) = 2.66$, $SE = 6.98$, $p < .05$, indicating there were more Same responses overall to the Start Light condition than to the Start Dark condition (Means of 42.5% and 39.4%, respectively). Note that this is opposite to the main effect found in Experiment 4, and opposite to the effect predicted by previous research (Uchikawa & Ikeda, 1986). We have no explanation for this effect at the present time.

Shift estimates were again derived for the two Luminance Directions, as in Experiment 4. First, an single overall shift estimate for each subject was derived by computing two shift estimates for each subject, one for each Luminance Direction, reversing the sign of one of the conditions, and taking the mean of those two values. Twelve of twelve subjects showed a shift in the backwards direction, a result significant with a sign test. This suggests that the distribution of Same responses overall was shifted away from Same in the backwards direction.

While these results seem to imply that the backwards shift remains intact for this manipulation, the data are shown to be somewhat more complicated when we look at shift estimates for each Luminance Direction. Figure 14 shows the distribution of Same responses averaged across the twelve subjects, for the two Luminance Directions. Separate t-tests support what may be readily seen in the figure. The backwards shift was significant in the Start Dark condition t(11) = 5.02, SE = 2.62, $p < .01$ (Mean shift estimate of -13.125). However, the distribution of Same responses for the Start Light direction, while in the predicted direction, was not significant, t(11) = 1.48, SE = 3.71, ns (Mean shift estimate of 5.5).

Discussion of Experiment 5

The fact that a significant overall backwards shift was shown for a display that had no retinal overlap provides strong evidence that some aspect of the response shift is post-retinal. For these displays, there was no retinal overlap between different displays in a trial, and yet twelve of twelve subjects showed an overall response shift in the direction consistent with previous experiments. This suggests that the effect is distinguishable from the Anstis (1967) ramp aftereffect, which has clearly been shown to be retinally specific. Further, that the effect transfers across retinal locations argues against any complete account of this effect on the basis of rapid local retinal luminance adaptation (Sachtler & Halevy, 1992).

The response shift observed for these four-location displays is considerably smaller than was observed in Experiment 4; the mean overall shift estimates were 19.17 in Experiment 4, but only 9.65 in Experiment 5. One possible explanation for this might be that there is more than one process contributing to the backwards shift, one retinal and the other post-retinal. For displays where the retinal component is more or less eliminated, such as Experiment 5, one might expect to find a smaller yet significant backwards shift.

A more parsimonious explanation might be that the same single process is at work in both situations whether or not there is retinal overlap. What, then, explains the decreased size of the effect with these four non-overlapping displays? It may be that a number of seemingly subtle differences may affect the size of the response shift. First, the simple fact that there were four rather than two peripheral locations may have increased task difficulty. Second, there may have been additional perceptual complexity added to the display as the result of the fact that the displays alternated between horizontal and vertical orientation throughout a trial. Third, we know that we are more sensitive in the horizontal periphery than the vertical one. This may have made the second inducing display less perceptible than the others, as well as perhaps making the determination of the probe stimulus luminance more difficult.

It is puzzling that the response shift was significant only for the Start Dark condition and not the Start Light condition. With this methodology, showing a significant effect in one direction only leaves open the possibility that simple response bias, in this case the tendency to respond that darker probes are Same more often, could result in the observed pattern of data. Indeed, evidence suggests that luminance memory judgements are reliably biased in the Darker direction (Uchikawa & Ikeda, 1986). For these data, this explanation is countered by the finding that all twelve subjects showed an overall shift in the Backwards direction (i.e.half Darker and half Lighter probes) suggesting that our typical backwards shift is the more robust effect. However, this does not explain the asymmetry in the size of effect between the Start Light and Start Dark conditions. A similar pattern of data was shown in Experiment 4. In that experiment, shift estimates were smaller in the Start Light direction, although not significantly so. It may be that there is a small tendency to respond to darker probes more often as Same, in addition to our Backwards effect. When the two effects are in concert, as is the case in the Start Dark condition, the shift is robust, while when the effects are in opposition, the effect may be less so.

Thus, there are a number of possible reasons why this task resulted in a weaker and more complex effect than that in Experiment 4. It is clear that more research is required to tell which aspects of this 4-stimulus display contributed most to the decreased size of the response shift. Regardless, we have now twice shown that an overall backwards shift can be observed when stimuli are presented to different retinal locations, indicating that as least some aspect of the effect is the result of some non-retinal mechanism, suggesting that the neural substrate of the mechanism is more central than the retina.

Section 2 - Constancy

When one is faced with explaining an effect of luminance in which the percept (or memory) is demonstrably different from the presented stimulus, one literature that springs to mind is that on brightness and colour constancy. Constancy in these contexts refers to the ability of the visual system to maintain a constant proximal stimulus despite dramatic changes in the distal stimulus such as changes in the illumination of a scene. To use an example from Jameson & Hurvich (1961), white snow generally looks white and coal generally looks black, even though altering the degree to which each scene is illuminated may result in more light being reflected to the eye by the coal than the snow (i.e. when the scene with the coal is very brightly lit, and the scene with the snow is very dimly lit).

That brightness and colour constancy exist and present non-trivial computational problems for the visual system has been known for a long time. Among the first to address the problem of constancy were Helmholtz (1911/1924), Hering (1920/1964) and Wallach (1948). In a classic set of studies, Wallach (1948) showed that perceived brightness was determined not by the absolute amount of light reflected to the eye from the stimulus, but rather the brightness of the stimulus in relation to its surround. This "ratio principle" has become widely accepted as an accurate description of brightness constancy for at least a certain range of illumination (but see Jameson & Hurvich, 1961).

A current debate in the constancy literature is whether or not constancy is the result of a low-level or higher-level mechanism. One argument is that constancy is effected by a "simultaneous", or low-level mechanism, which maintains an invariant stimulus brightness or color, regardless of the level of illumination. This is the approach outlined by the so-called "retinex theory" of Edwin Land and his associates (Land & McCann, 1971; Land, 1977). They argue that constancy can be maintained through a series of local contrast comparisons, and does not require representation of the overall illuminance of a scene for constancy to occur.

Another approach argues that such early perceptual processes do not result in constancy effects strong enough to explain the effect. These authors argue that the illumination of a scene must be encoded, represented, and corrected for at some point higher up in the visual system (Arend & Reeves, 1986; Arend & Goldstein, 1987; Troost & deWeert, 1991). In fact, evidence suggests that information about the illuminance of a scene is encoded and considered separate from the object (Gilchrist, 1980; Gilchrist, Delman, & Jacobsen, 1983). In addition, recent evidence suggests that people's responses about the colours or brightnesses of stimuli depend on whether or not they are asked to take the illuminance of the scene into account (Arend & Reeves, 1986; Arend & Goldstein, 1987; Troost & deWeert, 1991). Illuminance information is therefore stored and used in decisions involving brightness and colour. The idea that illuminance information is stored and then retrieved is consistent with the idea that some aspects of brightness constancy may stem from high level processes.

It may be that the response shift reported in Experiments 1-5 stems from an illuminance information mechanism. Given that the total amount of light entering the eye at any point in time is constantly changing, a snapshot measure of illuminance for purposes of constancy might be misleading. A more faithful representation of scene illuminance might be one that is derived from an average illuminance taken over a period of time. Such a measure would result in a more accurate illuminance measure of constantly changing visual scenes. In the displays used in our experiments, the only source of luminance change comes from the objects themselves. This proposed "background illuminant" mechanism might extract some average illuminance measure from these stimuli, a process that might then affect subsequent decisions about the brightness of a particular object. This idea that the effect is the result of some average of the stimuli presented is addressed more directly in Chapter 4.

An alternative account may be that instead of resulting from a constancy-related mechanism, the response distribution shift in fact may stem from a failure of constancy. The purpose of constancy is to maintain constant perception in the face of a changing distal stimulus. One could argue that this is exactly what is not happening with the backwards response shift, where the percept of an object is changed because of previous changes to the distal stimulus. Such a lack of constancy could be the result of presenting stimuli under conditions that are not conducive to showing constancy.

Recent evidence suggests that constancy is observed more strongly for lightness decisions (judging the reflectance of the stimulus) than brightness decisions (judging the absolute brightness of the stimulus) (Arend & Goldstein, 1987). It has been suggested that this difference may stem from observers not taking into account information about the illuminance of a scene while making brightness decisions. Troost and deWeert (1991), for example, argued that whether people exhibit colour constancy depends upon the degree to which information about illuminance is attended to by the subjects. Furthermore, people tend to make lightness decisions when presented with stimuli that are presented on bright backgrounds, while they tend to make brightness decisions when presented with stimuli that are on dark backgrounds (Jacobsen and Gilchrist, 1988b). This may be because stimuli on bright backgrounds allow subjects to make implicit assumptions about illuminance in a way that stimuli on dark backgrounds do not, although this idea has not yet been tested empirically.

If this backwards shift reflects a failure of lightness constancy, it may be due to the fact that all of the experiments thus far have involved light stimuli on dark backgrounds, and thus guided people towards making brightness decisions rather than lightness decisions.[5] If so, then presenting the same stimuli as decrements should result in a very different pattern of results, perhaps eliminating the backwards shift. If increment / decrement display is not the critical variable, or if the backwards response shift is the result of some process by which the ambient illumination in a scene is encoded and represented, one might expect the backwards shift to remain intact. We tested these hypotheses in Experiment 6.

Experiment 6 - Constancy; White background

Introduction

Experiments 4 and 5 indicate that the source of this response shift is not the same transient retinal mechanism that underlies the ramp aftereffect of Anstis (1967). Another possible mechanism that seemed worthy of exploration was brightness (or more accurately lightness) constancy. Wallach (1948) described a series of experiments that showed that subjects' judgements about the perceived brightness of a stimulus was governed not by the absolute luminance of the stimulus, but rather the contrast of that stimulus compared to its surround. He did this by demonstrating that when subjects matched the shade of gray of an adjustable comparison disk-annulus stimulus to a standard disk-annulus, they adjusted the comparison disk so that it had the same luminance ratio to its annulus as the standard. This "ratio principle" holds true whether the comparison and standard were under the same or different illumination.

The generality of the ratio principle has been the matter of some debate. Jameson and Hurvich (1961) reported experiments that suggested that the ratio principle only held for a limited range of illuminations, and when the stimuli were extended outside of this range, large departures from brightness constancy could be demonstrated. More recently, Jacobsen and Gilchrist (1988a) reported studies that suggested the ratio principle was far more generalizable than indicated by the Jameson and Hurvich studies, and that some aspects of Jameson and Hurvich's data were essentially unreplicable. Despite this debate, that the visual system exhibits constancy over some range of illumination is considered well established.

In addition to the proposition that some of the results of Jameson and Hurvich (1961) were unreplicable, Jacobsen and Gilchrist (1988b) suggested that part of the confusion over the generality of the ratio principle was that the earlier studies failed to differentiate between lightness and brightness. In attempting to resolve the apparent contradictions between the work of Wallach (1948), who found constancy, and that of Hess and Pretori (1894/1970) and Jameson and Hurvich (1961), who did not, Jacobsen and Gilchrist (1988b) pointed to the signs of the centers and surrounds as being a crucial variable, which leads subjects to make their judgements on two different qualities of the stimulus. Increments, defined by stimuli that are lighter than their surround (such as those used in our experiments thus far), are believed to lead subjects to match on the basis of the absolute luminance of the stimulus; Jacobsen and Gilchrist (1988b) labelled these brightness judgements. Decrements, or stimuli that are darker than the background, lead subjects to match the perceived reflectance, or shade of grey, of the stimulus; these have been termed lightness judgements. Jacobsen and Gilchrist (1988b) showed that the ratio principle does not hold for increments, or brightness judgements, but holds over a wide range for decrements, or lightness judgements.

It may be that the effect we are studying stems from a failure of lightness constancy. If a function of the visual system is to maintain a perception of constant object luminance, such a task may be more difficult under conditions where lightness constancy in general is weak. Constancy is weak for increment stimuli; this may result in a failure of the visual system to maintain constant object luminance under increment conditions. If this is the case, we may expect the response distribution shift to disappear under decrement conditions.

Note that all of the probe displays used in Experiments have involved increments, or stimuli of various luminance presented on a black background. If this backwards shift were somehow related to a failure of a constancy mechanism, one might predict that presenting stimuli on a white background would provide circumstances under which constancy is more likely to occur, perhaps resulting in an elimination of the response shift. However, if the mechanism underlying this shift is not related to constancy, we might predict no effect of this manipulation on the backwards shift.

Method

The one important difference between this experiment and the 1-2-3 condition of Experiment 3B was that the background in this experiment was white rather than black (log luminance = 2.1 cd/m^2). Subjects were 8 undergraduates (2 female) participating for course credit. As in Experiment 3A, Luminance was the attended dimension, while Orientation was the unattended dimension.

Results and Discussion

In Experiment 6, the basic experimental design was the same as in Experiment 3. Subjects saw objects changing both in luminance and in orientation. However, in Experiment 6 subjects were told to attend exclusively and respond to luminance while ignoring orientation. We included the dimension of orientation change in these studies to address issues not relevant here, as well as to provide a more interesting visual display for the subjects. Because in these experiments we are concerned solely with issues regarding the luminance of the stimuli, the orientation data are theoretically irrelevant. Initial analyses included analysis of the orientation data, but in all cases the effects of these variables were small. Data reported in these experiments are therefore reported collapsed across the irrelevant orientation variables.

As in Experiment 5, the data were submitted to a t-test to test whether there were more Same response to one luminance direction than another. The data collapsed across subjects are shown in Figure 15. Results showed a significant effect of Luminance Direction, $t(7) = 2.63$, MSe $= 9.58$, $p < .05$; this resulted from a higher rate of Same response overall to the Start Dark condition (means of 40.6% and 45.7%). Again, this bias is consistent with previous work (Uchikawa & Ikeda, 1986), but inconsistent with the results of Experiment 5. Further work involving successive brightness contrast experiments with more precise control over the luminance of the displays may shed light on the circumstances under which subjects show biases to the lighter direction under some circumstances, and to the darker direction under others.

Two shift estimates were then derived for each subject one for the Start Light condition, and the other for the Start Dark condition. A positive shift estimate indicated a shift in the predicted direction. The average of these two estimates yielded an overall measure of amount of shift. Eight of eight subjects showed a shift in the backwards direction, significant by sign test. Both directions showed a significant shift in the backwards direction as well; t(7) = 3.71, SE = 4.79, p < .01 for the Start Light condition, t(7) = 4.67, SE = 3.64, p < .01 for the Start Dark condition. In addition, analysis of the difference between the estimates showed that shifts in one direction were not bigger than those in the other direction, t(7) = 0.15, SE = 4.93, ns.

The data from this experiment clearly show that the response distribution shift is not affected in any important way by changing the background from black to white, thus creating decrement rather than increment displays. This not only shows that the effect is robust to such changes, but also suggests that the shift was not the result of a failure of constancy due to subjects making brightness rather than lightness decisions. Under conditions in which lightness decisions are typically made, namely decrement displays, the effect remained. This is not meant to imply that the phenomenon under investigation is entirely unrelated to constancy. Instead, it shows that the shift is not the product of an artefact that results in a failure of constancy.

Conclusions

The experiments reported in Chapter 3 described initial attempts to relate the backwards response shift reported in Experiments 1-3 to other effects in the visual perception literature. Experiments 4 and 5 showed that the shift is distinguishable from the Anstis' (1967) ramp aftereffect. A priori, there were reasons to doubt that the two effects stemmed from the same mechanism. These included the fact that a coherent direction of change was not needed to produce the effect, that the stimuli in the present experiments were discrete, and that luminance direction was varied within subjects. However, with Experiments 4 and 5 we have solid evidence that the loci of the mechanisms underlying the two phenomena are different, because the backwards response shift reported here is not retinally specific. Experiment 6 makes a similar point with respect to constancy, in that the backwards response shift is not affected by a variable that affects constancy.

While these data show that the effect reported in these experiments is distinguishable from these others, they do not preclude the possibility that they have some aspects in common. For example, Anstis (1979) argues that one effect contributing to the ramp aftereffect is simultaneous contrast with the background. In general, simultaneous contrast or induction serves to increase the perceived difference between a stimulus and its surround (Heineman, 1972). This initially seems to imply a unidirectional effect (i.e. one which always serves to increase the brightness of a stimulus presented on a dark background). However, Anstis (1979) argues that simultaneous contrast contributes to the bidirectional ramp aftereffect by making the central field seem to gradually brighten or dim, in a direction opposite to the change of the surround. It is this apparent change that afterwards results in an aftereffect. There may be similar interactions between contrast effects and the backwards response shift. The relation between these processes needs further investigation. For example, it would be interesting to examine the effect of simultaneous contrast on this luminance shift by varying the luminance of the background either in concert with or in opposition to the luminance change of the stimulus about which the decision was to be made. Perhaps the increasing contrast resulting from the center and surround changing in opposite directions might result in an increased effect.

That the effect seems to transfer across retinal locations has interesting implications for its possible underlying neural substrates. As discussed earlier, Cavanagh and Anstis (1991) found convincing evidence that the ramp aftereffect was probably a function of the ganglion transient receptors. They concluded that these receptors could not respond quickly enough to the sudden part of the ramp stimulus, resulting in an underestimation of the change in the stimulus at that point. Some aspect of the response shift reported here is clearly postretinal, as Experiments 4 and 5 demonstrate. However, there still may be some aspect of underestimation of the change of the inducing stimuli that applies in this case, whether it is at the level of the transient cells or further along in the system. Note that such an explanation predicts that more gradual inducing displays will result in a smaller response shift, another possible avenue of research.

The finding that this effect is not retinotopic may help eliminate candidate sites for the physiological substrate of the effect. Anstis and Harris (1987) suggested that there are some areas further into the system than the retina that receive monocular, retinotopic inputs that could be a potential locus of the ramp aftereffect. For example, certain cells of the pretectal area of the midbrain are monocularly driven, and have very coarse spatial tuning much like that exhibited with respect to the ramp aftereffect. Other cells in the midbrain respond to overall space-averaged luminance of the visual field (Clarke and Ikeda, 1981). These facts argue against these areas of the midbrain as likely loci of the shift, since it transfers across retinal locations, suggesting that these particular monocular cells could not exhibit the shift. Furthermore, the response shift does not stem from any spatial variation in luminance, something that is crucial for the response of these monocular cells, but rather from temporal variation. Indeed, the fact that the effect transfers across retinal locations on either side of fixation leads one to wonder whether input to separate hemispheres might result in the effect, indicating the mechanism might lie rather deep in the system.

The purpose of Experiment 6 was to examine whether the backwards shift reported here is closely tied to the more familiar phenomenon of lightness constancy. We showed that the effect remained whether subjects were presented with stimuli that would lead them to make non-constant brightness decisions (increments), or constant lightness decisions (decrements). These data do not establish conclusively that constancy has nothing to do with the backwards response shift reported here. It does, however, argue against any direct explanation of the shift solely in terms of failure of constancy mechanisms due to artefact.

In the introduction to this section we discussed another proposal, namely that this shift results from a temporal luminance-averaging mechanism required for brightness constancy (Arend & Goldstein, 1987). The data from the experiments in this chapter say very little about this hypothesis, other than if such a process is going on, it goes on at a level deeper than the retina. Such an hypothesis would suggest that the effect is in some respect memorial, in the sense that information about previous luminance states must be carried forward and averaged. This hypothesis would support the notion proposed in Chapter 1 that the effect is better characterized as memorial rather than perceptual. Chapter 4 addresses this issue more directly.

Chapter 4 - Memory mechanisms

Introduction

In Experiments 4-6, we found evidence to support the notion that the backwards response shift reported in these studies is distinguishable from better known phenomena such as the ramp aftereffect and lightness constancy. In Experiments 7-9, we turned to the problem of what this effect is, rather than what it is not. Our starting point came again from the RM literature, from a statement made by Freyd and Johnson (1987). They found that when the retention interval of a typical orientation RM trial was extended beyond one second, subjects sometimes showed facilitated responses to the Backward conditions rather than the Forward conditions, contrary to the typical RM result. They suggested that in the absence of any representational momentum pushing the response distribution in the forward direction, people's memory judgements, rather than resulting in no shift at all, may tend to revert back to the central tendency of the previous displays, resulting in this backwards response shift. They likened this to the idea of the prototype developed by Posner and Keele (1968).

While the authors did not specify how this central tendency might be instantiated, the idea that central tendency is an important mechanism for perception and memory is not uncommon. Posner and Keele (1968) asked subjects to classify exemplars of dot patterns created around category prototypes. At test, subjects classified the prototypes themselves, and these were classified more efficiently than other new exemplars, suggesting that the prototype had been abstracted during study of the exemplars. Pijnunborgh (1987) showed that memory for colours tends to revert to more prototypical hues of a colour category over time (cited in Troost & deWeert, 1991). Work on the representativeness heuristic (Kahneman & Tversky, 1972) describes our tendency to view certain exemplars of a category as more representative of that category. All of these phenomena have in common the tendency of the mind to prefer and recall the central tendencies of complex or difficult categories (but see, for example, Brooks [1978] and Whittlesea [1987] for the argument that a prototype is not stored explicitly).

It may be that such a central tendency mechanism is involved in making the luminance decisions required in these experiments. Remembering the luminance of an object is not a task that is particularly easy or natural, to which the comments of the subjects will attest. In general, the task of the visual system is not to detect subtle changes in the colour or brightness of an object, because such changes are omnipresent. Indeed, it could be argued that the most common activity of the visual system is to ignore such changes; this occurs in the cases of brightness and colour constancy. Perhaps the task of remembering a particular color or luminance is sufficiently difficult that the tendency to remember the central tendency of a complex or difficult category, in this case the luminance of the inducing displays, becomes apparent. Such a mechanism would result in the shifted response distributions shown in Experiments 1-6.

An argument consistent with this central tendency hypothesis was put forward in the introduction to Chapter 2. To reiterate, research has shown that some aspects of brightness constancy require information about overall illumination of the scene (e.g. Arend & Goldstein, 1987). In a dynamic natural world, the amount of light reaching the eye varies continually. One method of maintaining a relatively stable representation of overall illuminance might be a central tendency function of overall luminance entering the eye over some period of time.

There have been relatively few studies examining our ability to remember luminance. These have in general shown that judgements based on memory are poorer than direct perception judgements (Newhall, Burnham, & Clark, 1957; Nilson & Nelson, 1980). More recently, however, a study by Uchikawa and Ikeda (1986) examined the question in more depth. Not only are memory luminance judgements less accurate than perceptual judgements, but they are consistently biased in the Darker direction. Further, they showed that interfering stimuli placed between the two stimuli to be compared caused subjects to shift their responses in the direction of the interfering stimuli.

These results argue that luminance can be encoded in memory, and that this memory is affected by other stimuli presented in the visual field.

While central tendency is clearly an important theme in perception and memory, two other aspects of memory and perception that have been shown to be common to a variety of different tasks are primacy and recency. Both these effects have been the subject of considerable research in the memory literature. We know, for example, of the wide applicability of the anchoring and adjustment heuristic (Kahneman, Slovic, & Tversky, 1982), where various sorts of judgements are affected by the first piece of relevant information presented to the subject. Stimuli that appear either at the first or end of a list are more likely to be recalled during a subsequent recall or recognition test, although the relative strengths of the advantage for primacy and recency varies depending on many factors (Murdoch, 1962).

Primacy and recency are also factors in tasks with more of a perceptual component. The first and last items in rapid serial visual presentation (RSVP) displays are more likely than the other items in the list to be clearly perceived and remembered, and thus are less likely to be missed when the same item is presented earlier in the list, a phenomenon known as repetition blindness (Kanwisher, 1987). Recency is a factor in perceptual tasks such as perceptual priming (e.g. Warren and Morton, 1982), negative priming (Neill & Westberry, 1987), contrast and induction (Heinemann, 1972), forward masking (Turvey, 1973), and unconscious perception (Debner, in preparation), where effects on task performance are enhanced when the priming or inducing item in question is more recent. Part of the reason why recent items commonly affect perceptual judgements may be that phenomena that stem from perceptual systems often develop very quickly, and thus any interaction with previous events will be more effective when the previous event is very recent. Indeed, as was noted in Chapter 2, this idea that perceptual processes typically develop quickly has been used as a criterion for distinguishing between perceptual and memorial effects (Hubbard, 1993,1995).

It may be that primacy or recency effects are involved with the response distribution shift reported in Experiments 1-6. In all but the 2-1-3 condition of Experiment 3, both the first inducing display and the most recent inducing display before the two displays to be compared were either lighter (Start Light condition) or darker (Start Dark condition) than the pair to be compared. This implies that both might effect a response shift in the same directions, although perhaps for different reasons. Perhaps the first display in the inducing sequence sets an "anchor", in the terms of Kahneman and Tversky (1973), which from then on determines how much and in what direction the response distribution will be shifted. Memory for the final inducing display luminance might be affected by this anchor point, resulting in a backwards response shift. Alternatively, it may be that the effect is governed by the most recent item before the two to be compared. For example, memory for the final inducing display luminance might be confused with this most recent display, also resulting in a backwards response shift. In short, either or both of these effects could contribute to the backwards response shift reported in Experiment 1-6.

In order to constrain possible models of this response shift, and to gain further evidence about the locus of the mechanism underlying this effect, we examined which of these three general models, primacy, recency, or central tendency, best describes the observed data. Experiments 7 and 8 vary the first and most recent displays while holding the average of the displays constant. Experiment 9 varied the average of the inducing sequence while holding the most recent item constant.

Experiment 7 - LDM/DLM manipulation

Introduction

For all of the experiments reported thus far, only the first two displays in each trial varied with Luminance Direction. Subjects' task was to decide whether the object currently on the screen, the probe, was the same as the third inducing display. These two objects, hereafter referred to as the "comparison pair", are not responsible for the backwards shift, as they are identical for each Luminance Direction. Clearly the effect must come as the result of some interaction with one or both of the two preceding displays. This final series of experiments attempts to examine whether the effect stems largely from only one of those displays, or from both.

One possible answer to this question may be that the backwards response shift results from some combination in memory of all the inducing displays. Freyd and Johnson (1987) alluded to a similar mechanism in their discussion of an experiment that showed a backwards response shift for a momentum task with a long retention interval. While discussion of this effect was limited, they suggested this effect might be attributed to "a process that abstracts the most prototypical position or "central tendency" of the three stimuli (as in Posner & Keele, 1968)." (p. 263). In light of this idea we proposed an initial hypothesis, that memory for the luminance of the final inducing display may be characterized as an average log luminance of all three inducing displays. Perhaps the visual system is not geared to remember specific luminances, but rather extracts average luminances over periods of time. For the present purposes we will refer to this preliminary notion as the "averaging hypothesis".

Another possibility, dubbed here the "recency" hypothesis, is that the backwards shift may result from a more direct interaction with the display immediately preceding the comparison pair; that is, [illegible] second inducing display. This mechanism might take the form of a confusion of memory with the most recent inducing display, or a more sensory confusion stemming from the most recent change in luminance before the comparison pair. If this recency mechanism were driving the backwards shift, one might have expected the 2-1-3 manipulation employed in Experiment 3 to decrease the shift, because in that case the second inducing display was more distinguishable from the comparison pair. This was not the case, arguing a priori against the recency hypothesis, but it is possible that this manipulation was not extreme enough to make the effect significant. The next series of experiments tackles this issue more directly.

Finally, a third hypothesis, which we have named the "primacy" hypothesis, might argue that the first inducing display is critical with respect to this response distribution shift. Such a mechanism might take the form of an anchor from which subsequent judgements are adjusted (Kahneman, Slovic, & Tversky, 1982), or some initial visual adaptation. Again, such an effect might have been expected to decrease with the 2-1-3 manipulation of Experiment 3, as the initial anchor point was not as extreme in the 2-1-3 displays. Again, the experiments in Chapter 4 will address these issues more directly.

Experiments 7-9 describe attempts to determine whether primacy, recency or central tendency, or some combination thereof, is the most appropriate for explaining the backwards response shift. Experiments 7 and 8 do this by manipulating recency and primacy while holding central tendency constant. Experiment 9 manipulates the central tendency and primacy of the inducing displays while keeping the most recent display before the comparison pair constant. There were two main conditions for Experiments 7 and 8. In one condition, subjects were presented with a very Light stimulus, a very Dark stimulus, and a Middle stimulus, followed by the probe (condition LDM). This is the condition depicted in Figure 16. Condition DLM consisted of the Dark stimulus first, followed by the Light stimulus, the Middle stimulus, and the probe. This manipulation varies the most recent stimulus before the comparison pair, while keeping the central tendency (defined by the log luminance average of all three inducing displays) constant. If the Backward shift is the result of such a central tendency mechanism, then there should be no difference between conditions LDM and DLM. Since the first two displays are approximately equal luminances away from the middle luminance (See Appendix B), we further predict that there should be no backwards shift for either condition. On the other hand, if some sort of recency account is more appropriate, there should be large differences between condition LDM and DLM, each showing a shift in the direction of the most recent inducing display. Finally, if a strict form of primacy is critical, then the shifts in response distribution should be in the direction of the first inducing displays, that is, in the direction opposite to that predicted by the recency account.

Method

Eight undergraduates (4 female) participated in this experiment as part of a course requirement. With the exception of the order of the inducing display luminances, the method in this experiment was identical to that of Experiment 3b. A sample trial is depicted in Figure 16. The luminance of the first two inducing displays were an average of 1.06 log units away from the third middle luminance. Conditions DLM and LDM were identical except for the order of presentation of the first two inducing displays. The five probe luminances are reported in Appendix B. In all other respects the method was the same as in previous experiments. Subjects carried out a 50 trial practice session and a 500 trial test session.

Results and Discussion

The Same responses were submitted to a 2 (Luminance condition: DLM or LDM) x 2 (Luminance Direction) repeated measures ANOVA. There was an unexpected main effect of Luminance Condition [F(1,7) = 10.69, MSe = 18.72, p = .014], reflecting more Same responses made overall for the LDM Condition than the DLM condition (means of 67.43 and 62.19, respectively) The small difference between means and the fact that this finding was not replicated in Experiment 3 leads us to question the robustness of the effect. We have no explanation for it currently. Neither the main effect of the unattended dimension of Probe Orientation nor the interaction was significant (p > .02 in both cases).

In order to examine the size of the response shifts for each probe direction, estimates of shift were derived for each subject for each Luminance Condition. Positive shift estimates indicate shifts in the predicted, or backwards, direction. All t-tests are two-tailed. A mean shift for each subject averaged across the two Luminance conditions was first obtained to test whether overall there was a significant shift in the response distributions away from 0. Eight of eight subjects showed an overall shift in the direction of the most recent display. This result needs to be viewed in light of the interaction with Luminance Condition, however. Analysis of these shifts with respect to Luminance Condition supported the asymmetry one can see in Figure 17. Condition DLM showed a shift in the direction of the most recent stimulus before the comparison pair, t(7) = 3.39, SE = 5.30, p < .02. Condition LDM, on the other hand, showed no significant shift t(7) = 1.14, SE = 3.83, ns.

The overall data are shown in Figure 17. The backwards shift overall is far more elusive with this set of displays than with the displays in, for example, Experiment 3b (See Figure 10). While display differences make comparisons between experiments open to question, a global measure might demonstrate this point. Across the 8 subjects and the two Luminance Directions in the 2-1-3 condition of Experiment 3b, the mean shift estimate was 22.97, while for the 8 subjects in Experiment 7, the mean estimate was 11.19. The two distributions of shift estimates were significantly different when analyzed by independent samples t-test t(7) = 3.7, SE = 3.19, p < .01. These results suggest that the manipulation used in Experiment 7 resulted in a smaller shift.

The data from Experiment 7 suggest at the very least that the most recent item before the comparison pair does not entirely govern the size of the backwards shift. For example, compare a DLM trial from Experiment 7 (Figure 17) with a 1-2-3 Start Light trial from Experiment 3b (Figure 10). In both cases, the second inducing display was more luminant than either item in the comparison pair. The second inducing display from Experiment 7 was in fact further from the luminance defined as "Same" than was its Experiment 3b counterpart (eg: 1.08 log units from Same vs. 0.48 log units from Same). This predicts that the backwards shift if anything should have been larger for Experiment 7. In fact, the data indicated that the backwards shift was smaller in Experiment 7 than in Experiment 3b. These data are consistent with the conclusion that the backwards shift does not result solely from some interaction with the immediately preceding display.

Note, too, that the data are not consistent with a primacy explanation of the effect. While the effect is smaller for Experiment 7 relative to Experiment 3b, it nevertheless remains in the direction of the most recent display overall, rather than in the direction implied by the first display. While it is possible that there is some small effect of the first display at work, the effect is clearly not as strong as that of the recency effect.

The fact that the size of the shift was so much smaller than in Experiment 3b, for example, may be seen to support the central tendency explanation of the effect, because the average log luminance of the inducing displays was held constant at Same in this experiment. However, the effect was significant overall, even though the effect was only apparent for one condition; the shift was only significant for the DLM condition, and not for the LDM condition. This might be seen to argue **against** a central tendency mechanism underlying the Backwards shift, because this was held constant across DLM and LDM conditions. However, it may be that particularly salient objects do more to shift the response distributions. In order for this to be true, we would have to postulate that for some reason the Light stimulus in this experiment was more salient than the Dark stimulus. We did attempt to ensure that both stimuli were similar luminance differences (in terms of log luminance) away from the luminance arbitrarily defined as "Same" (See Appendix B). However, it is possible that our efforts were unsuccessful. Alternatively, it is known that the visual system is asymmetrically sensitive to different luminance ranges (Stevens & Stevens, 1963). It is possible that one or more of these variables could have resulted in different saliences of the two displays.

There are at least three possible explanations for the asymmetric response distribution shift reported in Experiment 7. One is that the Light stimulus is more salient than the Dark stimulus in Experiment 7 because it contrasts more with the background. While this might be seen to predict that the backwards shift should always be larger for the Start Light condition than the Start Dark condition in the previous six experiments, which has not been the case, it may be that something about this display makes such salience differences more noticeable. For example, the inducing display luminance steps are larger than in any of the previous experiments, which may have served to make more evident these salience differences.

Another possible explanation for the asymmetric response distribution is similar to the first, in that it suggests that the Light stimulus in Experiment 7 may have been more salient than the Dark stimulus. However, instead of defining salience as contrast to the background, it may be that the Light stimulus contrasts more with the luminance defined as "Same". Again, we attempted to control for this by making the Light stimulus the same log luminance distance away from "Same" as the Dark stimulus. However, there are situations where log luminance does not map directly on to psychological distance (Stevens & Stevens, 1963). Perhaps this is one such situation.

Finally, the asymmetric response distribution shift may simply be due to a spurious result based on a weak effect. We have shown that the shift is smaller in Experiment 7 than in previous experiments. It may not be that there is a large difference in the salience of the Light and Dark stimuli, but the asymmetry may simply be a chance expression of a weak overall response distribution shift. If such were the case, one would expect this asymmetry not to be a replicable effect.

The rationale for running Experiment 8 was to try to explain the asymmetric response distribution shift by attempting to separate between these three alternatives. We chose to run the same experiment with a white background, rather than a black background. If the asymmetry was the result of the Light stimulus contrasting more with a black background, then it will also contrast less with a white background. If this explanation is correct, then using the same stimuli on a white background should flip the asymmetry, resulting in no shift for the DLM condition, and a significant shift for the LDM condition. However, if salience is defined relative to the Same luminance rather than the background, this manipulation should have no effect, as the contrast between the Light and Dark stimuli and the Same luminance will not have changed. We would therefore predict a similar pattern of data for this manipulation as was seen in Experiment 7; a significant shift for the DLM condition, but no effect for the LDM condition. Finally, if the asymmetry were due to a chance expression of a weak overall effect, we would predict that the asymmetry should not be replicable.

Experiment 8 - DLM/LDM white background

Introduction

Data from Experiment 7 provided initial evidence for the central tendency hypothesis. Because the log luminance average of the display was held constant at Same, this hypothesis predicted that the effect should have disappeared. In contrast, the recency argument predicted an equal or greater shift, because the most recent display was further removed from Same for this experiment relative to previous experiments. The primacy argument predicted a shift in the direction opposite to the recency account. Data from this experiment showed a considerably decreased effect relative to previous experiments, one that if anything was in the direction of the most recent item. While the results do not conclusively show that primacy, and particularly recency, have no effect on the data, they do implicate the importance of central tendency most clearly. One reason for Experiment 8 was to test whether this pattern of results is replicable.

The second purpose of Experiment 8 was to further inspect the asymmetric response shift reported in Experiment 7. In that experiment, we showed that there was a significant shift in the direction of the most recent display for the DLM condition, but not the LDM condition. Is this asymmetry due to some robust difference in the salience of the Light and Dark stimuli we chose? If so, we should be able to replicate the effect. If salience can be defined in terms of contrast with the background, then flipping the background from black to white should change the asymmetry, so that now there should be a significant effect for the LDM condition, but not the DLM condition. If salience is defined as psychological distance from the luminance defined as "Same", then changing the background should have no effect on the asymmetry, because contrast between the inducing displays and "Same" remains unchanged. Finally, the asymmetry may simply be unreplicable, resulting from a chance expression of a weak overall effect. If so, whatever backwards shift results from this manipulation should not express itself in the same asymmetrical response distribution seen in Experiment 7.

Method

Subjects in this experiment were 8 McMaster undergraduates (7 female) participating in the experiment as part of a course requirement. The design of the experiment was identical to Experiment 7.

The one important difference between this experiment and the last was the simple change of background from black to white. Instead of a dark background of approximately 0.4 cd/m^2, the background was now 125.4 cd/m^2. While the luminances of the stimuli themselves remained the same, flipping the sign of the background from black to white resulted in a series of dark stimuli presented on a light background, rather than a series of light stimuli presented on a dark background, as was the case in Experiment 7.

Results

Initial analysis of the Same responses took the form of a 2 (Luminance condition) x 2 (Orientation Direction) ANOVA. Neither of the main effects nor the interaction reached significance.

The response distributions for each direction are depicted in Figure 18. Two shift estimates were obtained for each of the eight subjects, one for each Luminance Condition. A test of the overall shift collapsed across Luminance Condition indicated no significant shift away from "Same", t(7) = 1.08, SE = 0.98, ns. Separate single sample t-tests showed that there was no significant shift from Same for either condition t(7) = 0.11, SE = 3.32 for the LDM condition, t(7) = 0.62, SE = 3.99, ns., for the DLM condition. In addition, a dependent sample t-test showed that there was no significant difference in the shift estimates for the two directions, t(7) = 0.41, SE = 7.06, ns.

Discussion

The results of Experiment 8 support those of Experiment 7 in suggesting that the separate effects of the first and most recent items are relatively small, considering the normal robustness of the backwards response shift. In Experiment 7, we showed that the amount of shift resulting from these LDM/DLM displays was reduced relative to the results of Experiment 3b. This finding has been replicated here in Experiment 8; indeed, in Experiment 8 there is little hint of a shift for either the DLM or the LDM conditions. The disappearance of the backwards shift is not some function of presenting stimuli on a white background, because in Experiment 6 we showed that presentation of the typical 1-2-3 displays on a white background results in a robust effect. It seems that the effect of the first and most recent items on these luminance decisions is relatively small.

The other goal of this study was to attempt to further specify the source of the pattern of data from Experiment 7, which showed a significant shift in the direction of the most recent display for DLM trials, but not for LDM trials. It was hypothesized that if this pattern was robust, then it should be replicable in some form with the displays used in Experiment 8. If the Light stimulus was somehow more salient by virtue of its contrast with a black background, then presenting the same luminances on a white background should have reversed the pattern of data, resulting in a significant shift for the LDM trials. This did not occur. If the Light stimulus from Experiment 7 was more salient because of contrast with the "Same" luminance, then we should have seen a replication of the results with a white background, since the contrast of the inducing displays with the "Same" luminance remained constant between the two experiments. This also did not occur.

What can we take from these experiments with respect to the three alternative mechanisms originally proposed? It seems clear that the most recent item is not the entire story with respect to the size of the backwards shift. In both experiments, we showed that the effect is considerably less robust with these DLM / LDM displays than with the original 1-2-3 displays. However, we cannot rule out completely the hypothesis that the most recent item affects the size of the backwards shift in some way. While the results of Experiment 8 tempt one to make that conclusion, and to write off the asymmetry from Experiment 7 as a spurious result, the fact that there was a significant shift overall in the direction of the most recent display in Experiment 7 suggests that under certain circumstances the most recent display can play a role. More research is needed to examine the role of the most recent display for these decisions.

As for the primacy effect, it seems that any effects it may have must be smaller than that of the recency effect. In both Experiments 7 and 8, potential primacy and recency displays were in opposition to each other. Given that, it is informative to note that overall in both experiments the distribution was, if anything, shifted in the recency as opposed to the primacy direction. It is possible that separate effects of primacy could be estimated in situations where it was not placed in opposition to the recency effect, an avenue of future research. For the moment, it seems reasonable to characterize the effect of primacy alone as being small or nonexistent.

Finally, the data seem to support the idea that the backwards shift reported in these experiments is some function of the central tendency of the inducing displays. In previous experiments, such as Experiments 1-3, backwards shifts were reported when the average log luminance of the inducing displays was in the backward direction. In this experiment, we ensured that the average log luminance of the inducing displays was close or equal to the luminance defined as Same, and the results showed no shift. In the final experiment, we tested whether manipulating the average log luminance of the inducing displays would vary the size of the shift.

Experiment 9 - Manipulate average not recency

Introduction

In Experiments 7 and 8, we manipulated the most recent display before the comparison pair while keeping constant the average log luminance of the inducing displays as a whole. We showed that manipulating the most recent display had little (Experiment 7) or no (Experiment 8) effect on the size of the backwards response shift. It was hypothesized that perhaps the important variable was not the most recent display, but rather the average of all the inducing displays. Experiment 9 attempted to test this hypothesis more directly by manipulating the average of the inducing displays, while keeping the most recent item constant.

Method

Subjects in this experiment were 8 undergraduates (1 female) participating for course credit. The design of the experiment was a 2 (Luminance Direction) x 2 (Congruent/Incongruent) x 5 (Probe Luminance) repeated measures design. These displays were presented in an upright position (See Figure 19). The procedure was identical to the previous two experiments.

The important difference between this and the previous two experiments was the introduction of the new Congruency variable. An example of an Incongruent trial is presented in Figure 19. A Congruent trial was identical to a typical trial in previous experiments. For Incongruent trials, the initial inducing display was replaced with the initial inducing display from the other luminance direction. For example, for a Start Dark Congruent trial, inducing displays would first appear dark and get progressively lighter as the trial progressed. For a Start Dark Incongruent trial, the first inducing display would be light, followed by the second, third and fourth displays typical of a Start Dark trial. Log luminance average of the inducing displays for Congruent trials was closest to the second inducing display, while log luminance average of the Incongruent trials was closest to Same (i.e. the last inducing display). The Congruence variable allowed us to examine the effects of changing the average luminance across all luminance displays without changing the most recent inducing displays before the comparison pair. If central tendency and not recency guides the effect, we should see a significant effect for Congruent trials, and little or no shift for Incongruent trials.

Results and Discussion

The data were first analyzed with a 2 (Congruence) x 2 (Luminance Direction) repeated measures ANOVA, to test for any differences in overall number of Same responses. Neither of the two main effects nor the interaction reached significance.

In order to examine the size of shift with respect to the factors of Congruence and Luminance Direction, we obtained four shift estimates for each subject, one for each level of Luminance Direction and Congruency. These estimates were then analyzed using a 2 x 2 repeated measures ANOVA. There was a significant main effect of Luminance Direction $\underline{F}(1,7) = 7.49$, MSe = 73.29, p = .03, which resulted from larger shift estimates in the Start Dark direction than the Start Light direction. This finding is again consistent with those of Uchikawa and Ikeda (1986), who showed a bias to respond in the darker direction in a successive contrast experiment. There was a large main effect of Congruency $\underline{F}(1,7) = 75.56$, MSe = 14.23, $p < .001$, resulting from greater shift estimates for Congruent trials than Incongruent trials. This was the critical finding for the central tendency hypothesis; responses were shifted to a greater extent for Congruent trials when the average log luminance of the inducing displays was shifted backwards, than for Incongruent trials, when it was the Same. The interaction was not significant $\underline{F}(1,7) < 1$, MSe = 7.9,ns.

In addition to this analysis, each of the four groups of response was submitted to a single sample t-test to examine whether each exhibited a significant shift away from 0. As in previous experiments, all t-tests are two-tailed. Both Congruent sets of data showed a significant shift away from 0, t(7) = 6.72, SE = 1.59, p < .001 for the Start Light Congruent trials, t(7) = 7.43, SE = 2.47, p < .001 for the Start Dark Congruent trials). Neither Incongruent condition showed a significant shift from 0, although there was an effect for Start Dark Incongruent trials; (t(7) = 0.98, SE = 1.53, ns. for the Start Light Incongruent trials, t(7) = 3.30, SE = 2.23, p < .02 for the Start Dark Incongruent trials).

The fact that shifts were in general larger for the Start Dark condition relative to the Start Light condition is interesting, given that a similar pattern of data was obtained in Experiment 5. As mentioned in the discussion of that experiment, Uchikawa and Ikeda (1986) showed that memory for luminance tends to drift in the Darker direction. This is clearly an important effect to keep in mind when carrying out this type of research, as it tends to enhance the shift for Start Dark trials, and decrease the effect for Start Light trials. It is unclear what mechanism underlies this drift in the Darker direction for luminance memory judgements.

In general, data from this experiment support and extend the conclusions drawn in Experiments 7 and 8. First, Experiments 7 and 8 showed that manipulating the most recent item before the comparison pair had little effect of the size of the backwards shift. This suggested that something other than the most recent display determined the size of the shift. In Experiment 9, we found such a variable; manipulating the average of the inducing displays by altering the first inducing display has a significant effect on the size of the response shift. This result may be seen to support the notion that the size of the backwards shift is governed less by the most recent item before the pair of displays to be compared, but rather by some amalgam of the entire set of inducing displays. Note that the most recent item prior to the comparison pair was identical in both Congruent and Incongruent trials. However, there was significantly less shift for Incongruent trials, indicating that changing the average of all the inducing displays had a dramatic effect on the size of the shift.

Conclusions

The main purpose of Experiments 7-9 was to put constraints on models of this response distribution shift by looking at the effects of primacy, recency, or central tendency on the size and direction of the shift. Experiment 7 showed that when the log luminance average of the entire inducing display was held constant at Same, the backwards response shift reported in previous experiments was significantly decreased relative to previous experiments, and only different from 0 for the DLM condition. The results of Experiment 8 support the conclusion that the shift is decreased or eliminated for these DLM/LDM displays. They show that for stimuli presented on a white background, there was no significant shift in either the DLM or LDM conditions. These results argue against the idea that the asymmetry of response shift (i.e. the significant shift for the DLM condition but not the LDM condition in Experiment 7) was due to a replicable salience difference between inducing displays for the two conditions, either relative to the background, or relative to the luminance defined as "Same". The fact that in both Experiments 7 and 8 the distributions were if anything shifted in the direction of the most recent item rather than the initial item was taken as evidence that recency may be a more powerful determinant of this shift than primacy. Finally, Experiment 9 showed that holding the most recent event constant while varying the central tendency of the inducing displays resulted in distribution shifts in the direction of the central tendencies of the inducing displays.

What, then, is the relative status of our three candidate mechanisms proposed to underlie the response shift? As discussed earlier, Experiment 3 may be relevant here. In that experiment, results showed that changing the order of the first two displays did not significantly alter the size of the response shift. If only one of either recency or primacy caused the effect, then this manipulation should have resulted in a change in the response distribution. If the most recent item before the comparison pair determined the size of the effect, than the 2-1-3 manipulation should have served to increase the response shift, since the most recent item in the 2-1-3 displays were more extreme than those for the 1-2-3 displays. A similar argument can be made with respect to a primacy account of this response distribution shift. Because the first inducing display in a 2-1-3 display is less extreme than the 1-2-3 display, one might have predicted a smaller shift relative to a similar 1-2-3 display. The fact that if anything the 2-1-3 manipulation increased the distribution shift overall would argue a priori against the primacy explanation.

Experiments 7-9 addressed this issue more directly. The DLM/LDM manipulations of Experiments 7 and 8 show that the distribution was not primarily shifted in the direction of the most recent item; if the average luminance of the inducing display as a whole was centered around the luminance of the Same probe, the response distribution tended to be centered around Same. In Experiment 9, when recency was held constant, the response distribution reflected changes in the log luminance average (geometric mean) of the inducing displays, showing significant shift when the geometric mean was different from Same (Congruent trials), and not showing a shift when the mean was not different from Same (Incongruent trials). The data are clear that the recent item is not the most important factor with respect to this luminance shift.

Evaluating the relative importance of the central tendency and primacy hypotheses is somewhat more indirect, given the data reported in Experiments 7-9. First, recall from Experiment 3 that changing the order of the first two displays did not affect the size of the response distribution shift. This suggests that any primacy effect that was altered with this manipulation is probably less important than the overall central tendency of the inducing displays, which remained the same across the 1-2-3 / 2-1-3 manipulation. Second, overall shifts in Experiments 7 and 8 were never in the direction of the first display; in all cases, the shifts were in the direction of the most recent display, although the shifts were not always significant. Since these two hypotheses predicted opposite shifts in Experiments 7 and 8, the recency effect may be seen to be more effective than primacy in affecting the response distribution. For Experiment 9, primacy and central tendency were confounded. Based on the preceding evidence, however, it seems more likely that the pattern of data was the result of varying central tendency of the inducing displays, and not of the varying first inducing display. More direct evidence for this conclusion could be found by manipulating the central tendency of the inducing displays while keeping the first displays constant.

In general, the weight of evidence from this chapter seems to suggest that some average of the three inducing displays is the most important factor for the luminance effect. In Experiment 7, holding the average luminance constant at Same resulted in a reduced, although admittedly not eliminated, effect relative to previous experiments. For Experiment 8, a similar manipulation resulted in an almost completely eliminated luminance effect, consistent with the central tendency hypothesis, and counter to either the recency or primacy accounts. In Experiment 9, manipulating the central tendency while holding the most recent item constant resulted in a changes in the size of the luminance effect consistent with the central tendency hypothesis. Methods for further specifying this hypothesis are discussed in Chapter 5.

Finally, what do the data from Experiments 7-9 have to say about the question of whether this effect is better described as perceptual or memorial? The fact that the most recent display minimally affects the size of the shift makes less likely any short-term perceptual explanations of the effect. However, there are numerous indisputably perceptual effects that happen over a relatively long term. Dark adaptation, for example, typically takes 20 minutes or more, as the visual system gradually makes the transition between photopic and scotopic vision (Rushton, 1961). The McCollough effect (McCollough, 1965) is another example of a long lasting, supposedly perceptual effect, often lasting weeks (See, however, the work of Siegel & Allen (1992) for evidence that the McCollough has a learned component). Thus, while data from Experiments 4-6 and 7-9 indicate that the shift is not the result of a short-term, low-level perceptual process, further evidence will be required to decide whether the shift is better characterized as perceptual or memorial.

Chapter 5 - Conclusions and directions for future research

Summary of Experiments

This thesis reports and examines a response bias for luminance memory judgements in the direction of previously presented luminances. Experiments 1-3 showed initial demonstrations of the effect, distinguished the effect from representational momentum, and argued that the effect is better considered a memorial rather than a perceptual phenomenon. Experiments 4-6 distinguished it from two perceptual effects that reasonably might have been its source, specifically the Anstis (1967) ramp aftereffect and lightness constancy (Wallach, 1948; Jacobsen & Gilchrist, 1988b). Experiments 7-9 attempted to further specify the nature of the memory mechanism involved with the response distribution bias. It was concluded that of the three alternative mechanisms considered, primacy, recency and central tendency, the central tendency alternative best explained the available data. These constrain potential models of this phenomenon. Chapter 5 discusses the major conclusions to be drawn from these experiments, and some possible mechanisms that could underlie the effect.

The demonstration of a new effect

One of the main points of this set of experiments is to report an interesting new effect, and to show that it is replicable, robust, and interesting. We have shown in this set of experiments that the effect is clearly replicable. We have shown evidence for the effect in one form or another in all but one of the experiments (Experiment 8), showing more than 10 replications of the effect overall. The effect is not due to speed/accuracy tradeoff (Experiment 1). It survives numerous changes in procedure, including direction of luminance change (Experiments 1-9), time course manipulations (Experiment 2), changes in the order of the inducing displays (Experiment 3 and 7), peripheral presentation (Experiments 4 and 5), displays with spatial changes, (Experiments 1-6), and changes in background illumination (Experiment 6). The effect is clearly replicable; in fact, one of the practical problems in carrying out this exploratory research was to find conditions under which the effect did not occur (but see Experiment 8).

Not only is the effect replicable across procedural changes, but it is clearly very robust within subjects as well. In general, one need only run a small number of subjects (8 or fewer) in order to get a significant effect; indeed, under circumstances in which the effect has been shown to be strongest, virtually all of the subjects show it (e.g. Experiment 1). In addition, the choice of stimuli and method of presentation of trials was dictated more by the attempt to equate these findings with those of the RM literature (Experiments 1-3), rather than by extensive piloting in order to maximize the effect. Thus, there is no particular reason to expect that the sort of display presented in these experiments necessarily shows the effect in its strongest form. Future research should vary such display parameters as number and range of inducing displays, size and shape of stimuli, time course and retention intervals of a trial, and state of light adaptation of the observer in an attempt to find the conditions under which this response distribution shift is maximized. This endeavour will not only make the effect even easier to study, but also may contribute to the study of the mechanisms underlying the effect (for example, see Cavanagh & Anstis,1991 for a similar approach to the study of the ramp aftereffect).

These experiments demonstrate that the effect is robust and replicable. The question as to whether the effect is interesting in any tangible way, however, is another matter. In order for an effect such as this to be useful and interesting, it must be useful as a tool for studying some aspect of the visual system in a way that distinguishes it from other methods. The study of memory for colour and luminance is a relatively new one, largely dominated by constancy issues (see, for example, Troost & DeWeert, 1991). This effect may allow for expansion of the study of memory for luminance into domains more common in the memory literature. For example, the discussions of the relative contributions of primacy, recency, and central tendency are new to this area. In addition, most studies on memory for luminance to date have examined small effects that require labor-intensive psychophysical procedures. A robust effect such as the one reported here may make the study of memory for luminance more accessible.

Another way in which such an effect may prove useful is if it inspires the examination of current problems from another perspective. The dimension of luminance is one that has received considerable attention from psychophysicists, who have described the sensitivity of the visual system to such input in impressive detail (e.g. Stevens & Stevens, 1963). This attention is warranted due to the fact that the dimension of luminance is relevant both to virtually any psychological experiment involving visual stimuli, and, like motion, is a critical aspect of vision in the natural environment. However, relatively little emphasis is placed on top-down influences on the perception of luminance. If information about illuminance is stored and later retrieved, as suggested by some of the color constancy literature as well as this research, it may be that information about illuminance is subject to the same processes and biases of memory as are the other forms of information more typically studied in the memory literature. This bias for the memory in the direction of an average of the preceeding displays may provide an explicit method for studying these top-down effects on luminance processing.

Implications for the RM literature

A second conclusion from this set of studies was that these data point to potentially important constraints on the RM effect. That an RM effect for luminance change is either non-existent or at least very elusive suggests that the characterization of RM as being a function of the way the brain stores all information may be misguided. Not only did we not find any indication of an RM effect for luminance (Experiments 1-3), we showed that the pattern of data for luminance is different from RM in terms of time course (Experiment 2) and in terms of display characteristics that alter the effects (Experiment 3). The relevant issues in the RM literature upon which these data bear were discussed at length in the conclusion of Chapter 2, and thus will only be discussed briefly here.

First, we disagree with the argument made by Freyd and her colleagues (Freyd, 1987; Freyd, Kelly, & DeKay, 1990) that RM reflects a mechanism that has its effect on virtually any dimension of change that may be mentally represented. The evidence is clear that under conditions where the dimension of change in question is associated with motion in the real world, RM is involved in its representation. However, for dimensions of change for which there is no strong relation to motion in the real world, such as luminance change, we have shown that there may be no such mechanism at work. We believe that RM does not stem from a mechanism that is fundamental to the way we represent information in general, but rather a mechanism that is simply fundamental to the representation of motion.

Note that the data presented here in no way prove conclusively that all non-motion-based dimensions of change do not show an RM effect. We have shown that there is no evidence to support the existence of an RM effect for one such dimension of change, namely luminance. It may be, for example, that other non-motion-based dimensions of change, such as hue or saturation change, may show RM; in such a case it would be necessary to examine why some such dimensions do and others do not show the effect. Further research will be necessary to address this issue. At the very least, however, these data suggest that there is reason to question the generality of the RM effect as proposed by Freyd and her colleagues, and a need to distinguish between certain dimensions of change and others with respect to RM.

Note too that we have no way of showing conclusively that there is no such thing as RM for luminance. Many dimensions of change have exhibited an RM effect under conditions similar to the ones we tested here, suggesting we might have expected to find RM for luminance if it was there to find. However, it is theoretically possible that some other method would result in RM for luminance. If this is the case, there remains to be answered the question of why RM for luminance is more difficult to demonstrate than for other dimensions. Furthermore, the luminance effect itself can be used to answer interesting questions in its own right. In short, whether or not RM for luminance ultimately is proven to exist, this form of research will prove useful. We will address this in more detail shortly.

Finally, we believe that the assertion that RM is limited to motion-based dimensions of change may lead to a more tractable theoretical discussion about the mechanism underlying RM. For example, if we assume that RM is an all-pervasive mechanism, we are faced with a difficult task when trying to establish the specific neural mechanisms that give rise to the effect, because the neural substrate of RM could be anywhere (or indeed everywhere) in the visual system. Limiting our search to the pathways sensitive to motion detection and processing may well lead to potentially interesting physiological work on RM. The following section addresses this issue in more detail.

Physiological Considerations for RM

Consideration of the physiology underlying RM may be one area where this shift in theoretical emphasis may benefit. To an extent, this work has already begun; RM is reported to be stronger in the right hemisphere than the left (White, Minor, Merrell, & Smith, 1993), consistent with the notion that analog processing is stronger in that hemisphere (Kosslyn, Koenig, Barett, Cave, Tang, & Gabrieli, 1989). However, the assumption that RM is a universally applicable process does little to further specify candidate sites of this mechanism. On the other hand, if we consider RM to be motion-based, we may begin to explore how RM may fit into the large literature on the physiology of motion perception. Tipper, Weaver, Jerreat, and Burak (1994) outlined a distinction between environment-based and object-based systems with respect to inhibition of return. They found support for their argument from the physiological literature. One system extending from the superior colliculus to the pulvinar region responds to moving stimuli, but does not encode the direction of that motion (Goldberg & Wurtz,1972a; 1972b; Gross, 1991; Schiller, 1972). Another cortical system beginning in the superior colliculus and striate cortex and projecting to the medial temporal cortex (MT) and medial superior temporal cortex (MST) may be responsible for encoding direction and speed of motion (Newsome, Wurtz, Dursteler, & Mikami,1985).

There is considerable evidence that suggests that information about direction of motion is lost when the cortex is disrupted. Work on such varied species as the cat (Wickelgren & Sterling, 1969), the rabbit (Graham et al, 1982), and the hamster (Palmer & Rosenquist, 1974) has shown that information about direction is lost to the motion-sensitive cells of the superior colliculus when the striate cortex is abolished. Ingle (1981) showed that lesions of the primary visual cortex in gerbils eliminated the ability to anticipate the future position of a moving object, but rather resulted in action towards the initial position of the moving target. In this behaviour the decorticate gerbil is similar to noncortical lower animals such as frogs, which cannot make such anticipatory actions (Ingle, 1982). All these data are consistent with the idea that motion is encoded in the superior colliculus, but detailed information about the direction of motion requires cortical input.

More recently, Pasternak, Horn, and Maunsell (1989) demonstrated that lesions to the lateral suprasylvian cortex in the cat do not result in deficits for discriminating gratings moving in opposite directions. This might be considered surprising, because previous research had implicated this area as being important for direction discrimination (Pasternak & Leinen, 1986). One possible explanation for this finding may be that opposite directions of motion are a special case that is subserved by earlier mechanisms (Pasternak et al, 1989). In the monkey, specific lesions of areas MT and MST resulted in permanent deficits in performance of tasks involving detection of differences in direction and speed both of moving gratings and arrays of moving dots (Pasternak & Merigan, 1994). These results suggest that these areas are important for perceiving direction and speed of motion. In general, the evidence from various species supports the idea that the direction of at least some forms of motion require cortical input.

This distinction between an early directionless form of motion perception followed by a directional component later in the system is consistent with an idea discussed by Finke and Freyd (1989). In response to the criticism that the direction of RM seems to be affected by subject expectancies (Ranney,1989; Hubbard & Bharucha,1988; Verfaillie & D'Ydewalle, 1991) they concluded that while the direction of RM may be subject to expectancy, the momentum itself is not. They likened the situation to a train moving along its tracks; while the direction of the train may be changed by switching tracks, the momentum of the train remains. The implication that the momentum may be separable from, and earlier in the system than, the directional component is consistent with the characterization of the motion perception physiology that information about the presence of motion might involve an earlier system than information about direction of motion.

While this proposed direct relationship between RM and the early physiology of motion perception may seem attractive, it could also ultimately prove misleading. Phenomenologically, RM displays do not give a perception of motion; rather, they are seen as discrete displays that result in a distorted memory for the final position of the object. Because these are discrete displays, one might not expect early motion-sensitive striatal or collicular cells to respond strongly to such displays. If an animal model of RM could be developed, single-cell studies might prove informative. One question might be whether RM-type, discrete displays might activate the early, motion-sensitive collicular cells only weakly or not at all. Instead, perhaps these displays might activate cells in MT, MST, or parietal area 17, which are said to respond to complex sorts of motion (Gizzi et al, 1983; Movshon et al, 1984). This finding would be consistent with the idea that RM has a top-down component. Considering RM as a motion-correlated phenomenon therefore not only allows us to make contact with literature on the physiology of motion, but also can allow us to generate useful new empirical questions. While limiting the generality of the RM effect might be seen as limiting the interest it engenders, we suggest that such limitation may serve to open the study of RM to a wider audience, in showing how its physiological substrates might be examined.

The luminance effect is distinguishable from other perceptual effects

A third major theme of this work was to ensure that the luminance effect we are studying here is not covering old ground; that it is not simply the expression of a well-known effect in a slightly different guise. To this end, we showed evidence that distinguished this effect from other perceptual effects, including representational momentum, the ramp aftereffect, and constancy.

The data from Experiments 1-3 clearly distinguish this effect from the RM effect as discussed by Freyd and her colleagues (Freyd, 1987; Freyd & Finke, 1989). First, the effect is in the direction opposite to that predicted by the RM effect (Experiments 1-3). Second, it has a very different time course than that of RM, and furthermore seems only to increase with increasing retention interval (Experiment 2), rather than building slowly over the first 250-300 ms, then dying away and eventually reversing itself (Freyd & Johnson, 1987). Finally, we showed in Experiment 3 that a variable that reversed RM did not change the luminance effect. Thus, the evidence is clear that RM and the luminance effect stem from different mechanisms. Note that these data were obtained under conditions designed to maximize any similarity between the two phenomena. This conclusion not only limits the number of ways in which the luminance shift may be explained, but it puts important constraints on the generality of the RM effect.

Experiments 4-5 showed that this effect is distinguishable from the ramp aftereffect first reported by Anstis (1967). Unlike RM, the aftereffect did predict response shifts in the direction observed, if one postulated that discrete inducing displays were sufficient to cause adaptation. However, the ramp aftereffect cannot explain the luminance shift reported in these experiments. In Experiments 4 and 5, stimuli were presented to different parts of the retina, and a significant shift was obtained. Because the ramp aftereffect is retinally specific, it cannot be the source of this response shift.

That the luminance effect described here is not retinally specific implies a more central locus for this effect than for the ramp aftereffect. Research by Cavanagh and Anstis (1986) suggests the ramp aftereffect is due to an inability of the transient cells to fully register the steep part of the ramp, thus underestimating the degree of luminance change. While the results from Experiments 4-5 suggest that this effect is not the result of the transient retinal ganglion cells, it nevertheless may be that there is a similar lack of registration of the sudden, discrete changes inherent in our displays. This under-registration could occur at post-retinal locations in the visual system. Further attempts to specify the physiological locus of the effect may prove useful. For example, it is unknown at present whether our effect transfers interocularly; an answer to this question either way might serve to limit candidate sites for the mechanism underlying this effect.

Finally, Experiment 6 attempted to distinguish the effect under study from that of simple lightness constancy. To a great extent, this is still an open issue. In Experiment 6 it was hypothesized that the backwards response shift could result from a failure of constancy processes due to presentation of increment displays, which are known to impede constancy (Arend & Goldstein, 1987; Jacobsen & Gilchrist, 1988b). We flipped the sign of the background from black to white with the expectation that constancy would reassert itself under these conditions, and the response distribution shift would disappear. It did not, arguing against this simple relationship between constancy and our effect.

Note that there are other interpretations of the data from Experiment 6. It may be, for example, that the manipulation of a change in background luminance for this task was simply not extreme enough to induce a shift in the response distribution afforded by a shift in underlying constancy processes. To a certain extent, we are basing our conclusions on those of Jacobsen and Gilchrist (1988b) and Arend and Goldstein (1987) who showed that the differences in response to increment vs decrement displays are dramatic. The extent to which this is true supports the notion that the response shift reported here cannot be directly tied to these same constancy processes, because if the backwards response shift were the result of a failure of constancy, then the manipulation of the background should have eliminated or changed the direction of the shift.

Further research is needed to further specify the relationship between the various components of lightness constancy and our response distribution shift.

Is the luminance effect perceptual or memorial?

Another main theme of this set of experiments was whether this response distribution shift for luminance decisions is better characterized as perceptual or memorial. Data showed that the effect is not limited to very small retention intervals between the inducing displays and the probe; apparently response to the probe can be affected even when the most recent inducing display disappeared almost a full second before (Experiment 2). Indeed, the amount of shift seemed to increase rather than decrease as length of retention interval increased, which may be seen as consistent more with a confusion of memory hypothesis than a perceptual confusion hypothesis (Experiment 2). Data also showed that changing the order of the inducing displays did not affect the size of the shift (Experiment 3).

Why should these results be considered to support a memorial rather than a perceptual confusion? Hubbard (1995) argues that if an effect is the result of a perceptual confusion between rapidly presented displays, then increased amount of processing should provide the system with more time to resolve the confusion, thus decreasing the effect. If our effect were the result of a perceptual confusion between the probe and the inducing displays, then, one would predict that the effect should be largest with very short retention intervals, and then decrease with increasing retention intervals. On the other hand, if an effect is due to a memorial confusion, Hubbard (1995) argues that the effect should increase rather than decrease as the amount of time between the two things being compared increases. Our data clearly showed this latter pattern, where the amount of shift increased as the amount of time between the inducing displays and the probe increased. According to the criterion set out by Hubbard (1995), our data seem to support the hypothesis that the shift is the result of a memorial rather than a perceptual confusion.

As discussed previously, because an effect increases over time does not necessarily mean that the effect cannot have a perceptual basis. For example, full dark adaptation often takes between 20 and 30 minutes, as the visual system makes the transfer from photopic to scotopic vision (Rushton, 1961). If an hypothetical experimental effect were due to such dark adaptation, one might expect it to continue increasing as long as the adaptation progressed, that is, at least 20 minutes. Our support for the notion that the backwards shift is not perceptual is not limited to issues of time course, however; the finding that the effect transfers across retinal locations eliminates some potential perceptual explanations of the effect (Experiments 4 and 5). Ultimately, we believe that any attempt to delineate processes as strictly perceptual or memorial is destined to fail; the system is far too interactive to label any process as solely one or the other. Given the definitions discussed in the literature, however, the luminance effect seems to fall into the category of a memorial process.

Another example of a long-term effect with perceptual components is the McCollough effect (McCollough, 1965). The McCollough effect is an orientation-specific, colour- contingent aftereffect that can last days or weeks after induction (Jones & Holding, 1975; Holding & Jones, 1976). It has been argued that the effect is the result of chromatic adaptation of orientation-specific receptors (McCollough, 1965). It is conceivable that such an adaptation effect could be happening with the backwards response shift reported here, where adaptation over many trials results in a McCollough-like perceptual aftereffect that may then affect response on later judgements. However, this explanation is made less convincing when one remembers that the effect does not develop over the several blocks of trials in an experiment (Experiment 3), and that the effect is not retinally specific, in contrast to the McCollough effect. Further, more recent research suggests that one of the reasons that the McCollough effect lasts so long is that the aftereffect is at least partly conditioned (Siegel & Allan, 1992; Siegel, Allan, & Eissenberg, 1992).

In summary, while the data from Experiments 2 and 3 seem to point to a memorial explanation of the response distribution shift, perceptual explanations cannot be ruled out solely on the basis of these results. Data Experiments 4 and 5, however, argue against three possible perceptual explanations for this effect, namely transient ganglion cells, rapid light adaptation and the McCollough effect. A more complete answer to the perceptual / memorial question awaits further research.

What sort of memorial effect is it?

The purpose of Experiments 7-9 was to further specify the nature of the mechanism underlying the response distribution shift by examining which aspects of the inducing displays account for the greatest amount of the distribution shift. We showed that when the log luminance average of the inducing displays was held constant at Same, and first and most recent luminances were varied, the distribution shift essentially disappeared (Experiments 7 and 8). However, when the log luminance average of the inducing displays was varied, the effect also varied (Experiment 9). The results were consistent with the notion that the effect stems from the visual system taking some luminance average of the inducing displays, storing it in memory, and comparing this representation to the probe at the time of judgement.

The nature of this "average" is clearly a point that will require further research. One possibility is that the judgement on a particular trial is disproportionately weighted toward the first display in the inducing sequence. While it was argued in Chapter 4 that this "primacy" explanation would have resulted in a different pattern of data for Experiments 7 and 8, it nevertheless was confounded with central tendency in Experiment 9, and thus could inflate the current informal estimate of the effects of log luminance average. An experiment attempting to determine the relative contributions of central tendency independent of primacy would be a useful future experiment.

An alternative instantiation of the "central tendency" hypothesis might be a running average of some subset of the inducing displays. All the displays in the current experiments involved very brief, three display inducing sequences. An experiment with a larger set of inducing displays would allow us to further specify the nature of the average being stored in memory.

Regardless of the specific nature of the central tendency, it remains an interesting question what demands upon the visual system give rise to this central tendency mechanism. Cavanagh and Anstis (1986) argue that the ramp aftereffect and similar effects are due to the inability of the transient cells to fully reflect in their response the fast part of the ramp, thus underestimating the change in luminance of the ramp. It is possible that a similar phenomenon may be happening as the result of our displays. The fact that the response distribution shift transfers across retinal locations (Experiments 4 and 5) indicates that this inability may be happening at an area more central than that of the ramp aftereffect, but the principle may be the same. Each of the inducing displays in a trial was a discrete presentation of a different luminance. If at some stage the system was unable to properly record the sudden, discrete changes of these displays, it is conceivable that smearing from one display to another might result in a running average representation such as the one discussed above. That this average must happen at a different level from that of the ramp aftereffect seems clear, because the displays reported in these experiments change on a completely different scale of temporal frequency - i.e. one change every 500 ms as opposed to relatively continuous change.

Even though this effect might stem from the inability of the visual system to fully reflect the change in a stimulus, this may not reflect a failure of the visual system. It is possible that such a process is adaptive. For example, by far the most common source of change in the luminance of objects results from change in the illumination of those objects. It is relatively rare in the natural world that an object in the world gets more or less luminant, with illumination remaining constant. In many situations in the natural world when that does happen, it may be the result of the visual system somehow being fooled about the illumination of the object. Imagine the situation where you watch a deer walk through a forest. At any point, some parts of the animal might be more luminant than others, due to sunlight breaking through the trees at various points. If the visual system is accustomed to dealing with uniformly illuminated scenes, then this situation presents a problem for the visual system. If the system assumes a single illumination for the deer, then it will appear that some parts of the deer brighten and then dim as it moves through the forest.

A way to avoid this problem would be to take an average luminance reading across different times of the same object. Each local change in luminance would change the overall estimate of object luminance minimally, resulting in a percept of an object of stable brightness as it moved through complexly illuminated backgrounds. Perhaps this is the mechanism that we are tapping into with the procedure used in these experiments. Note that this predicts that the response distribution shift should be object-specific. For example, if we showed people inducing displays of a particular object, and then a probe of a different object, we might predict that the effect should disappear. This would be consistent with the overall smaller shift in Experiment 5; the fact that the displays were presented in four locations and at very different orientations may have made the display seem less like a single object. This is clearly an important avenue of future research.

If this idea proves accurate, it would suggest that local retinal explanations of brightness constancy (e.g. Land & McCann, 1971) would be insufficient, as they cannot account for change across time. As such, it would help to resolve a current debate in the constancy literature about whether non-retinal information is required for brightness constancy. Further, if this idea of object-specific brightness constancy is accurate, it will bring a new perspective to the way we think about brightness and colour constancy in general. Object specificity implies that visual information has been processed to a high level, and thus evidence for object-specific brightness constancy would be further evidence for the notion that information about luminance is affected by top-down processing.

Psychophysical considerations

There clearly are psychophysical issues with respect to this shift of luminance decisions that future research will have to address. For example, while the stimuli in Experiments 2 and 3 were made to be roughly equal log luminance differences from each other, Stevens and Stevens (1963) showed that psychological brightness varies with physical luminance more as a power function with an exponent of .33 for the dark-adapted eye, and with an increasing exponent for higher levels of adaptation. This suggests that the stimuli chosen for these experiments may not have been equivalent psychological distances from one another. Note, however, that because the luminance shift is bidirectional, it cannot be easily explained by unequal spacing of inducing or probe luminances. It could, however, affect the estimates of the magnitude of the shifts obtained from these experiments. It could also explain some of the unexpected asymmetries in overall number of Same responses for the two luminance directions found in, for example, Experiment 3A. Further research should take into account the effect of level of light adaptation and the psychophysical power function when examining this shift.

Psychophysical investigations of successive and simultaneous contrast stimuli also raise relevant issues. Procedures that involve stimuli that are to be matched on the basis of colour or brightness successively rather than simultaneously elicit a number of systematic errors in memory. Successive saturation matches, for example, result in memory shifts in the direction of more saturated colours (Uchikawa, 1983; Newhall, Burnham, & Clark, 1957). Similarly, successive brightness matches yield memory shifts in the darker direction (Uchikawa & Ikeda, 1986). While these again are unidirectional shifts, and thus distinguishable from the shift reported here, they may explain some of the asymmetries in response shift reported in these studies. Furthermore, any complete explanation of luminance processing will need to explain these effects as well as the one reported in this thesis.

Uchikawa and Ikeda (1986) report another memory shift that on the surface seems quite relevant. When subjects are asked to make successive brightness contrast judgements, and an intervening event is placed between the test and comparison stimuli, an interference effect results, where memory judgements are shifted in the direction of the luminance of the intervening event (i.e. darker if the intervening event was darker than the test stimulus, lighter if the intervening event was lighter than the test). The relation of this to the current shift is unclear, although the two are similar in their bidirectional nature. Again, further research is required to examine whether the memory shift reported here is usefully framed in an interference context.

Summary

In summary, several main conclusions may be drawn from this set of experiments. First is the response shift itself; it is robust, replicable, and potentially interesting. Second, the effect seems to be new; it is easily distinguishable from representational momentum, and also has attributes that differentiate it from Anstis' (1967) ramp aftereffect and lightness constancy. Third, the data reported have interesting implications for the RM literature, among them that they point to situations where the RM effect does not occur. Fourth, a number of aspects of the data point to the conclusions that the response shift itself is better characterized as memorial rather than perceptual in nature. Furthermore, the evidence suggests that the memory of the inducing displays is best characterized as an average of the inducing displays for these experiments. Finally, it was suggested that the effect might be adaptive, in reflecting a mechanism that keeps constant the luminances of objects under conditions of complex illumination.

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Note 1: In these and in all subsequent experiments, subjects reported having normal or corrected-to-normal visual acuity. Subjects' ages were not collected, as is the practice with most RM research. However, previous experience with this subject pool indicates that it is relatively homogeneous with respect of age of the subjects, usually with a mean of approximately 20 years.

Note 2: Timing verification was carried out in a number of ways. The accuracy of the timing routine itself was examined by using the routine to measure raster scans of the monitor, which are of a known frequency (usually 50, 60, or 70 hz). Stimuli were always presented in the space of one raster scan or less. This was accomplished by first drawing the stimuli to a graphics page not currently displayed, then waiting for the top of the raster scan and switching to the graphics page which held the stimulus. Because all the lengthy draw commands had already been executed offscreen, any of the stimuli presented in these experiments could be presented in one raster scan.

Note 3: In Experiments 3-9, the five-level variables of Probe Luminance and Probe Orientation were excluded from analysis. Because these variables result in response curves that are always parabolas, i.e. more Same responses to the middle probe defined as Same, with decreasing Same responding with more extreme probes, analyses of these variables invariably resulted in a main effect of these variables. Furthermore, some manipulations such as Direction of the inducing display served to shift these response distributions to the left or right. Again because of the shape of response curves, there invariably was an interaction between the five-level variables and any manipulation which resulted in a response shift. As such, analysis of these variables in the Same response ANOVAs was uninformative. Analysis of these variables was incorporated in analysis of the shift estimates.

Note 4: Note that in this experiment the unattended dimensions were varied orthogonally to the attended dimensions. It is an open issue whether more interaction between attended and ignored dimensions would result from unattended dimensions that were correlated with the attended dimensions (See, for example, Garner, 1985). Such a finding would be relevant to the discussion about whether the two types of displacement reported in this paper reflect two different underlying mechanisms, or whether their independence was dependent on the task at hand.

Note 5: The Start Dark displays reported in these experiments were in fact increment displays with less contrast to background than Start Light displays.

Figure Captions

Figure 1: Graphical depiction of a typical trial from Experiment 1A. Time progresses from bottom to top. The probe could be positioned in one of three orientations; Same, Forward, or Backward, as indicated at the top of the figure. This figure portrays a Clockwise trial. A Counterclockwise trial differed in that the first two displays were presented at 86° and 66°, and the probes labelled Forward and Backward were reversed.

Figure 2: Depiction of a trial in Experiment 1B. The patterns are meant to denote an object increasing in luminance (Start Dark condition). Subjects saw one of three possible probes, as before. Luminance of each object is reported in the top left corner of the frame.

Figure 3: Data from Experiments 1A and 1B. RTs for correct trials are reported on the left side, errors on the right. Points plotted are group means ± 1 S.E. Experiment 1A shows the typical orientation RM effect, with longer RTs and greater error rates to the Forward condition relative to the Backward condition. Experiment 1B shows that subjects in the luminance task showed the opposite effect, with RTs and error rates greater in the Backward condition than the Forward condition.

Figure 4: Example of a trial from Experiment 2A. Note the variable retention interval (RI) between the third inducing display and the probe. Note also that there are now 9 possible probes, rather than 3.

Figure 5: Data from Experiment 2A. The top portion of the figure shows the distribution of Same responses, averaged across all subjects and all retention intervals. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol.

If there were no systematic bias, both distributions would lie directly on top of one another. These distributions would peak at "Same", and decrease symmetrically as probes differed more from "Same". The degree to which these distributions are shifted in the positive direction (i.e. to the right for the Clockwise condition, the left for the Counterclockwise condition) is indicative of the RM effect.

The bottom portion of the figure shows estimates of the shift in these distributions for each retention interval, averaged across all subjects. Closed diamonds indicate the data from Experiment 2A; open triangles indicate approximately the data taken from Freyd and Johnstone(1987) Experiment 1. Both indicate a linear increase in the size of the RM effect as RI increases. The best fitting regression line for Experiment 2A was Y = 0.107 + 0.017X. For the original study, it was Y = 0.07 + 0.019X.

Figure 6: Data from Experiment 2B. The top portion indicates the distributions of Same responses across subjects and retention intervals for the two directions of luminance change. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol. The degree to which the distribution is shifted in the negative direction (i.e.to the right for the StartLight condition, the left for the StartDark condition) is indicative of the negative luminance shift for these short retention intervals.

The bottom portion shows shift estimates at each retention interval averaged across subjects. The shifts are very small; however, no point is above zero, indicating a positive shift.

Figure 7: Data from Experiment 2C. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol. The top portion shows the substantial negative luminance shift in the distributions of Same responses for these longer retention intervals.

The bottom portion plots the estimates of shift for each retention interval, averaged across subjects. The effect is much larger than in Experiment 2B, and seems to increase as retention interval increases.

Figure 8: Example of a trial from Experiment 3. Note that the objects are now changing both in Orientation and in Luminance. The Unattended dimension of change was always varied 1-2-3 (as depicted here along the Luminance dimension). The Attended dimension of change could vary 1-2-3 or 2-1-3 (as depicted here along the Orientation dimension). Note that there are now five possible probe Orientations and five possible probe Luminances. Orientations are shown in the upper left of the frame, while luminances are shown in the lower right.

Figure 9: Data from Experiment 3A. The top portion shows the distribution of Same responses for both directions of Orientation change, Clockwise and Counterclockwise, for the 1-2-3 group. With no systematic bias, both distributions would lie on top one another, symmetrically around Same. The data indicate a robust RM effect. Points plotted are group means ± 1 S.E. Absence of standard error bars indicates that the bars are smaller than the symbol.

The bottom portion shows the same data from the 2-1-3 group. Note that the effect has reversed; both plots now show robust negative shifts. The 2-1-3 manipulation clearly affects performance in the Orientation task.

Figure 10: Data from Experiment 3B. The top portion shows the distribution of Same responses for both directions of Luminance change, Start Light and Start Dark, for the 1-2-3 group. The data show a clear negative luminance shift. Points plotted are group means ± 1 S.E. Absence of standard error bars indicates that the bars are smaller than the symbol.

The bottom portion shows the same data for the 2-1-3 group. The data also show a clear negative luminance shift. The 2-1-3 manipulation does not affect performance in the Luminance task.

Figure 11: Depiction of a Start Dark trial for Experiment 4. Subjects fixate on the center cross, while stimuli alternate either side of fixation. Numbers in parentheses are log luminance values.

Figure 12: Percentage of Same responses for the two luminance directions in Experiment 4. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol. The data show a significant shift in the direction of the inducing displays when these displays are presented to different areas of the retina.

Figure 13: Depiction of a Start Dark trial for Experiment 5. Subjects fixate on the center cross, while the stimulis are presented at four predictable locations around fixation.

Figure 14: Percentage of Same responses for the two luminance directions in Experiment 5. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol. While the effect was significant overall, the shift was greater for the Start Dark condition than the Start Light condition.

Figure 15:Percentage of Same responses for the two luminance directions in Experiment 6. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol. Overall, there were more Same responses to the Start Dark condition. Both conditions showed a significant shift in the predicted direction.

Figure 16: Depiction of an LDM trial for Experiment 7. The third inducing display is in between the

first two in terms of luminance. Numbers in parentheses are log luminance values.

Figure 17: Percentage of Same responses for the two luminance directions in Experiment 7. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol. The effect is considerably decreased for this type of display, and significant only in the LDM condition.

Figure 18: Percentage of Same responses for the two luminance directions in Experiment 8. The shift has clearly disappeared for this display. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol.

Figure 19: Depiction of a Start Dark Incongruent trial. Note that the final three displays are consistent with a Start Dark trial, while the first display is the typical first display of a Start Light trial.

Figure 20: Percentage of Same responses for the two luminance directions in Experiment 9. Points plotted are group means ± 1 S.E. Absense of standard error bars indicates that the bars are smaller than the symbol. Shifts are only significant for the Congruent trials, not the Incongruent trials.

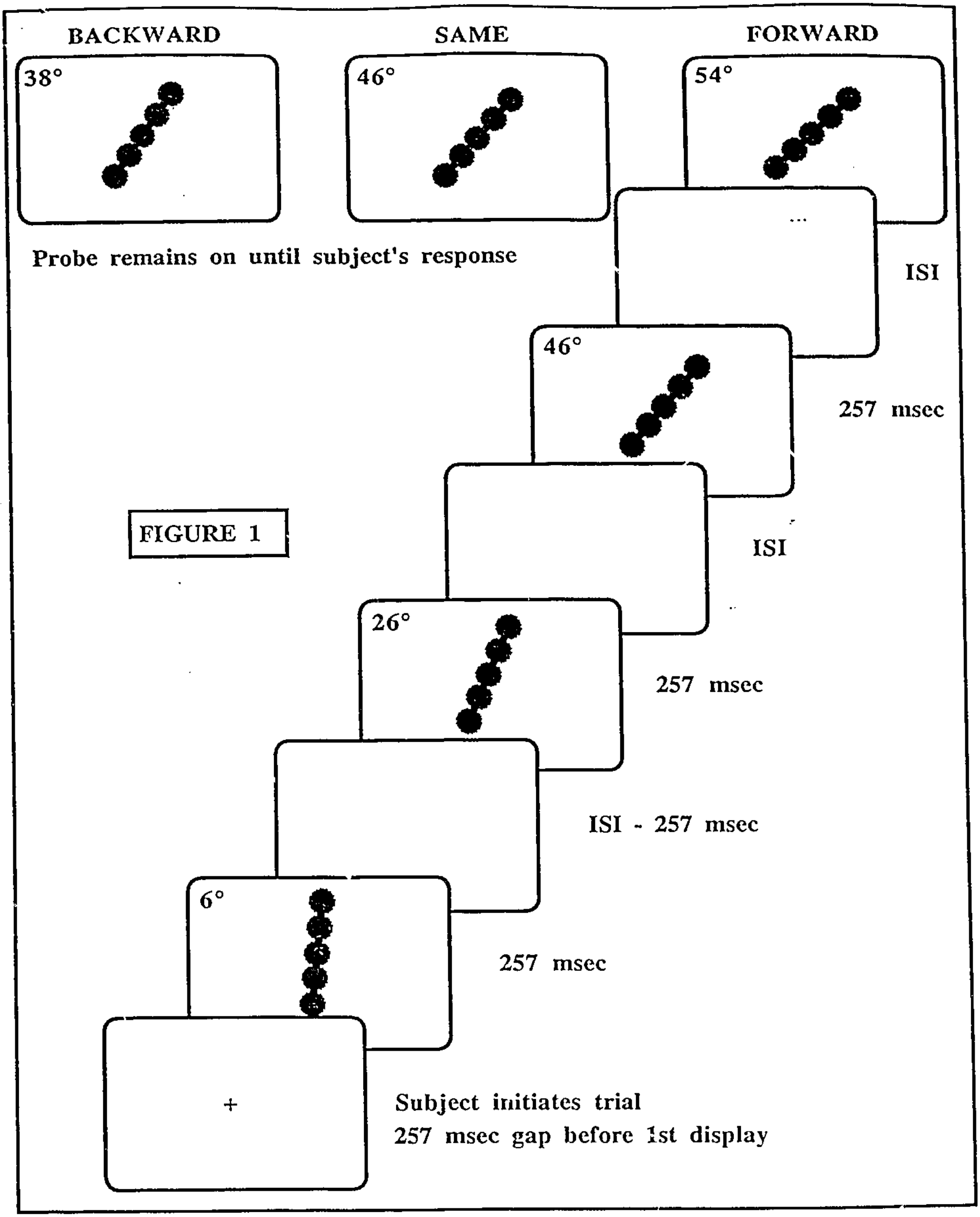
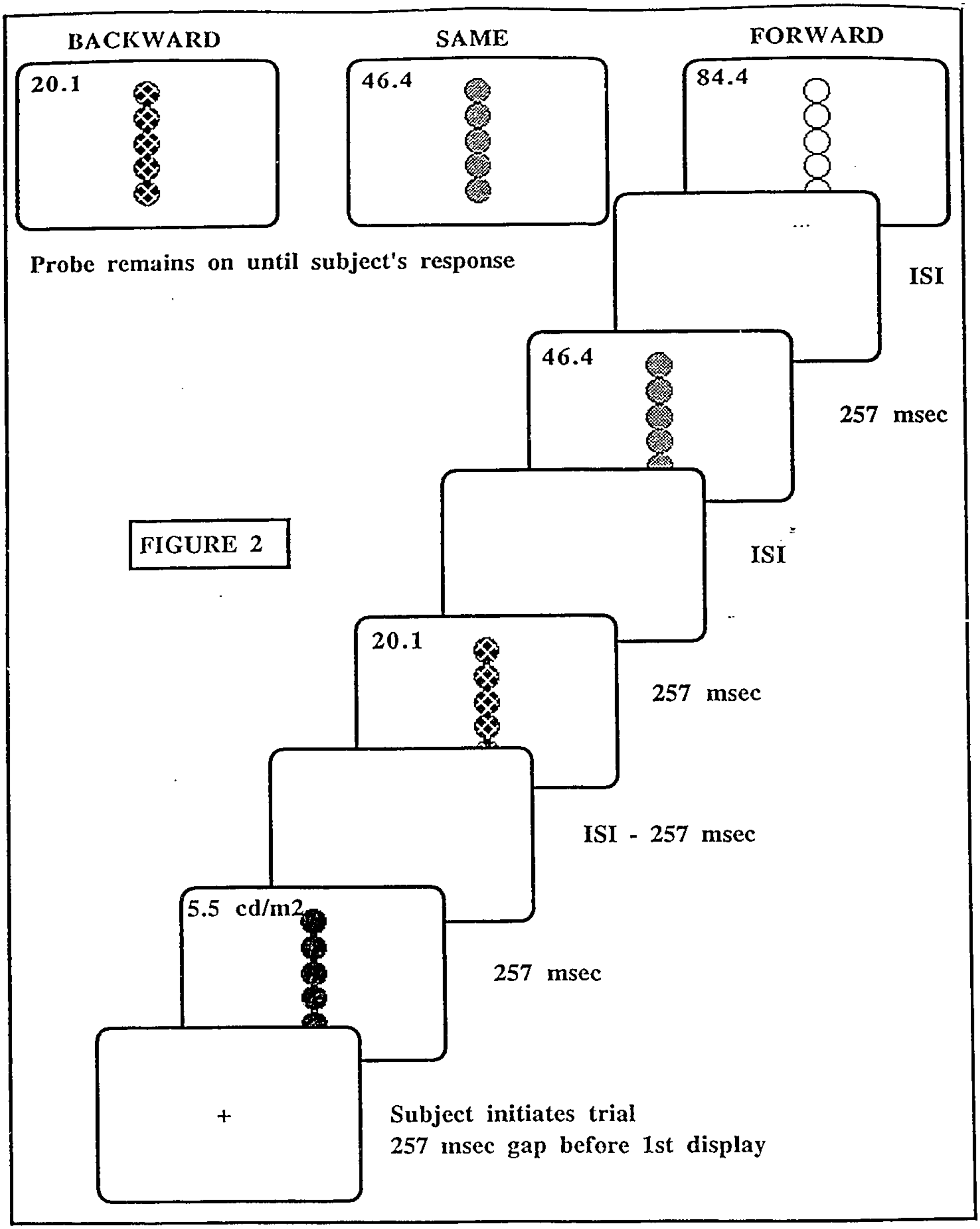


FIGURE 1

BACKWARD
SAME
FORWARD
38°
46°
54°
Probe remains on until subject's response
ISI
46°
257 msec
ISI
26°
257 msec
ISI - 257 msec
6°
257 msec
+
Subject initiates trial
257 msec gap before 1st display

FIGURE 2


BACKWARD
SAME
FORWARD
20.1
46.4
84.4
Probe remains on until subject's response
ISI
46.4
257 msec
ISI
20.1
257 msec
ISI - 257 msec
5.5 cd/m2
257 msec
+
Subject initiates trial
257 msec gap before 1st display

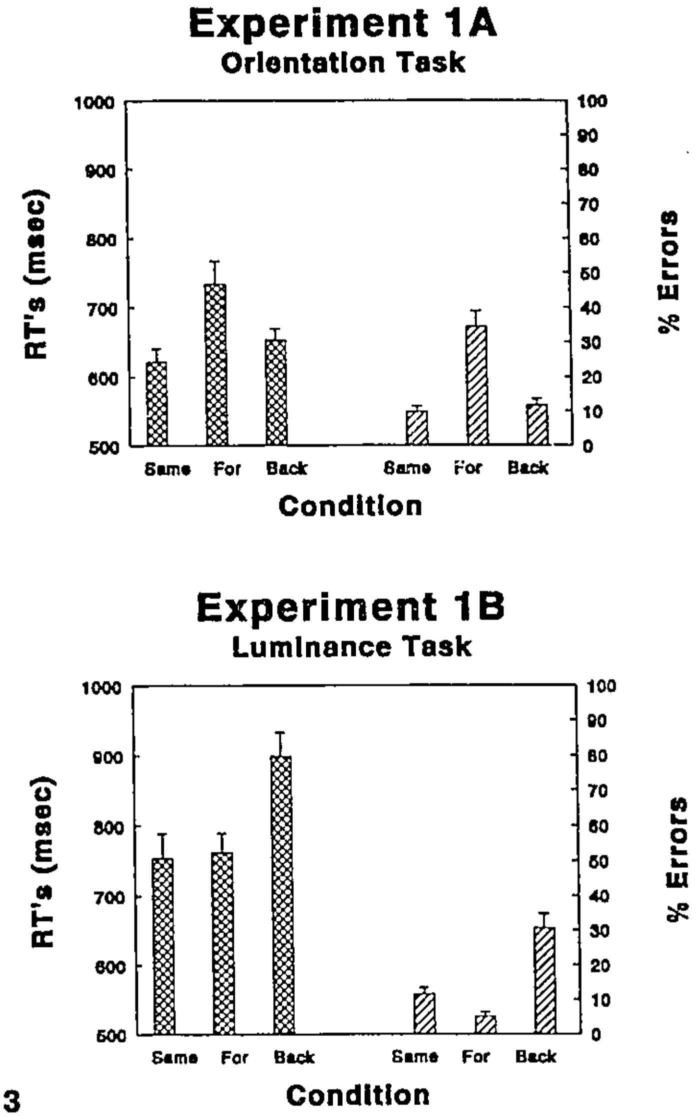

Experiment 1A
Orientation Task
RT's (msec)
% Errors
1000
900
800
700
600
500
100
90
80
70
60
50
40
30
20
10
0
Same
For
Back
Same
For
Back
Condition
Experiment 1B
Luminance Task
RT's (msec)
% Errors
1000
900
800
700
600
500
100
90
80
70
60
50
40
30
20
10
0
Same
For
Back
Same
For
Back
Condition

Figure 3

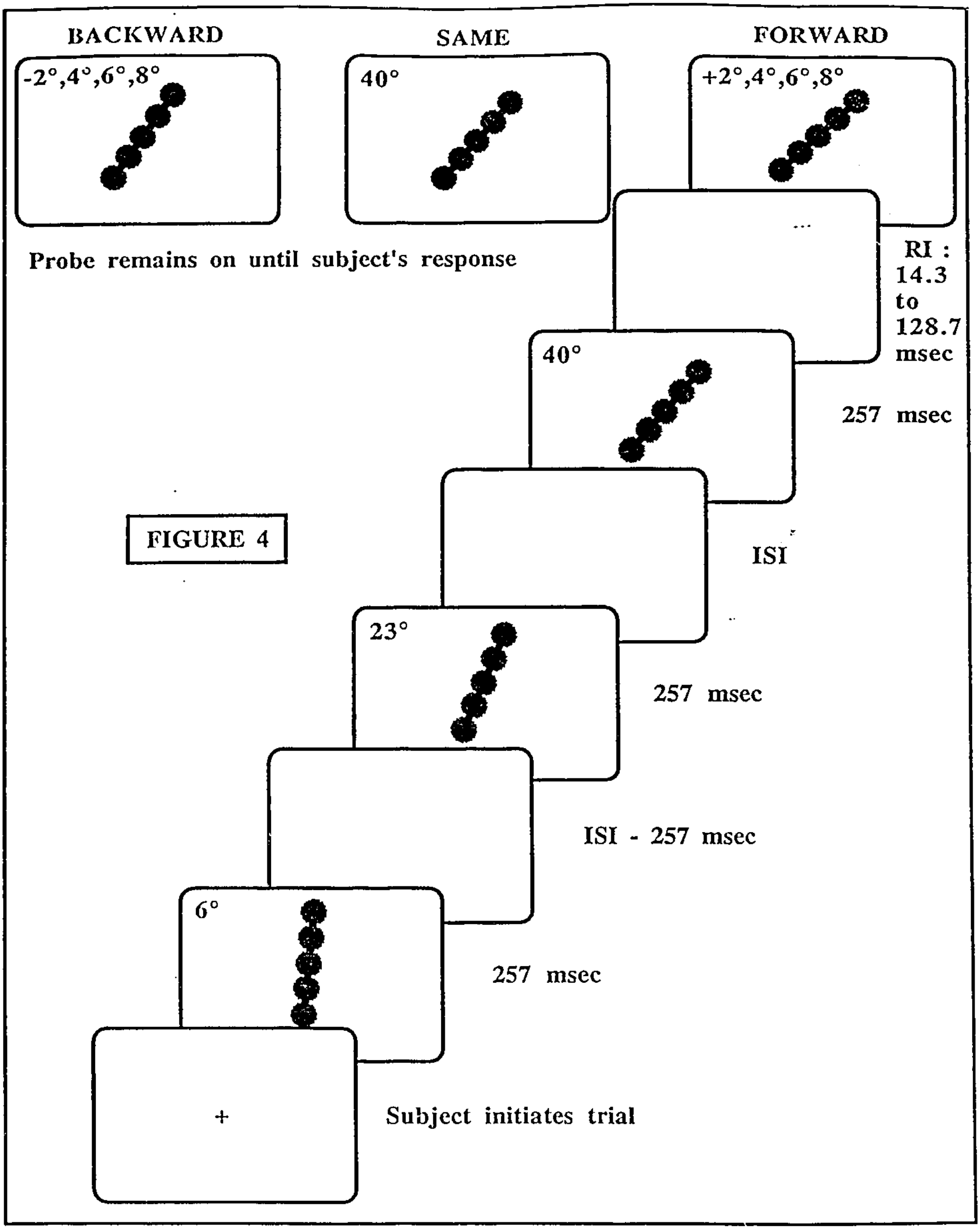
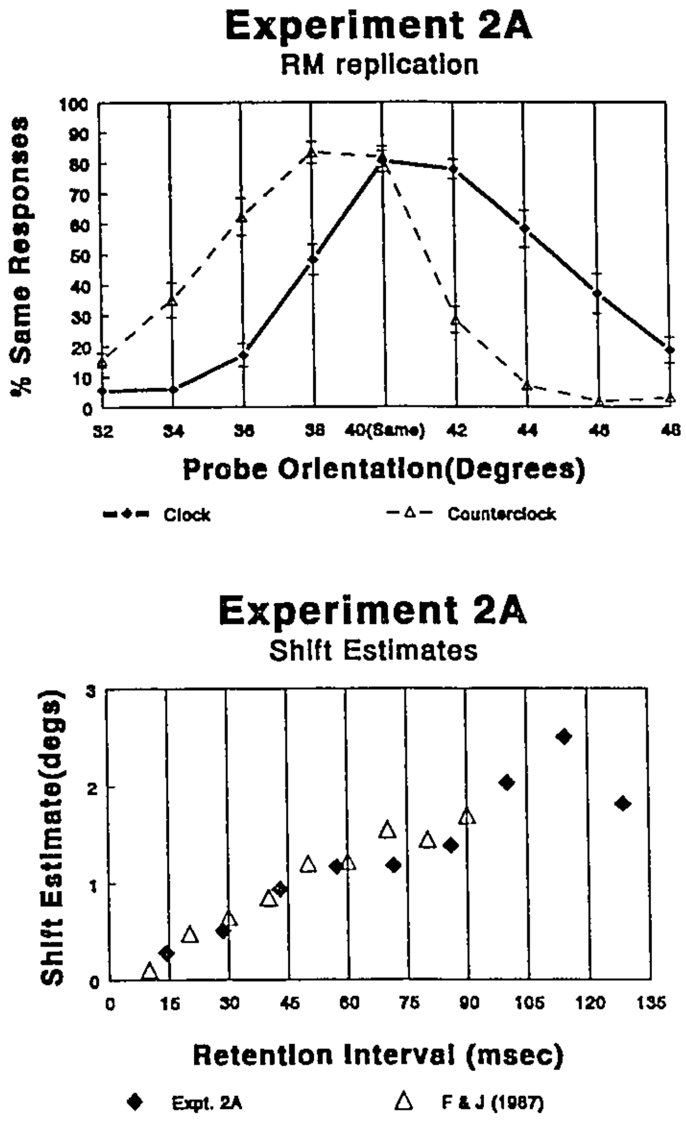

BACKWARD
SAME
FORWARD
-2°,4°,6°,8°
40°
+2°,4°,6°,8°
Probe remains on until subject's response
RI : 14.3 to 128.7 msec
40°
257 msec
ISI
23°
257 msec
ISI - 257 msec
6°
257 msec
+
Subject initiates trial

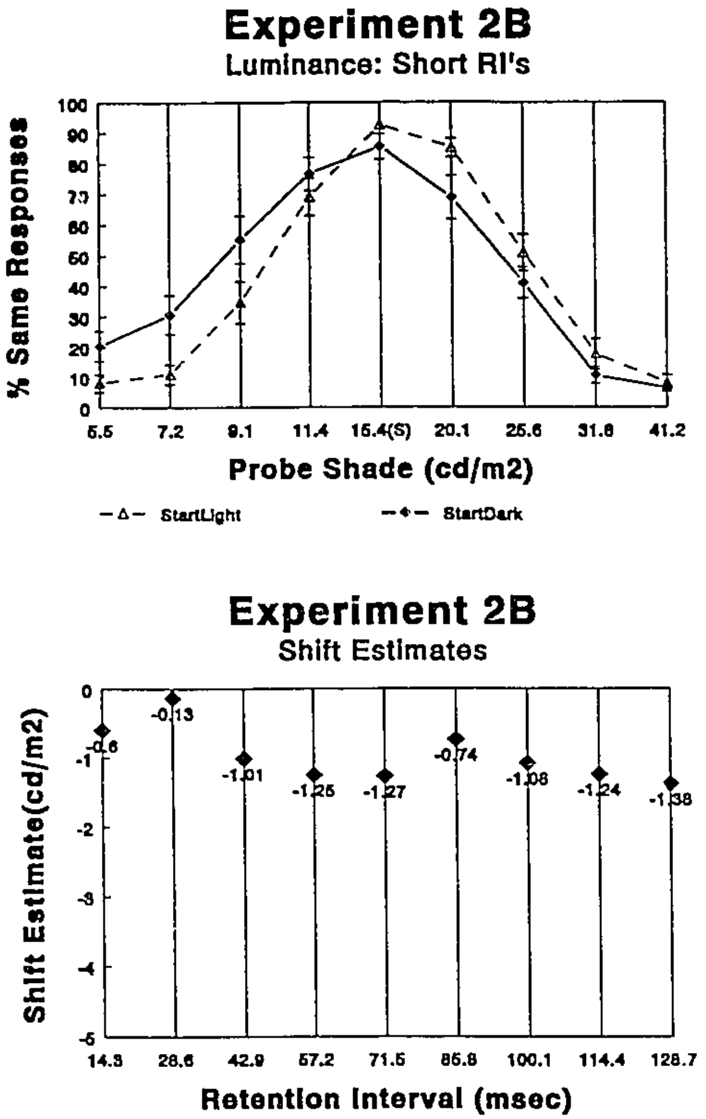
FIGURE 4



Experiment 2A
RM replication

Experiment 2A
Shift Estimates

Figure 5



Experiment 2B
Luminance: Short RI's
% Same Responses
100
90
80
70
60
50
40
30
20
10
0
5.5
7.2
9.1
11.4
15.4(S)
20.1
25.6
31.8
41.2
Probe Shade (cd/m2)
StartLight
StartDark
Experiment 2B
Shift Estimates
Shift Estimate(cd/m2)
0
-1
-2
-3
-4
-5
-0.6
-0.13
-1.01
-1.25
-1.27
-0.74
-1.08
-1.24
-1.38
14.3
28.6
42.9
57.2
71.5
85.8
100.1
114.4
128.7
Retention Interval (msec)

Figure 6

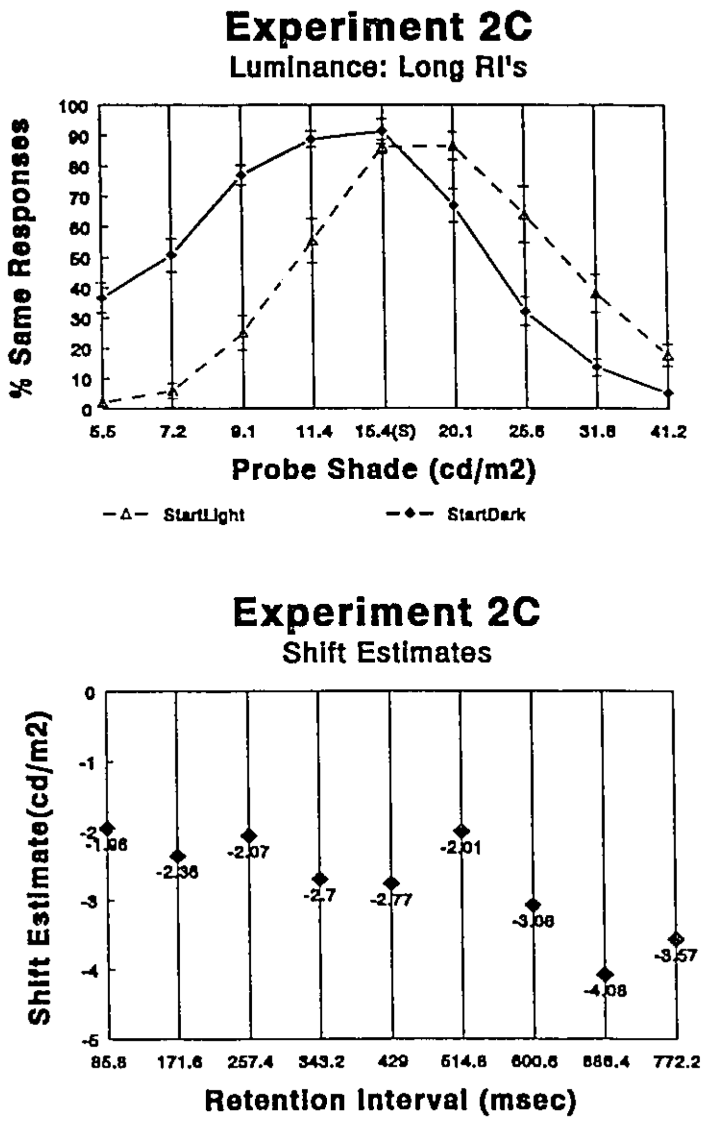

Experiment 2C
Luminance: Long RI's
% Same Responses
100
90
80
70
60
50
40
30
20
10
0
5.5
7.2
9.1
11.4
15.4(S)
20.1
25.6
31.8
41.2
Probe Shade (cd/m2)
–Δ– StartLight
–◆– StartDark
Experiment 2C
Shift Estimates
Shift Estimate(cd/m2)
0
-1
-2
-3
-4
-5
-1.96
-2.36
-2.07
-2.7
-2.77
-2.01
-3.06
-4.08
-3.57
85.8
171.6
257.4
343.2
429
514.8
600.6
686.4
772.2
Retention Interval (msec)

Figure 7

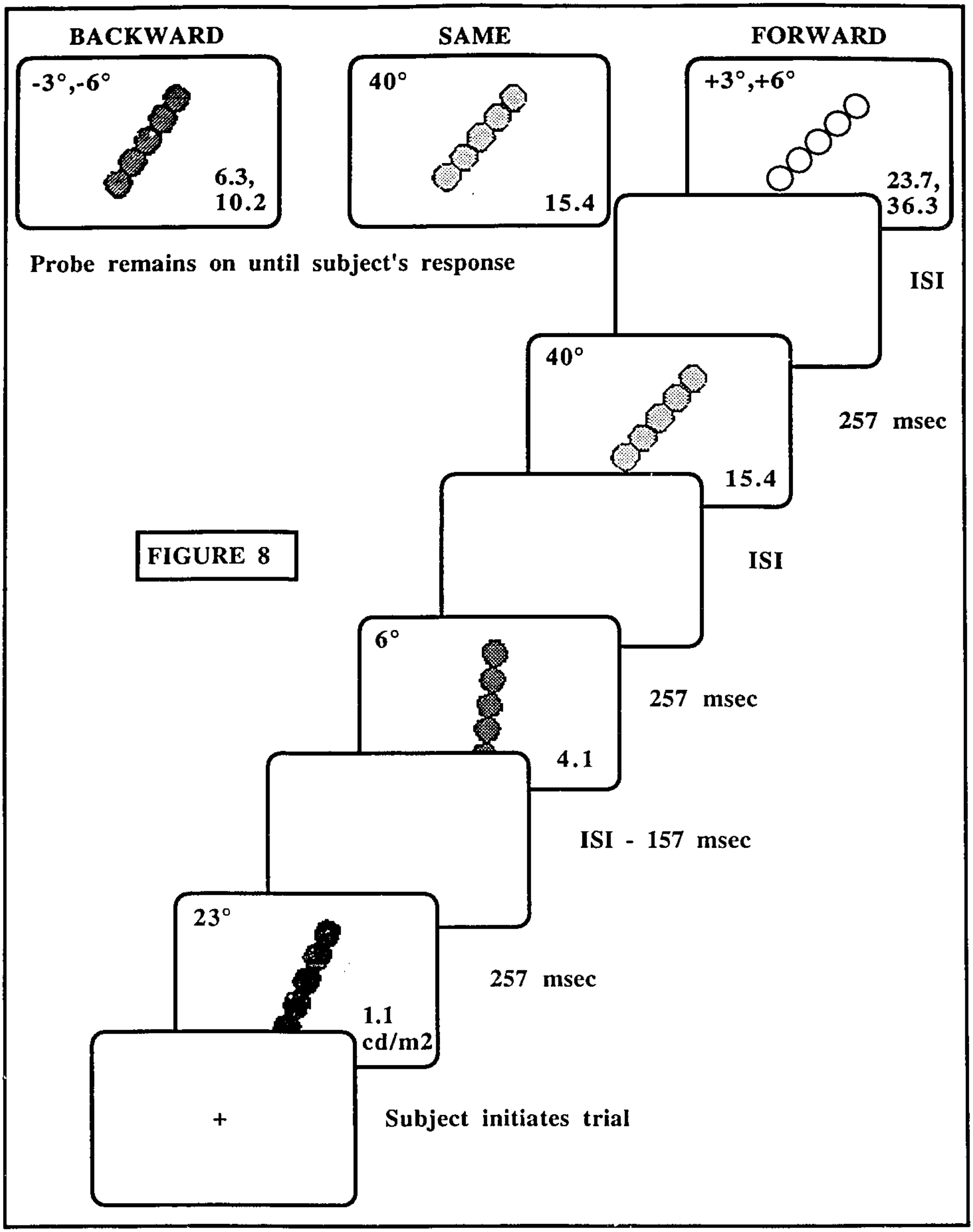
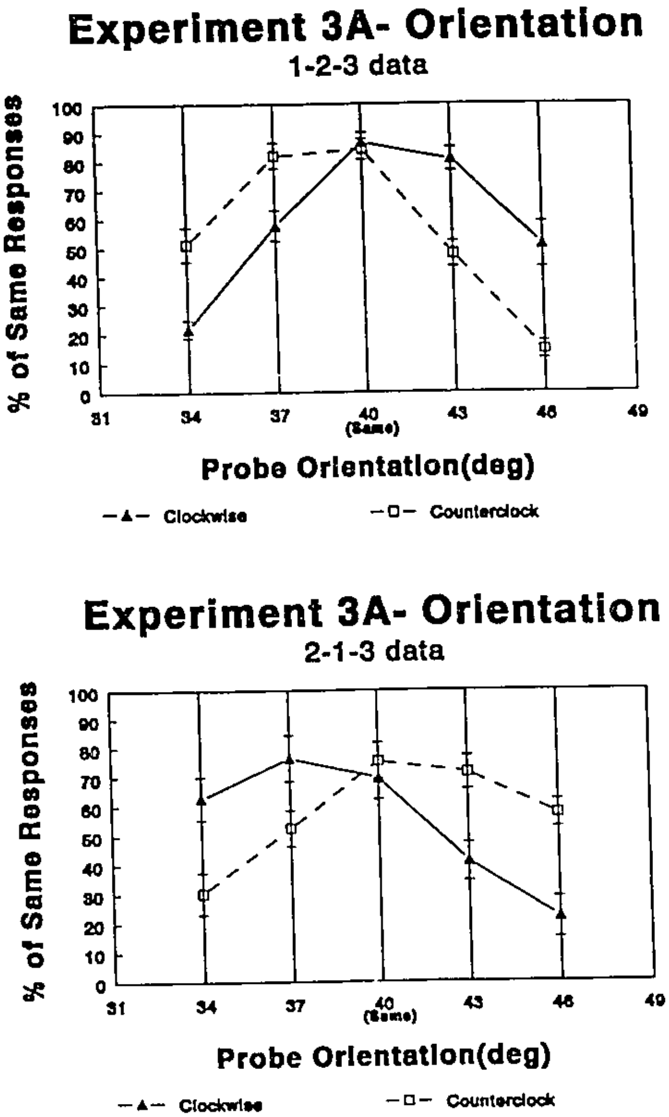


FIGURE 8

BACKWARD
SAME
FORWARD
-3°,-6°
6.3,
10.2
40°
15.4
+3°,+6°
23.7,
36.3
Probe remains on until subject's response
ISI
40°
15.4
257 msec
ISI
6°
4.1
257 msec
ISI - 157 msec
23°
1.1
cd/m2
257 msec
+
Subject initiates trial



Experiment 3A- Orientation

1-2-3 data

Experiment 3A- Orientation

2-1-3 data

Figure 9

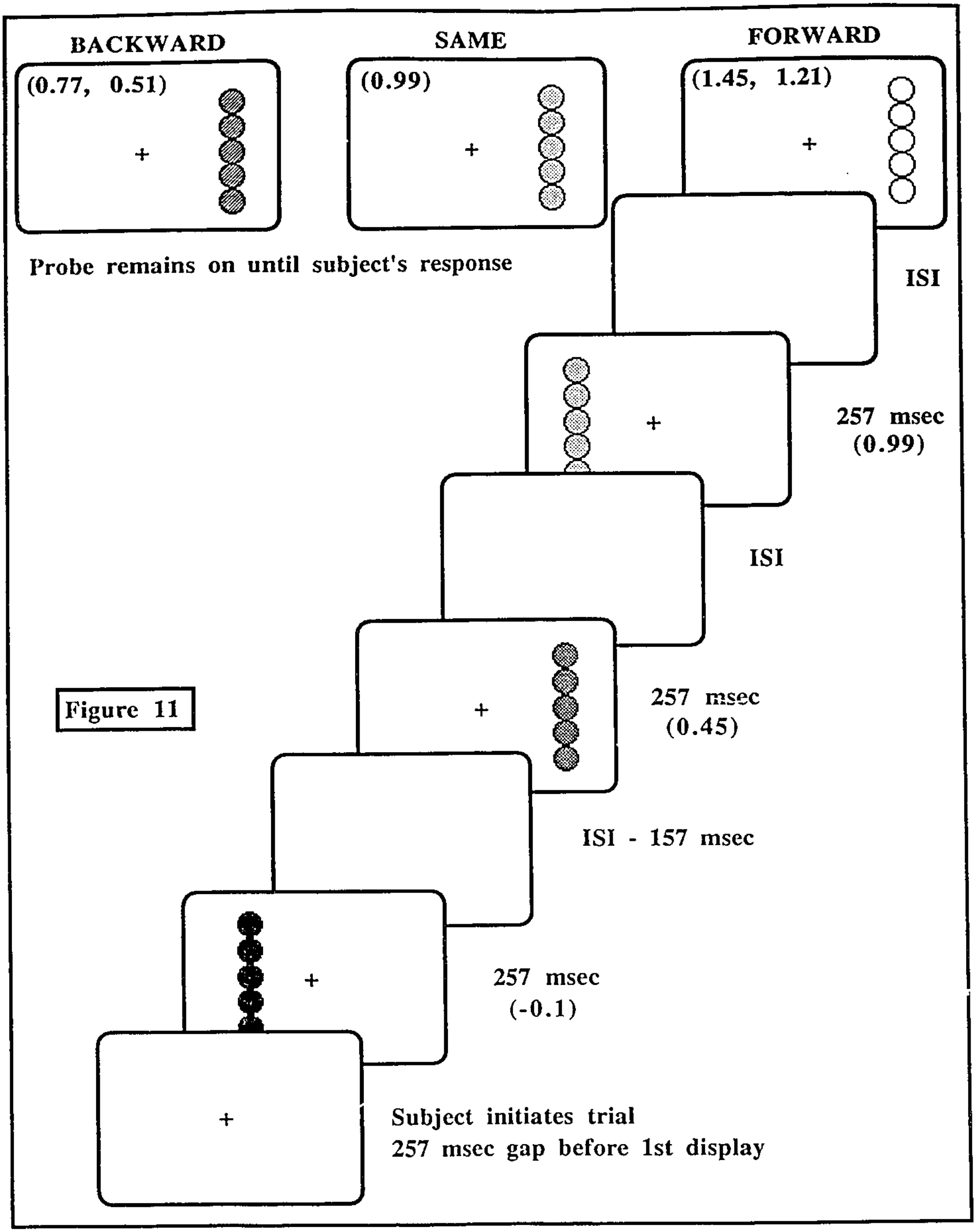


Figure 11

BACKWARD
(0.77, 0.51)
SAME
(0.99)
FORWARD
(1.45, 1.21)
Probe remains on until subject's response
ISI
257 msec
(0.99)
ISI
257 msec
(0.45)
ISI - 157 msec
257 msec
(-0.1)
Subject initiates trial
257 msec gap before 1st display

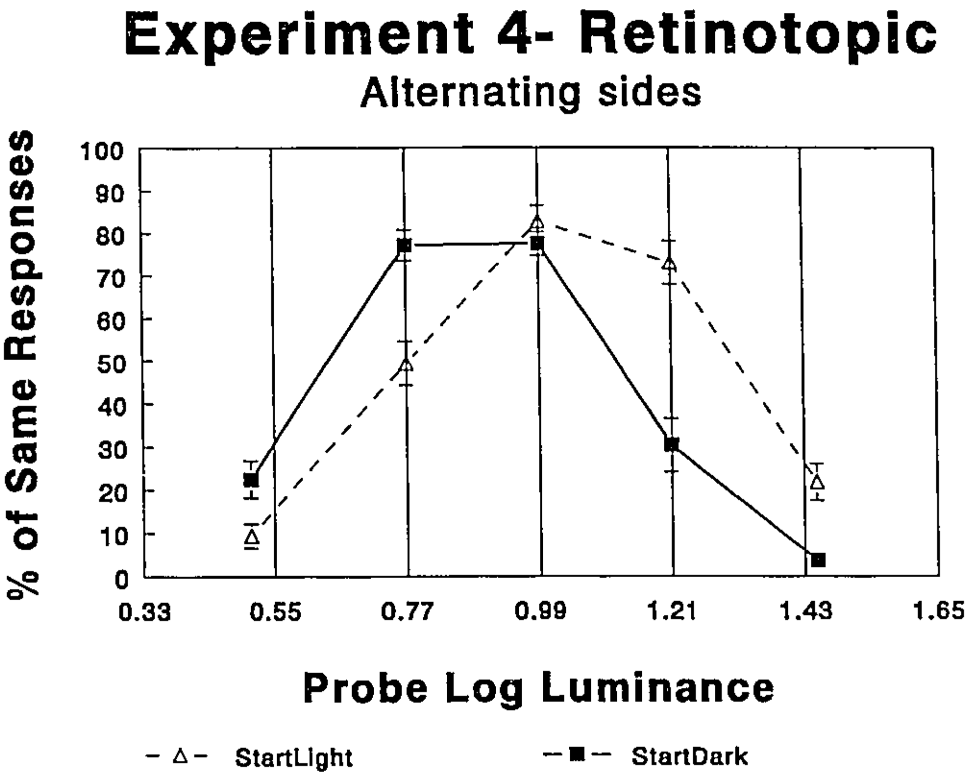
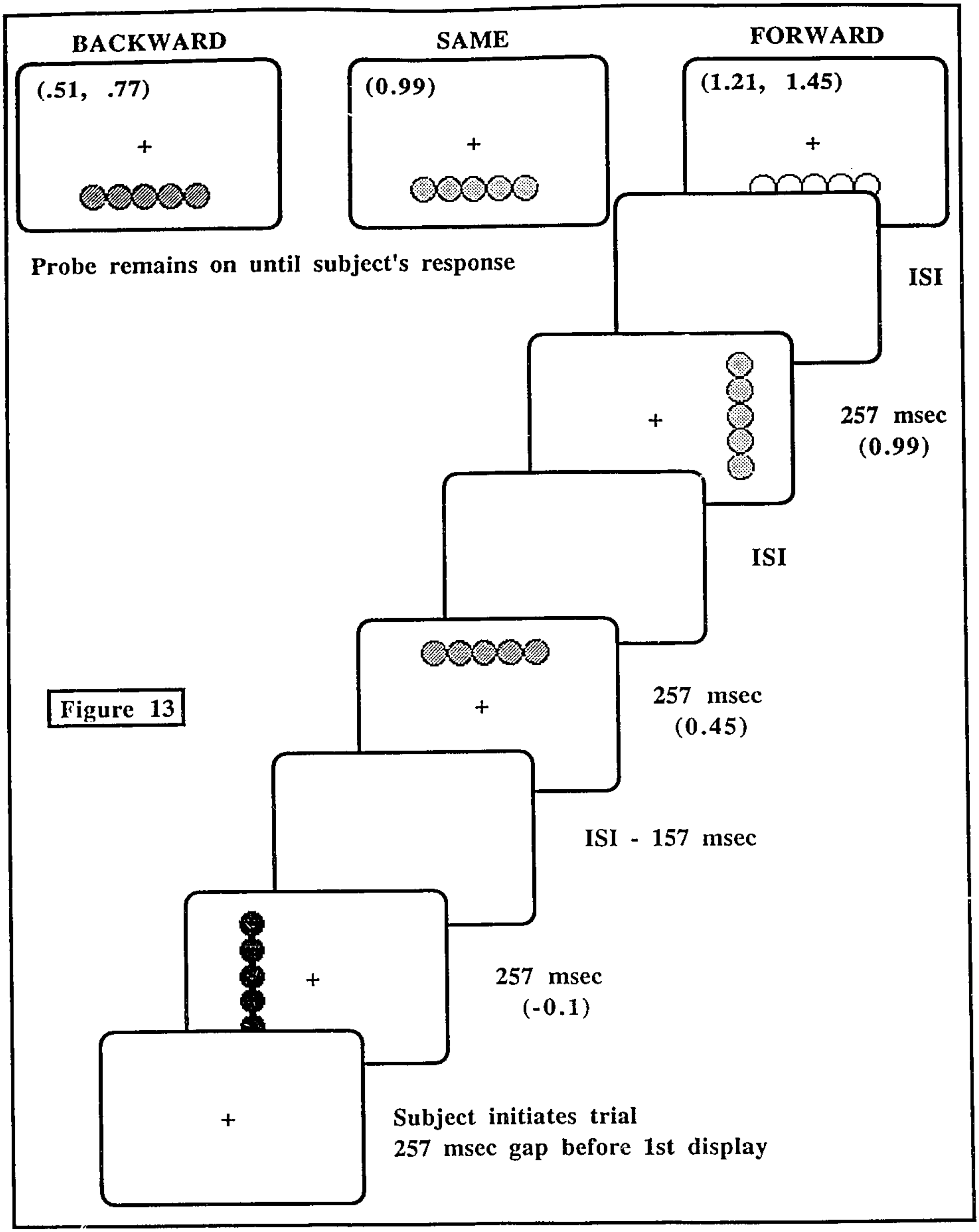
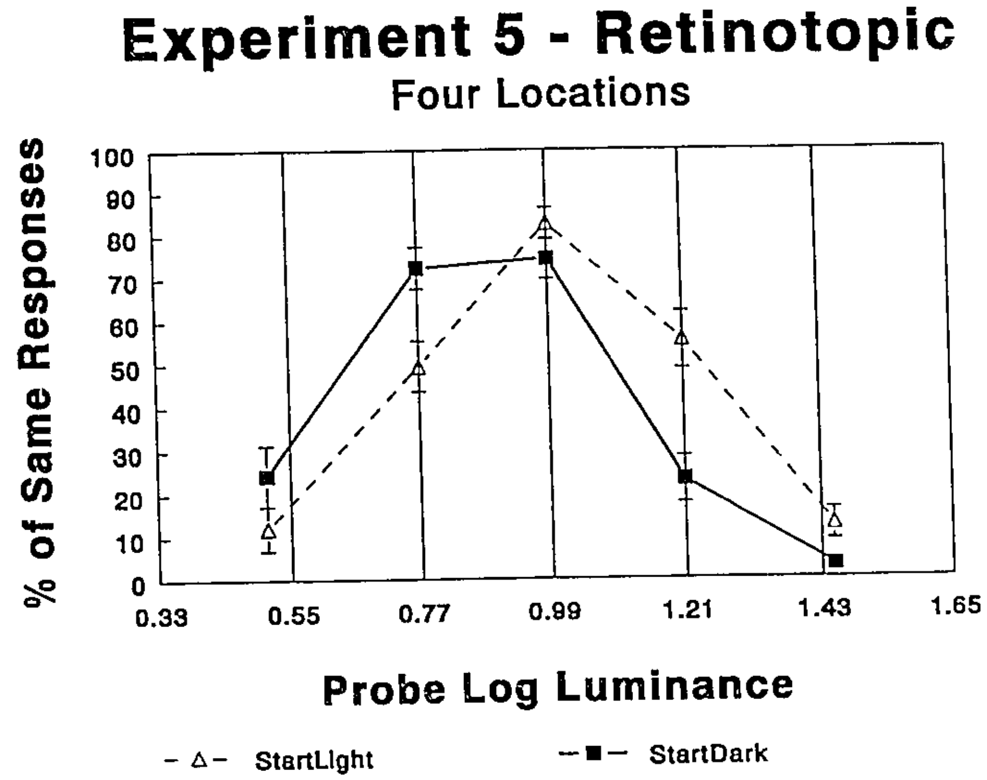

Experiment 4- Retinotopic
Alternating sides
% of Same Responses
100
90
80
70
60
50
40
30
20
10
0
0.33
0.55
0.77
0.99
1.21
1.43
1.65
Probe Log Luminance
StartLight
StartDark

Figure 12



BACKWARD
(.51, .77)
SAME
(0.99)
FORWARD
(1.21, 1.45)
Probe remains on until subject's response
ISI
257 msec
(0.99)
ISI
257 msec
(0.45)
ISI - 157 msec
257 msec
(-0.1)
Subject initiates trial
257 msec gap before 1st display

Figure 13


Experiment 5 - Retinotopic

Four Locations

Figure 14

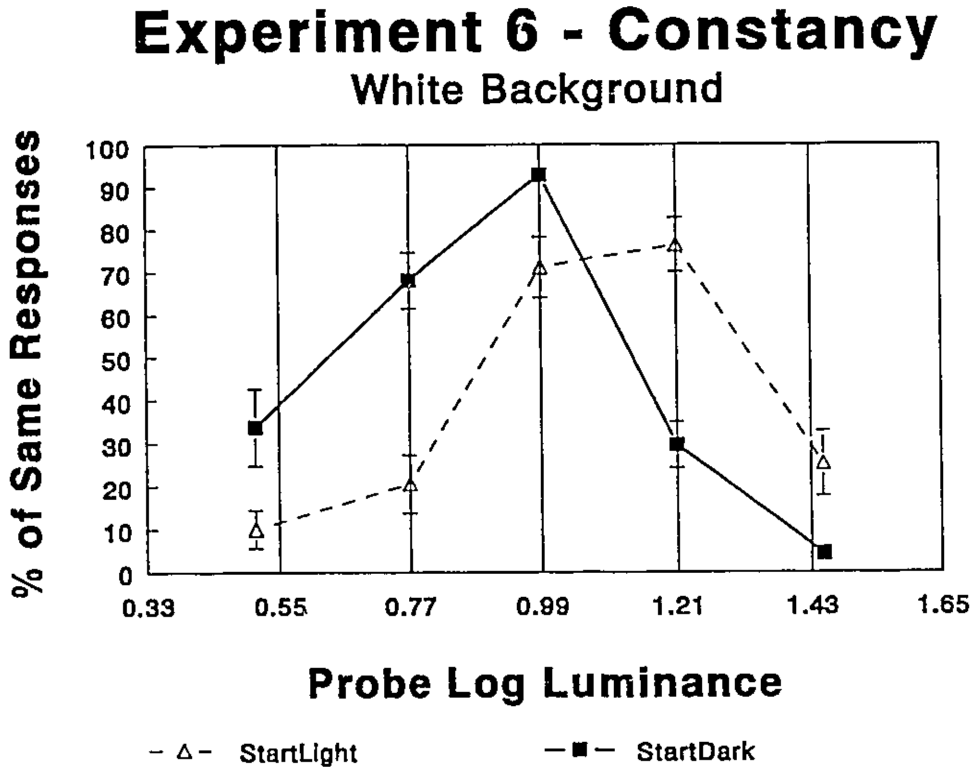

Experiment 6 - Constancy
White Background
% of Same Responses
100
90
80
70
60
50
40
30
20
10
0
0.33
0.55
0.77
0.99
1.21
1.43
1.65
Probe Log Luminance
- △ - StartLight
—■— StartDark

Figure 15

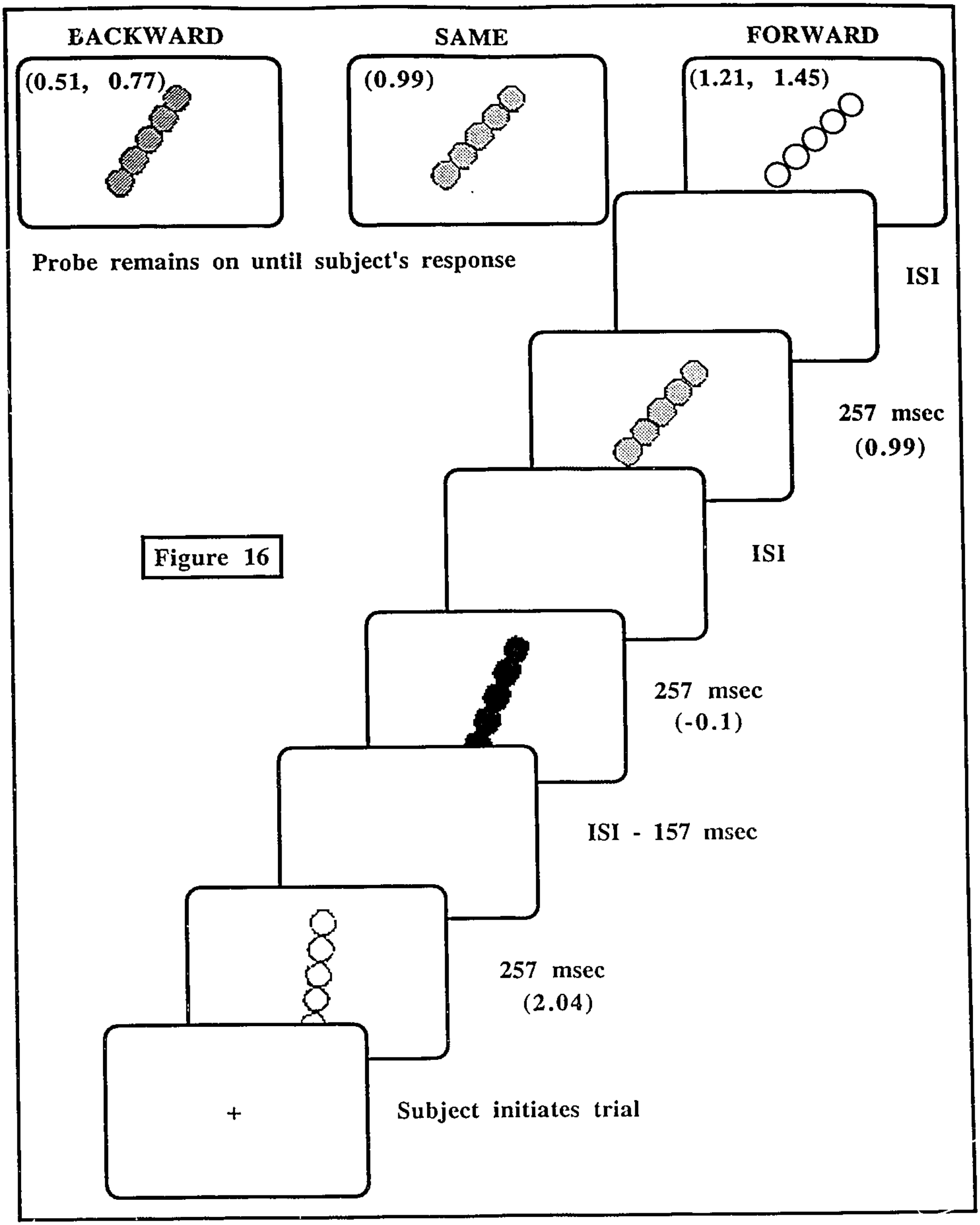

BACKWARD
SAME
FORWARD
(0.51, 0.77)
(0.99)
(1.21, 1.45)
Probe remains on until subject's response
ISI
257 msec
(0.99)
ISI
257 msec
(-0.1)
ISI - 157 msec
257 msec
(2.04)
+
Subject initiates trial

Figure 16

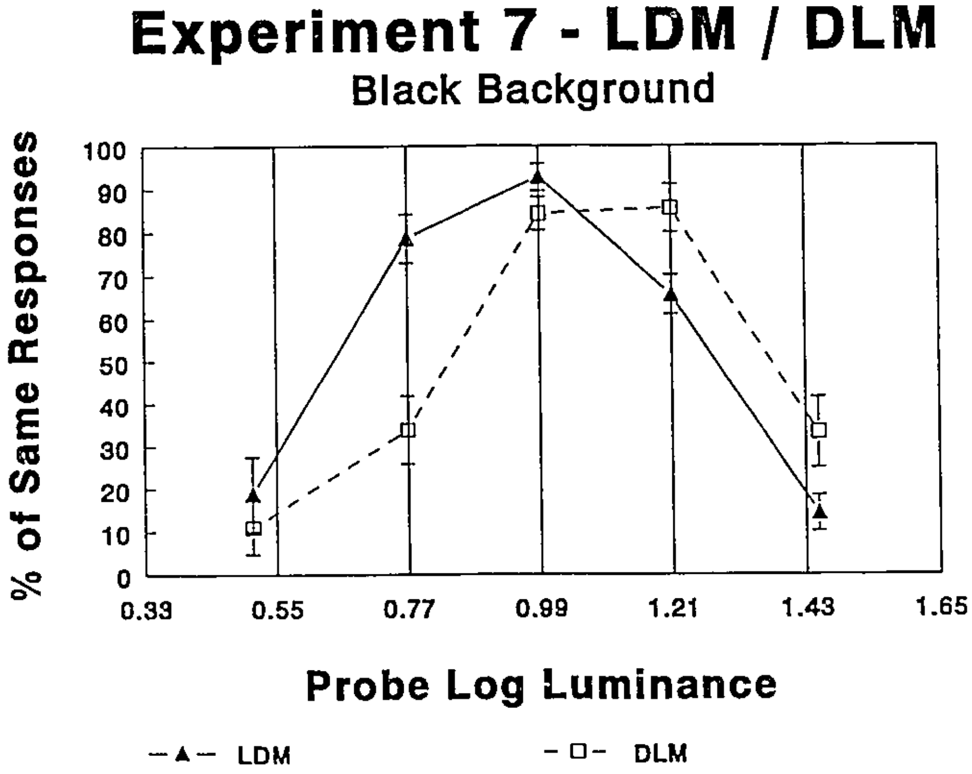
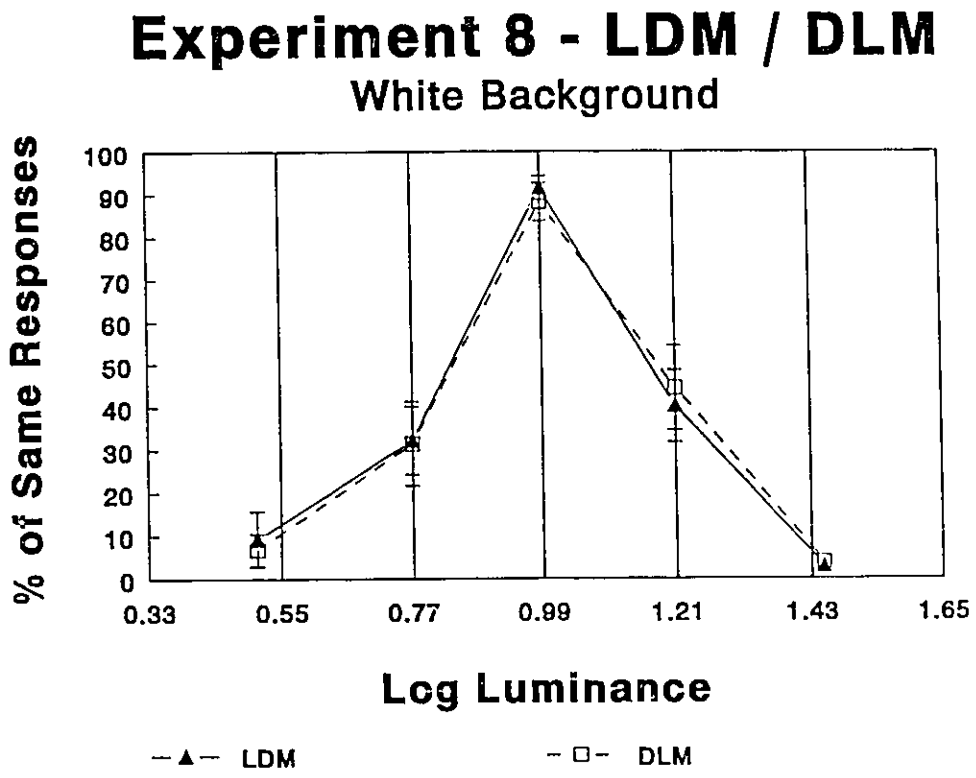

Experiment 7 - LDM / DLM
Black Background
% of Same Responses
100
90
80
70
60
50
40
30
20
10
0
0.33
0.55
0.77
0.99
1.21
1.43
1.65
Probe Log Luminance
—▲— LDM
- □ - DLM

Figure 17



Experiment 8 - LDM / DLM
White Background
% of Same Responses
100
90
80
70
60
50
40
30
20
10
0
0.33
0.55
0.77
0.99
1.21
1.43
1.65
Log Luminance
—▲— LDM
- □ - DLM

Figure 18

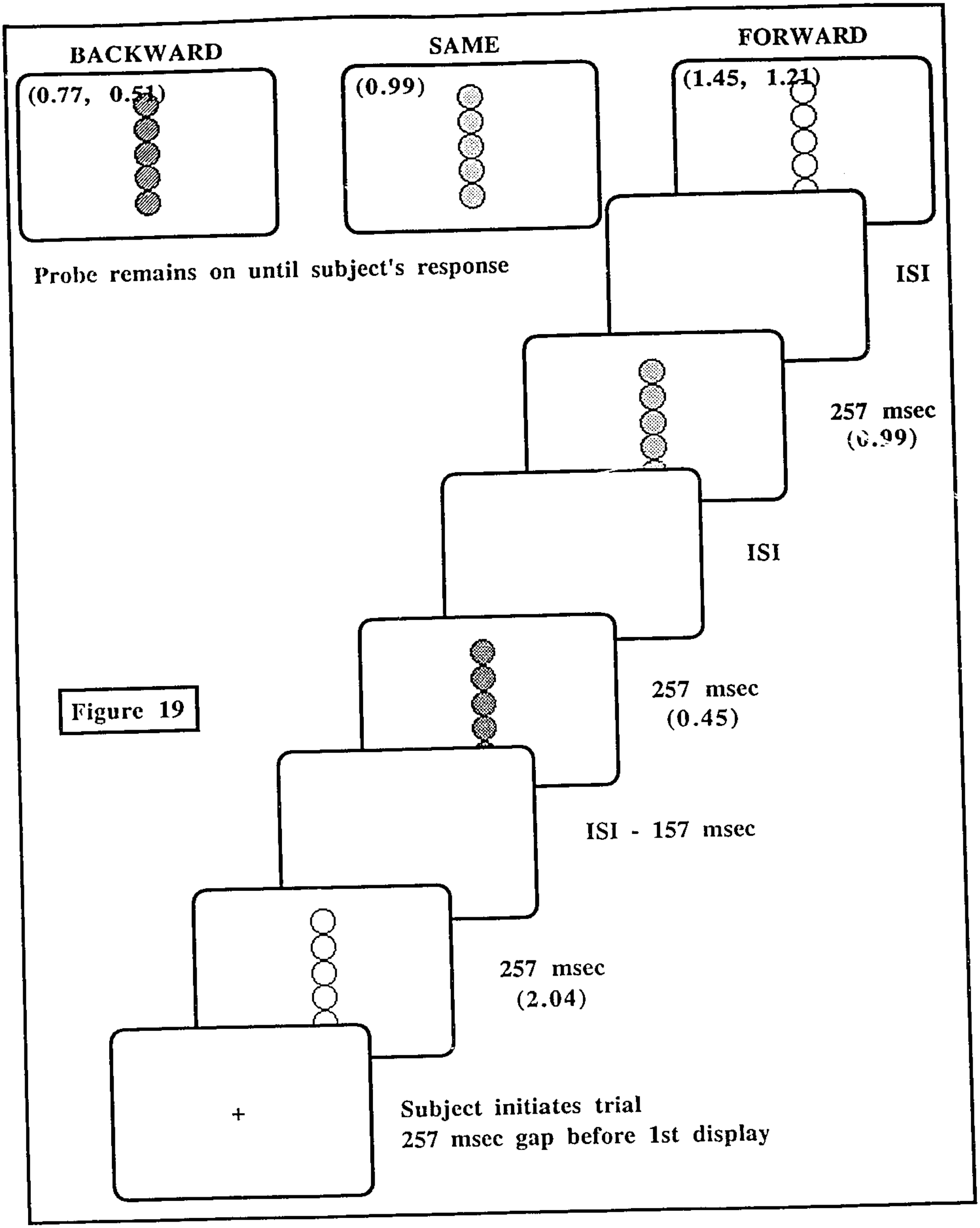
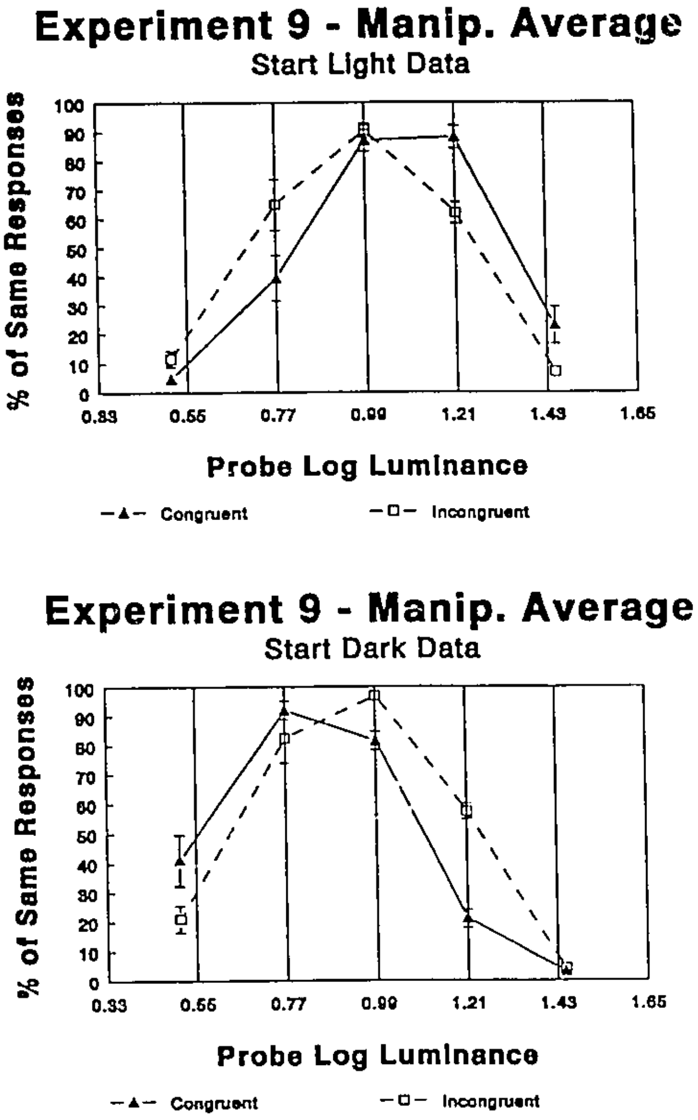


Figure 19

BACKWARD
(0.77, 0.51)
SAME
(0.99)
FORWARD
(1.45, 1.21)
Probe remains on until subject's response
ISI
257 msec
(0.99)
ISI
257 msec
(0.45)
ISI - 157 msec
257 msec
(2.04)
+
Subject initiates trial
257 msec gap before 1st display


Experiment 9 - Manip. Average

Start Light Data

Experiment 9 - Manip. Average

Start Dark Data

Figure 20

Appendix A: Luminance and log luminances used in the three Experiments

N.B. "Adjacent" column indicates log luminance difference between a given luminance and the adjacent lower luminance. "Same" column indicates log luminance difference between a given luminance and the luminance defined as "Same".

Gun Value	Luminance(cd/m^2)	Log luminance	Adjacent	Same
Experiment 1B				
Inducing displays				
63	134	2.127	0.201	0.460
51	84.4	1.926	0.259	0.259
39	46.4	1.667	-.---	-.---
15	5.5	0.740	0.563	0.927
27	20.1	1.303	0.364	0.364
39	46.4	1.667	-.---	-.---
Probe Displays				
27	20.1	1.303	0.364	0.364
39	46.4	1.667	0.259	-.---
51	84.4	1.926	-.---	0.259
Experiment 2				
Inducing Displays				
63	134	2.127	0.461	0.940
39	46.4	1.667	0.479	0.479
24	15.4	1.188	-.---	
5	1.1	0.041	0.571	1.146
13	4.1	0.613	0.575	0.575
24	15.4	1.19	-.---	-.---
Probe Displays				
15	5.5	0.740	0.117	0.447
17	7.2	0.857	0.102	0.330
19	9.1	0.959	0.098	0.228
21	11.4	1.057	0.131	0.131
24	15.4	1.188	0.116	-.---
27	20.1	1.303	0.105	0.116
30	25.6	1.408	0.094	0.221
33	31.8	1.502	0.112	0.315
37	41.2	1.615	-.---	0.427
Experiment 3				
Inducing Displays				
63	134	2.127	0.461	0.940
39	46.4	1.667	0.479	0.479
24	15.4	1.188	-.---	-.---
5	1.1	0.041	0.571	1.146
13	4.1	0.613	0.575	0.575
24	15.4	1.19	-.---	-.---
Probe Displays				
16	6.3	0.799	0.209	0.388
20	10.2	1.009	0.179	0.179
24	15.4	1.188	-.---	-.---
29	23.7	1.375	0.187	0.187
35	36.3	1.560	0.185	0.372

Appendix B: Luminance and log luminances in Experiments 4-9.

(Probe displays are the same throughout)
Dark background - 0.4 cd/m^2 (log = - 0.4); Bright background - 125.4 cd/m^2 (log = 2.1)

Gun Value	Luminance(cd/m^2)	Log luminance	Adjacent	Same
Experiments 4,5,6				
Inducing displays				
60	109.7	2.04	0.53	1.05
35	32.5	1.51	0.52	0.52
21	9.8	0.99	---	___
6	0.8	- 0.10	0.54	1.08
12	2.8	0.45	0.54	0.54
21	9.8	0.99	---	---
Probe Displays				
33	28.3	1.45	0.24	0.46
26	16.3	1.21	0.22	0.22
21	9.8	0.99	---	---
17	6.0	0.77	0.21	0.21
13	3.3	0.51	0.26	0.47
Experiment 7 & 8				
Inducing Displays				
60	109.7	2.04	0.53	1.05
6	0.8	- 0.10	0.54	1.08
21	9.8	0.99	---	---
6	0.8	- 0.10	0.54	1.08
60	109.7	2.04	0.53	1.05
21	9.8	0.99	---	---
Experiment 9 - Inducing displays				
Congruent trials				
60	109.7	2.04	0.53	1.05
35	32.5	1.51	0.52	0.52
21	9.8	0.99	---	___
6	0.8	- 0.10	0.54	1.08
12	2.8	0.45	0.54	0.54
21	9.8	0.99	---	___
Incongruent trials				
6	0.8	0.10	0.54	1.08
35	32.5	1.51	0.52	0.52
21	9.8	0.99	---	___
60	109.7	2.04	0.53	1.05
12	2.8	0.45	0.54	0.54
21	9.8	0.99	---	___

- Log luminance means for inducing displays in Experiments 7 and 8 - 0.98
- Log luminance means for inducing displays in Experiment 9 -

Start Light Congruent:	1.51
Start Light Incongruent:	0.8
Start Dark Congruent:	0.44
Start Dark Incongruent:	1.16