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Disappearing Percepts: Evidence for Retention Failure in Metacontrast Masking

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Results from a number of paradigms (including change blindness, inattentional blindness, integration over saccades, and backward masking) suggest that most of the visual information we take in is not retained, even for very short periods of time. This has led some to question whether such information is ever really perceived. We examine this issue using a variant of the classic metacontrast stimulus. When a briefly presented disk is followed by a briefly presented ring, observers may report not seeing the disk. Rather they report seeing the ring flicker as if the change in form from disk to ring is not recorded. This effect is highly dependent on the interval between the onset of the disk and the onset of the ring (the "stimulus onset asynchrony" or SOA). The maximum effect is usually found at a critical SOA of about 50 msec. Here we show that the ability of observers to distinguish such a disk/ring pair from a flickering ring is dependent also on how soon after the stimulus they respond. Early responses show a much smaller masking effect than late responses: Near the critical SOA accuracy improves when the observer responds more quickly (the opposite of the standard speed–accuracy trade-off), although at longer and shorter SOAs observers are less accurate on these early responses (a typical speed–accuracy trade-off). We interpret this finding as demonstrating that, at least in the case of metacontrast, retention of form information is disrupted, rather than initial access.

There are a number of paradigms used in psychology which have the following form: A stimulus is presented, followed, at a lag of a fraction of a second, by a

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second stimulus; the observer is supposed to make a judgement that crucially involves some knowledge of the first stimulus. These paradigms include backward masking (Breitmeyer, 1984; Forster & Davis, 1984; Greenwald, Draine & Abrams, 1996; Turvey, 1973), integration over saccades (Irwin, 1991; Jonides, Irwin, & Yantis, 1983; O'Regan & Levy-Schoen, 1983), inattentional blindness (Mack, Tang, Tuma, Kahn, & Rock, 1992; Rock, Linnett, Grant, & Mack, 1992), and change blindness (Grimes, 1996; Phillips, 1974; Rensink, O'Regan & Clark, 1997; Simons, 1996). The surprising result from all of these paradigms has been how little we appear to retain from the first stimulus. The similarity of these findings across a number of different paradigms suggests a common conclusion: That the cognitive system assumes that the current perceptual description of an object is correct and simply ignores earlier information.

Although these paradigms all push us toward similar conclusions, they are clearly quite different experimentally. The differences include the complexity and duration of the stimuli as well as the observer's attentional set. This reflects how each of the paradigms deals with one undeniable fact: Given enough time and attentional resources, observers can memorize a limited amount of information. These paradigms are really about exploring the boundary conditions for this statement. In change blindness and integration of information over saccades, too much information is provided in the first stimulus to allow memorization. When the relevant information is more salient or higher order or when less information is presented, better retention is observed (Hayhoe, Lachter, & Feldman, 1991; Lachter & Hayhoe, 1995; Rensink et al., 1997; Simons, 1996). In inattentional blindness, attention is directed away from the relevant target. When observers are aware that the actual target may be relevant, performance improves dramatically (Mack et al., 1992; Rock et al., 1992). Finally, in backward masking paradigms observers are not given sufficient time to memorize the first stimulus before the second occurs. If the offset between the first and second stimuli is increased, the first stimulus is easily seen and remembered (Breitmeyer, 1984; Turvey, 1973).

The most intriguing aspect of these various stimuli is the issues they raise about consciousness. When studying consciousness, most researchers are interested in the nature of experience, or as Chalmers calls it, "The Hard Problem" (Chalmers, 1996). Because we cannot measure experiences directly, experimentalists rely on reportability. For the paradigms that we are discussing, this leads to some interesting conflicts. In the cases of change blindness and integration of information over saccades, observers feel that they consciously experience the stimuli completely. However, if they do, they can neither report them nor make simple judgements based on them. Dennett (1991) has argued that there is no fact of the matter as to whether we were ever conscious of such information. With inattentional blindness and backward masking observers claim *no* conscious experience of the first stimuli. Yet

semantically salient stimuli (such as your name) appear immune to the inattentional blindness phenomenon suggesting that these "unseen" stimuli were highly processed (Mack, 1996; Mack & Shelley-Tremblay, 1997). In backward masking, a great number of studies have illustrated indirect effects of the first stimulus. That is, if we ask people to classify the second stimulus in some way, the first stimulus can have a large impact on their response latencies (Forster & Davis, 1984; Greenwald et al., 1996). In both cases the suggestion has been made that observers do see these stimuli but do not remember them (Dennett, 1991; Wolfe, 1997). If this is the case, one should be able to find a period early in the processing of these stimuli where information identifying the stimuli is available followed at once by the loss this information.

We have recently been examining the time course of information availability in the best known of the backward masking paradigms, metacontrast. Elsewhere we argue that early responses (responses made when the observer is under pressure to respond quickly) reflect the early stages of processing of such stimuli, whereas late responses (those made after a short delay) reflect the final outcome of such processing (Lachter & Durgin, 1999). Here we show that early responses, and thus early processing, may more accurately reflect the initially presented stimulus.

Metacontrast differs from other forms of backward masking in that the target and mask do not occupy the same spatial position. (For reviews of metacontrast see Alpern, 1952; Bachmann, 1994; Breitmeyer, 1984; Lefton, 1972). A traditional metacontrast display consists of a briefly flashed disk followed by a ring (Werner, 1935). These are arranged so that the inner boundary of the ring is spatially coincident with the outer boundary of the disk. At certain disk–ring SOAs (typically 50–100 msec), observers report only the ring flickering without any perception of the disk. However, these judgements are given hundreds of milliseconds after the event occurred. We wondered whether this failure to report seeing the disk was due to failed initial access or to failed retention. To answer this question we examined the temporal development of the masking effect by comparing early speeded reports with late delayed reports. We reasoned that the early responses would tap information available quickly, whereas late responses would integrate that information with information that was slower to arrive. In order to facilitate rapid responding and get a more objective measure of detection, we used a two-alternative forced-choice procedure. On each trial a disk–ring stimulus was to be discriminated from a ring–ring stimulus presented at the same time (see Figure 1; cf. Schiller & Smith, 1966, for a related paradigm). Notice that this form of masking occurs under conditions of direct attention and minimal memory load. It does not seem to be related to an attentional bottleneck.

Normally for a perceptual task one expects to find a speed–accuracy trade-off (Luce, 1986). That is, when responses are rushed, performance should decline due to motor-command selection errors and a reduction in

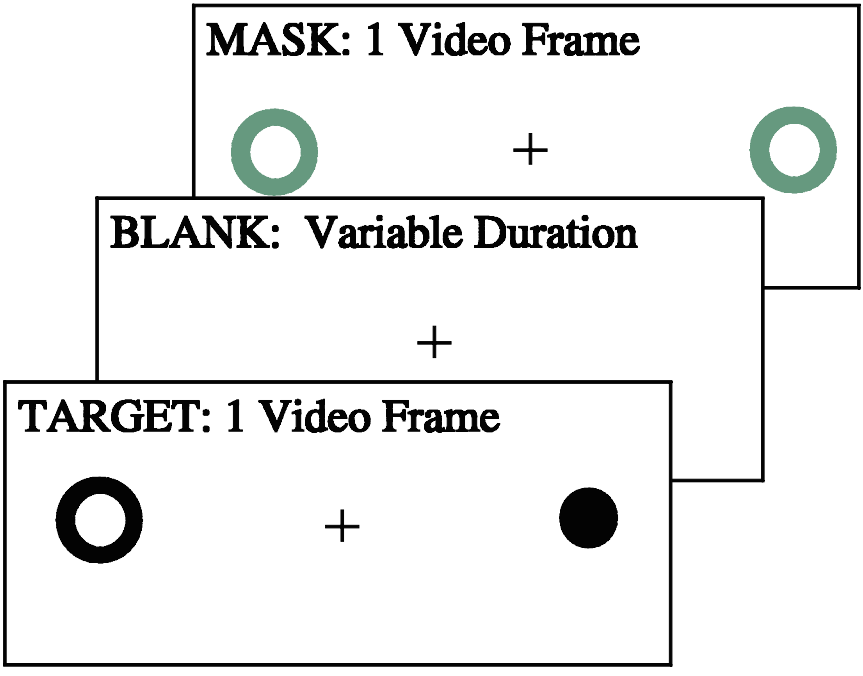

FIG. 1. Stimuli: A disk is briefly flashed on one side of fixation simultaneous with a ring on the other. Two rings mask these locations after a variable interval. The video rate was 75 Hz, so that the interval between a particular pixel being drawn and its being redrawn on the next frame was 13.3 msec.

error-checking: "Haste makes waste". However, if this perceptual information is soon to be compromised by incoming masking information, rushing responses may prove beneficial: "He who hesitates is lost". Because metacontrast is greatest for a particular range of SOAs, our prediction is that speeded responding should selectively improve performance at SOAs where masking is most severe. Rushing responses should have the normal deleterious effect at shorter and longer SOAs.

METHODS

Two versions of this experiment were run. The methods employed in these experiments were identical except for the range of SOAs used, blocking of trials, screen luminances, and the subject pool. Note that these methods are similar to those used in Experiments 1 and 2 of Lachter and Durgin (1999) except that here observers were not given feedback on their performance.

Participants

Sixty students at the University of Arizona participated in Experiment 1. Thirty of these were paid and thirty participated in partial fulfillment of a course requirement. Sixty students at Swarthmore College participated in Experiment 2 in partial fulfillment of a course requirement.

Stimuli

Stimuli like those shown in Figure 1 were presented using a Macintosh Computer. Observers were initially positioned 45 cm from the screen; however, no head restraint was employed so all angular dimensions are approximate. All stimuli were presented centred on a white background at approximately 80 cd/m^2. Each trial began 1.5 sec after the subject responded to the previous trial. In the first frame there was a black (approximately 10 cd/m^2 for Experiment 1 and 2 cd/m^2 for Experiment 2) disk 1 cm in diameter (1.3 degrees) centred 6 cm (7.8 degrees) to the right or left of fixation, and a ring with outer diameter 1.4 cm (1.8 degrees) and inner diameter of 1 cm on the opposite side of fixation from the disk. The disk and ring had nearly identical area and thus nearly identical stimulus energy. These remained on the screen for one video frame (at 75 Hz). (Bridgeman, 1998, has noted that stimuli presented on a video monitor are physically a train of pulses and are thus not continuously present. We thus speak of video refresh rates and SOAs, rather than the duration of our stimuli.) Next came a variable delay (0–120 msec) followed by two rings (masks) presented for one video frame. These had an inner diameter of 1 cm and outer diameter of 1.4 cm and were centred 6 cm to the right and left of fixation (so that one ring precisely surrounded the location of the disk in the target frame whereas the other coincided with the location of the ring in the target frame). The masking rings were grey (approximately 35 cd/m^2 in Experiment 1 and 20 cd/m^2 in Experiment 2). The masks were lower contrast than the target to minimize the contribution of other forms of masking such as simultaneous contrast or lateral inhibition. In order to prevent observers from developing strategies based on properties of the display other than their perception of the disk, no feedback was given (see Discussion).

Response Latency Manipulation

In the early-response condition, observers were required to respond within 480 msec on every trial. If they failed to do so on three consecutive trials the computer would display a message encouraging them to go faster. A similar manipulation was used to require latencies in the late-response condition to be greater than 730 msec. The median response times for the unconstrained practice trials averaged 560 msec with a standard deviation of 181 msec across all 120 subjects who participated in these experiments. (Response times have been

corrected for the latency to draw the targets on the screen and the latency for the computer to detect a key press.)

Procedure

Trials were run in blocks of 100. The first 10 trials of each block were warm-up trials with no mask and the second 10 were practice trials with SOAs and disk side chosen at random. In Experiment 1, the remaining 80 trials consisted of 8 trials in each combination of disk side (right or left) and SOA (13, 40, 80, and 133 msec and no mask) ordered at random with the constraint that trials 21–40, 41–60, 61–80, and 81–100 had the same number of each type of trial. In Experiment 2, the remaining 80 trials consisted of 4 trials in each combination of disk side and SOA (13, 27, 40, 53, 67, 80, 93, 107, 120, and 133 msec), ordered at random. For both experiments, the first block was considered practice and conducted without time constraints. The remaining blocks alternated between the fast and slow instructions. In Experiment 1 there were six such blocks in Experiment 2 there were four such blocks. Initial response speed was alternated between observers.

RESULTS

As predicted by the retention–failure hypothesis, observers' performance at SOAs within the metacontrast range is actually better in the early-response condition than in the late-response condition (Figure 2). Reliable differences were found in Experiment 1 at the 40 msec SOA ($t59 = 2.71$; $p < .01$), and in Experiment 2 at the 27 msec ($t59 = 3.11$; $p < .01$), 40 msec ($t59 = 3.64$; $p < .001$) and 53 msec ($t59 = 2.21$; $p < .05$) conditions, using paired t-tests with subjects as the random factor. These results contrast with the findings outside the metacontrast range, for which observers performed better when responding slowly. This difference was significant in Experiment 1 at SOAs of 13 msec ($t59 = 5.29$; $p < .001$) and 133 msec ($t59 = 2.82$; $p < .01$) and in the no-mask condition ($t59 = 5.89$; $p < .001$), and in Experiment 2 at SOAs of 120 msec ($t59 = 2.17$; $p < .05$) and 133 msec ($t59 = 2.08$; $p < .05$). Put another way, when observers respond early the metacontrast effect is much smaller than when they respond late. This suggests that the metacontrast effect is not part of the initial perception of the disk but rather develops over time.

DISCUSSION

The data presented here show a clear change in the nature of the metacontrast effect as the rate at which observers respond changes. We document this change and detail its consequences for theories of metacontrast in a separate paper (Lachter & Durgin, 1999). Here we focus on the improvement in

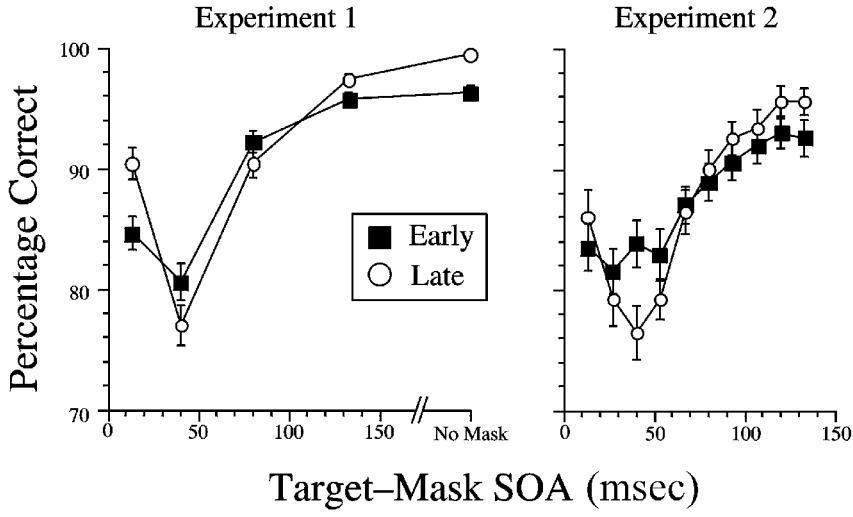

FIG. 2. Results: Percentage correct locating the disk as a function of SOA. Conditions in which the observer was to respond in under 480 msec are shown as squares. Conditions in which the observer was to delay response until after 730 msec are shown as circles. Error bars indicate one standard error calculated across subjects.

performance as observers respond earlier. Early responding not only changes the shape of the masking function, it allows observers to perform more accurately on heavily masked stimuli. Although this trend was noted in our other experiments, it seems far more robust in the experiments reported here where observers were not given feedback. We believe that data obtained from observers without feedback better reflects their access to perceptual information about the disk for two reasons. First, many of the observers who received feedback reported feeling that the fast condition was easier. At least two of the Arizona observers developed a strategy in the late condition of raising a finger immediately after the stimulus display and then pressing the button after a short delay. This amounts to responding quickly in the late condition, thus counteracting our latency manipulation. Others may have done this implicitly. No such strategies were noticed for the experiments reported here where observers were not given feedback. Second a large number of observers given feedback reported using the way the mask appeared to move or flicker as a cue. This information may be maintained allowing observers to improve their performance in the slow condition. Substantially fewer reported using such cues in the current experiments.

In assessing the magnitude of this reversal of the speed–accuracy trade-off, it is important to keep two things in mind. First, the normal reasons one finds a speed–accuracy trade-off still hold. That is, when pressed to respond quickly, observers make anticipatory responses, just as they do for other stimuli. The

speed–accuracy reversal thus must overcome this effect to be seen. Second, observers vary widely in their susceptibility to metacontrast (see Eriksen, Becker, & Hoffman, 1970). A number of observers were essentially perfect on both early and late responses. For such subjects it is not possible to obtain large effect sizes. Taking these two facts into account we are quite impressed by how much better our observers perform when responding quickly than when responding slowly.

A reversal of the speed–accuracy trade-off could be caused by a number of things such as motivational and attentional factors. As we have discussed elsewhere (Lachter & Durgin, 1999), one would ordinarily expect such influences to affect all trials in a particular condition. Here though, the normal advantage of slowing responses down appears at SOAs where masking is weak. It appears that whatever gives observers an advantage when going fast only operates where masking is strongest. The natural explanation is that information about the disk has not yet been suppressed when observers respond early. This conclusion is in line with several other claims in the literature. Forster and Davis (1991) and Greenwald and colleagues (Greenwald & Abrams, 1998; Greenwald et al., 1996) both used paradigms where a "prime" stimulus was masked by a target which occurred immediately afterwards. In Forster and Davis's experiment the task was to name the target as quickly as possible. They found that observers would occasionally pronounce the masked prime even though they claimed not to have seen it. The pronunciation of the word, occurring immediately after the occurrence of the prime, was thus greatly affected by the prime, whereas their recollection a short time later, was not. Similarly Greenwald and colleagues (Greenwald & Abrams, 1998; Greenwald et al., 1996) have found that masked words can influence various semantic judgements but only when the observer is under extreme time pressure to respond soon after the masked item. Cumming (1972) found in one experiment that fast observers could more accurately report masked letters than slow observers (although this failed when he attempted to control observers' speed experimentally by rewarding them for speed or accuracy: Observers did not feel they were more accurate when they responded slowly). The idea that fast responses can capture information from an object that is later backward masked is also central in some neural network models of masking (Bridgeman, 1971, 1978; Mathis & Mozer, 1996). Thus, a variety of evidence points to a brief, but active life to representations of backwardly masked objects.

To summarize, a number of interesting phenomena seem to arise from the visual system's failure to retain information over very short periods of time. We have shown that for at least one such phenomenon the timing of the response plays a crucial role. If a response is generated early, the observer appears to have access to information which is rapidly lost. Thus our data support those who believe that these phenomena point to a kind of amnesia, a failure to remember the earlier stimuli, rather than a kind of blindness, a failure to

process them in the first place. However, the question of whether one consciously experiences these rapidly forgotten stimuli remains open. Many believe that retention for some period is necessary for information to be experienced consciously (e.g. Libet, 1996); on such a model these unremembered stimuli might be unconscious even though highly processed. Others associate conscious experience with controlled (as opposed to automatic) processing (Debner & Jacoby, 1994; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). It is possible that the improved performance (reduced masking) in the early-response condition is due to memory-less response routines, which can be run off "automatically" in real time but which cannot normally be triggered after a delay. Such response routines might be construed as "implicit" or "sub-perceptual". Such explanations illustrate ways in which the same response to the same stimuli could be made with conscious experience in one case and without it in the other.

Although our experiments do not demonstrate a brief conscious experience of a stimulus masked with metacontrast, they do demonstrate the difficulty with using reportablitity as an operationalization of consciousness. Dennett's (1991) discussion of metacontrast presciently articulated this problem. Dennett wrote (p. 142) "The Multiple Drafts model agrees that information about the disc was briefly in a functional position to contribute to a later report, but this state lapsed; there is no reason to insist that this state was inside the charmed circle of consciousness until it got overwritten, or contrarily, to insist that it never quite achieved this privileged state." Dennett's argument is based on the abstract possibility that there might be such brief reportable states. The data reported here make that abstract possibility a concrete reality.

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