Research Article

OBJECT ATTENTION REVISITED:
Identifying Mechanisms and Boundary Conditions

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Abstract—*Multiple attributes of a visual array are often more efficiently processed when they are attributes of a single object than when they are attributes of different objects—a pattern reflecting the limitations of object attention. This study used psychophysical methods to evaluate the object attention limitations in the report of attributes (orientation and phase) computed early in visual analysis for spatially separated objects. These limitations had large effects on dual-object report thresholds when different judgments were required for the two objects (orientation for one object and phase for the other), but the effects were small or nonexistent when the same judgment was made about both objects. Judgment consistency reduced or eliminated the expression of object attention deficits. Thus, the deficits in dual-object report reflect both division of attention over objects and the calculation of independent reference or judgment operations. Dual-object deficits, when they occurred, were substantial in displays with external noise masks. Smaller effects were observed in clear displays, even when difficulty was equated by stimulus contrast. Thus, the primary consequence of object attention is the exclusion of external noise, or mask suppression, and enhancement of the stimulus in clear displays is a secondary consequence.*

> If subjects must report two aspects of a brief visual display, performance should depend on whether these aspects concern the same or different objects. Reporting two aspects of one object should be no more difficult than reporting only one because focal attention is paid to the object as a whole. In contrast, reporting aspects of two different objects should be less successful, reflecting competition between these objects for focal attention. Duncan (1984, p. 501)

Since Duncan's early investigation of limitations in the report of multiple aspects or attributes of separate objects, *object attention* has been considered a primary explanatory principle in the distribution of attention. A fundamental limitation in the distribution of attention over multiple objects is evinced by the observed disadvantages in dual-object report; several features of the same object are encoded efficiently, but features of different objects are encoded inefficiently (Duncan, 1984; see also Isenberg, Nissen, & Marchak, 1990; Vincent & Regan, 1995). Two judgments that concern the same object can be made simultaneously with little or no loss of accuracy compared with a single judgment about that object. However, two judgments about separate objects exhibit losses compared with single or dual judgments about a single object. This *dual-object deficit* has been demonstrated for many pairs of features, including brightness and orientation (Duncan, 1984); displacement and orientation (Duncan, 1993b); "where" and "what" (Duncan, 1993a); pairs of surface properties such as color, brightness, and texture; and pairs of boundary properties such as length and location (Duncan & Nimmo-Smith, 1996). Other elaborations of object attention have focused on the relationship between attributes that are parts of a hierarchically defined perceptual object (Egly, Driver, & Rafal, 1994; Moore, Yantis, & Vaughan, 1998) or object part (Vecera, Behrmann, & Filapek, 2001; Vecera, Behrmann, & McGoldrick, 2000). Indeed, object attention has evolved as an organizing principle for cortical mechanisms of visual object representation and visual attention (e.g., Desimone, 1998; Kastner & Ungerleider, 2000). The current study examined the roles of consistency of judgment frames and of masking in object attention effects in the perception of basic visual features. Object attention was evaluated using full psychometric analysis across a wide range of performance levels.

JUDGMENT FRAMES IN OBJECT ATTENTION

Duncan (1984, 1993b, 1998) has argued that object attention limitations are paramount—that object attention deficits do not depend on whether the same or different perceptual analyzers or codes are used (Duncan, 1984, 1993a, 1993b; Duncan & Nimmo-Smith, 1996). Object attention explanations of dual-report accuracy have historically been contrasted with alternative explanations of dual-task performance, including explanations based on capacity limitations within feature processors when they are required for both tasks (Allport, 1971; Wickens, 1971; Wing & Allport, 1972) and cross talk, competition, or confusion between responses (Navon & Miller, 1987). Both of these alternatives to the object attention position predict that the existence and size of dual-report deficits should depend on the nature and content of the reported judgments. In the prior literature (Duncan, 1993a, 1993b; Duncan & Nimmo-Smith, 1996), tests of the importance of the type of judgment have been incomplete. In this study, we explicitly tested the importance of judgment identity in deficits of dual-object report by contrasting conditions in which judgments based on the same feature were made for two objects and conditions in which different feature dimensions were judged for the two objects. This study differs from prior investigations in that the same-feature conditions were identical in reference frame, decision criteria, and response mapping. Both same-feature and different-feature dual-object report conditions were contrasted with single-object report conditions.

NOISE EXCLUSION IN OBJECT ATTENTION

Recent theories of spatial attention have suggested that attention has a special role in noise or mask suppression (Dosher & Lu, 2000a, 2000b; Enns & Di Lollo, 1997; Lu & Dosher, 1998, 2000; Shiu & Pashler, 1994). Previous investigations of dual-object report deficits generally used brief displays and high-contrast postmasks (e.g., Duncan, 1993a, 1993b) to reduce performance to measurable levels. This choice may have important theoretical implications. Are dual-object report deficits restricted to masked, or high-noise, situations and therefore a

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reflection of a noise-exclusion mechanism? An answer to this question will provide insight into the function of object attention. Object attention effects in high noise reflect noise-exclusion mechanisms, whereas object attention effects in the absence of noise or masks reflect stimulus enhancement (Dosher & Lu, 2000b). We evaluated object attention in both zero- and high-noise conditions.

PSYCHOMETRIC EVALUATION OF OBJECT ATTENTION IN BASIC VISUAL STIMULI

Traditionally, investigators have studied dual-object report deficits by measuring performance for high-level features and objects at a single difficulty level. We evaluated object attention report deficits in a psychophysical task requiring the identification of basic visual features processed early in the visual system (Graham, 1989). Performance was measured across a full psychometric function, from chance to maximal accuracy. We used spatially separated objects in order to avoid the considerable theoretical and technical complications of compound visual stimuli. (Compound visual stimuli, e.g., Olzak & Thomas, 1992, generally consist of spatially overlapped or summed individual stimuli. Such stimuli, in which the two "objects" are offset at different orientations, prevent the very equivalence of judgment frame that we investigated in this study.) We provisionally adopted the working view that object attention effects dominate even for spatially separated objects (Baylis & Driver, 1993; Egly et al., 1994; Vecera & Farah, 1994; see also the Discussion). The results obtained provide essential information about the function or mechanism of object attention and document new boundary conditions on classic object attention effects.

GENERAL METHOD: EXPERIMENTS 1 AND 2

Definition of Report Conditions

All displays consisted of two objects (Gabor patterns), one on each side of fixation, varying randomly and independently in orientation and phase (Fig. 1). The objects were oriented with the top tilted either to the left or to the right. Two phases were used: center bar dark (with light adjacent side bars) or center bar light (with dark adjacent side bars).

Object attention was assessed with four report conditions: (a) single-object, single-response (1O1R) condition, in which the observer judged either phase or orientation for a single object; (b) single-object, dual-response (1O2R) condition, in which both phase and orientation were judged for one object; (c) dual-object, same-response (2OSR) condition, in which either phase or orientation was reported for both objects; and (d) dual-object, different-response (2ODR) condition, in which a phase judgment was made for one object and an orientation judgment for the other. The labels "same" and "different" response refer to the response judgment types, not to the individual responses themselves (e.g., to orientation or phase judgments, not to individual responses like "left" or "right").

Design

Experiment 1 measured full psychometric functions for all conditions within a single observer; conditions were blocked by and counterbalanced for response instruction and report order. Psychometric functions measure performance accuracy from chance to asymptotic levels as a function of stimulus contrast. Experiment 2, suggested by Duncan and modeled on earlier object attention experiments (e.g., Duncan, 1993b), measured performance at a single contrast level and counterbalanced report order across observers in order to simplify the report structure experienced by any individual observer.

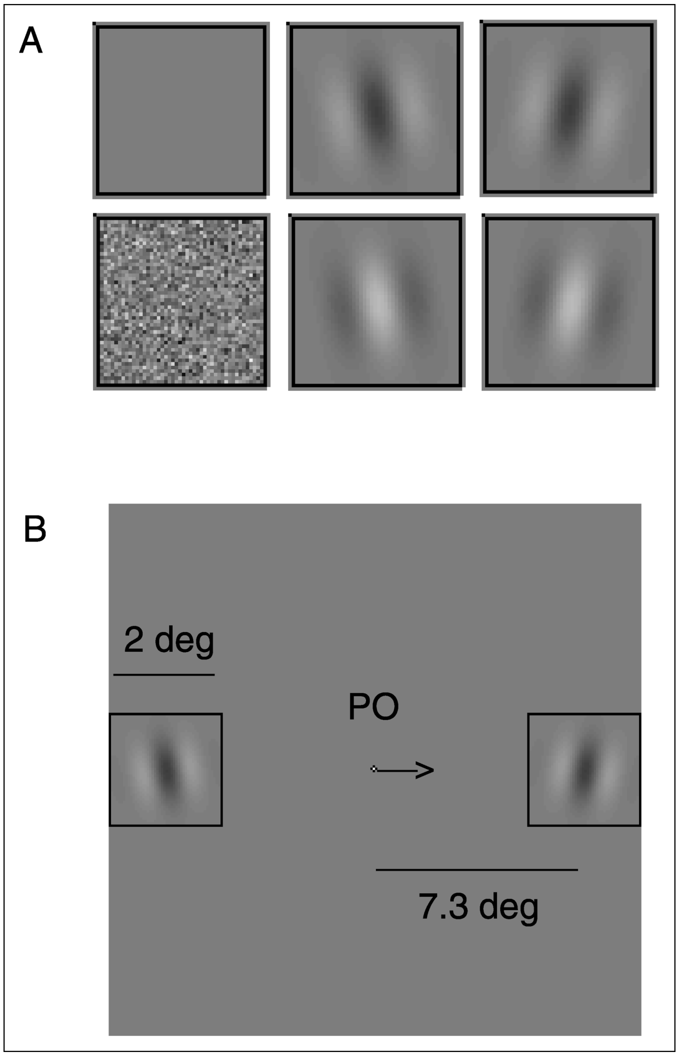

Fig. 1. Experimental stimuli (a) and layout (b). The four different Gabor patches, shown in the middle and right columns in (a), differed in orientation and phase (center black, tilted left; center black, tilted right; center white, tilted left; center white, tilted right). No-noise and high-noise images, shown in the left column in (a), appeared before and after the Gabor stimulus. The illustration of the spatial layout of the display elements shows the location of the 2° × 2° signal and noise frames (shown as Gabor signal frames) appearing 7.3° on the left and right of fixation. The one- or two-character instruction (e.g., "PO" for phase and then orientation judgments) appeared with the fixation mark. The central arrow indicated the object location of the first (or only) response; it appeared prior to the signal stimulus and remained until response.

Seven signal contrasts measured the psychometric functions for each report condition in two external-noise conditions (no noise and high noise). Report conditions (1O1R-P, 1O1R-O, 1O2R-PO, 1O2R-OP, 2OSR-PP, 2OSR-OO, 2ODR-OP, and 2ODR-PO, where O = orientation and P = phase) were blocked separately. The object to be reported (single-object conditions) or reported first (dual-object conditions) was cued randomly on each trial. Single-object blocks had 168 trials; dual-object blocks had 84 trials, but two copies were run, yielding 168 trials. This equated the number of trials per condition. Blocks were suitably rotated in order to balance testing order for conditions.

Each observer completed 11 experimental sets. Data from the 2nd to the 11th experimental sets were analyzed and are reported here. The sample sizes were 120 responses (single-response conditions) and 240 responses (dual-response conditions) per external-noise and contrast condition.

Experiment 2 tested whether our findings generalized to the simplified response situations typical of the original object attention studies (e.g., Duncan, 1993b). Experiment 2 was identical to Experiment 1 except that (a) only a single signal contrast, the intermediate contrast for each psychometric function of Experiment 1, was tested and (b) individual observers participated in a particular report-order condition, so that the response structure for each observer was simplified.[1] Report orders were balanced over subjects for 24 subjects, each participating for two sessions.

Stimulus

On each trial, two patterns, each consisting of a signal frame and (optional) noise frames (48 × 48 pixels, or 2° × 2°), appeared 7.3° to the left and right of fixation (see Fig. 1b). Signal stimuli were Gabor patterns (spatially windowed sine waves) varying in orientation (top tilted to the left or right of vertical) and phase (center dark or light; Fig. 1):

$$l(x,y) = l_0\left(1.0 \pm c\cos(2\pi f(x\cos(\theta) + y\sin(\theta))) \times \exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)\right).$$

The orientation, θ, was ± 4° from vertical; the spatial frequency, *f*, was 1 cycle/deg; and the standard deviation of the spatial window, σ, was 0.75°. Values of θ and σ were chosen to titrate task difficulty and approximately equate the orientation and phase judgments. The value l_0, is the neutral (background) luminance. On the basis of pilot data, we selected values of *c*, the maximal Gabor contrast, that would yield full psychometric functions. The external-noise frames were created by taking independent samples of 2 × 2 pixel (0.083° × 0.083°) noise from a Gaussian pixel noise distribution with a mean of zero and standard deviation of 33% of the maximum achievable contrast (100%). Signal and noise frames were combined via temporal integration (noise-signal-noise).

Apparatus

Signal and noise frames were computed on-line and displayed by a Power Macintosh 7300/200 on a Nanao monitor (P4 phosphor; refresh rate = 120 Hz) with two 8-bit video output channels combined to produce 6144 distinct gray levels (12.6 bits). A psychophysical procedure was used to linearize the luminance range. The minimum, maximum, and background luminance values of the monitor were 1 cd/m^2, 50 cd/m^2, and 25 cd/m^2, respectively. Displays were viewed binocularly at a viewing distance of approximately 70 cm in a dark room.

Procedure

A block cue indicating report condition (e.g., "OP" for orientation and phase) appeared above the fixation point at the beginning of each new block, followed by five practice trials. The display sequence of each trial was as follows: a 333-ms fixation display consisting of a central fixation point, one- or two-letter instruction, and two outline squares marking the location of the two Gabor patches; a 183-ms precue display with a central arrow pointing to the left or right; a 50-ms noise (or blank) display; a 50-ms signal display; a 50-ms noise (or blank) display; and a poststimulus cue display identical to the precue (until the first response). Observers responded by pressing keys on a computer keyboard. For orientation judgments, "d" indicated "top tilted left" and "f" indicated "top tilted right" for the left object; the corresponding responses for the right object were "j" and "k." For phase judgments, "d" indicated "center black" and "f" indicated "center white" for the left object; again, the corresponding responses for the right object were "j" and "k." In this arrangement, the left hand responded for the left object, and the right hand responded for the right object.

Observers

Three observers, naive to the purpose of the experiment, were paid for their participation in Experiment 1. Twelve paid observers participated in Experiment 2. All observers had normal or corrected-to-normal vision.

RESULTS

In Experiment 1, 16 seven-point psychometric functions were measured for each observer. Figure 2 shows the average psychometric functions for orientation and phase judgments in the no-noise condition and high-noise condition, as well as smooth curves from the best-fitting Weibull functions.[2] These results are representative of the data of the 3 individual observers.

The signal contrast thresholds at 75% accuracy (Table 1) for the average data provide an assessment of the contrast necessary to achieve the same performance level for the different conditions. Contrast thresholds also provide a basis on which to quantify the size of differences between conditions.

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[1] The advantages of the report structure in Experiment 1 include (a) within-subjects design; (b) control of eye movements; (c) elimination of location uncertainty by the precue; (d) counterbalancing of left and right positions of all tests; (e) balancing of orders of judgment for each response type; and (f) fully consistent response mappings both for category decisions and for spatial consistency. In contrast, the classical dual-object report experiments that simplify the response structure for individual observers but counterbalance over observers often yield on one or more of these points.

[2] The Weibull function is $p = min + (max - min) \times (1 - 2^{-(x/\alpha)\wedge\beta})$, where *p* is the correct percentage, *x* is the contrast level, *min* is the correct percentage at chance level (.5 in the current experiment), and *max* is the asymptote level. The four psychometric functions in either high or low noise were simultaneously fitted with a system of Weibull equations with four α (location) parameters (one per condition), four *max* (maximum) parameters (one per condition), and a single shared β (slope) parameter, with r^2 for each individual curve greater than .9. Additionally allowing β to vary did not improve the quality of the Weibull model fits. The 75% thresholds are interpolated from the Weibull model.

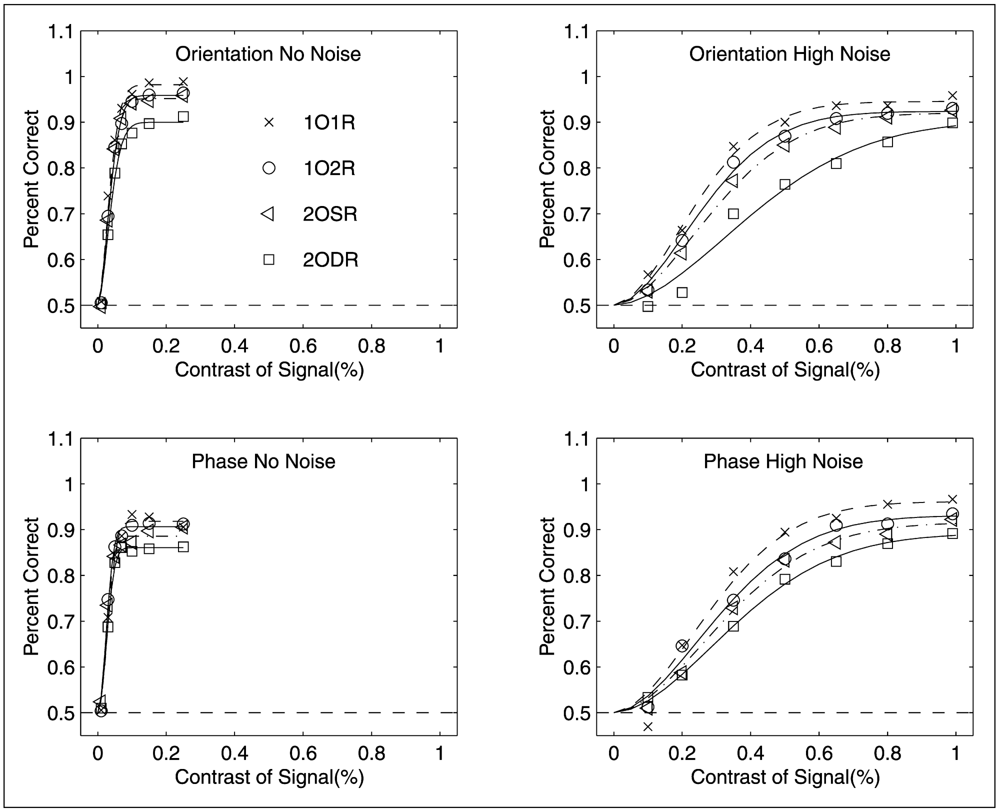

Fig. 2. Psychometric functions, averaged over observers, for orientation (top) and phase (bottom) judgments, for zero-noise (left) and high-noise (right) conditions. In each graph, separate psychometric functions are shown for the four conditions: single-object, single-response (1O1R); single-object, dual-response (1O2R); dual-object, same-response (2OSR); and dual-object, different-response (2ODR). The smooth curves are Weibull functions fit to the psychometric functions.

According to the object attention view, each of two responses to a single object should be as accurate as the corresponding single response to a single object. To test this hypothesis, we compared psychometric functions for the 1O1R and 1O2R conditions by comparing the fit of two independent Weibull models with the fit of a single (identical) Weibull. Table 2 shows the chi-square values (based on nested likelihood ratio tests,[3] Borowiak, 1989) for the model comparisons for the average data. The psychometric functions for 1O1R and 1O2R conditions were nearly equivalent. Our more sensitive tests reveal very small decrements for dual responses within a single object not obvious in previous data (e.g., Duncan, 1984), but nonetheless are generally consistent with the object attention hypothesis.

According to the object attention theory, making two responses to a single object is privileged relative to making two responses to two different objects (1O2R vs. 2ODR). In this comparison, the two required judgments were the same (an orientation and a phase judgment). The psychometric functions showed higher accuracy for the 1O2R condition than for the 2ODR condition across a range of stimulus contrasts and accuracy levels (Table 2). The magnitude of the dual-object deficits was relatively large in the high-noise condition. In high noise, the dual-object load increased the magnitude of contrast

Table 1. *Average signal contrast thresholds at 75% accuracy*

	No external noise		High external noise	
Condition	Orientation judgment	Phase judgment	Orientation judgment	Phase judgment
1O1R	.0351	.0365	.266	.308
1O2R	.0379	.0319	.300	.352
2OSR	.0369	.0318	.339	.374
2ODR	.0393	.0333	.472	.407

Note. 1O1R = single-object, single-response condition; 102R = single-object, dual-response condition; 2OSR = dual-object, same-response condition; 2ODR = dual-object, different-response condition.

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[3] The likelihood ratio test statistic for a fuller and a nested reduced model is $\lambda = [RSS(\text{full})/RSS(\text{reduced})]^{n/2}$. Corresponding to this equation, $-2\ln\lambda = n\ln[(RSS(\text{reduced})/RSS(\text{full})]$ is distributed as χ^2 with degrees of freedom $k(\text{full}) - k(\text{reduced})$, where n is the number of data points, $k(\text{full})$ and $k(\text{reduced})$ are the number of free parameters of the models, and RSS is the residual squared errors, or $1 - r^2$ for a model.

Table 2. *Likelihood ratio comparisons of conditions*

	No external noise		High external noise	
Comparison	Orientation judgment	Phase judgment	Orientation judgment	Phase judgment
1O1R vs. 1O2R	6.221†	3.931	12.415†	1.602
1O2R vs. 2ODR	19.659**	20.812**	25.650**	22.523**
1O2R vs. 2OSR	0.842	4.383	10.992*	7.401†
2OSR vs. 2ODR	20.813**	13.812*	20.122**	17.600**

Note. The values shown represent the likelihood ratio test, χ^2 with 3 degrees of freedom. Significant differences between pairs of conditions were tested using a likelihood ratio test comparing nested full and reduced Weibull models for the two psychometric functions. 1O1R = single-object, single-response condition; 1O2R = single-object, dual-response condition; 2OSR = dual-object, same-response condition; 2ODR = dual-object, different-response condition.
$^{\dagger}p < .1$. $^{*}p < .05$. $^{**}p < .01$.

Table 3. *Proportion correct identification in Experiment 2*

	No external noise		High external noise	
Condition	Orientation judgment	Phase judgment	Orientation judgment	Phase judgment
1O1R	.93 (.02)	.88 (.03)	.86 (.02)	.79 (.03)
1O2R	.90 (.02)	.86 (.03)	.84 (.02)	.76 (.03)
2OSR	.88 (.02)$^{\text{n.s.}}$	.86 (.02)$^{\text{n.s.}}$	.82 (.02)$^{\text{n.s.}}$	.73 (.02)$^{\text{n.s.}}$
2ODR	.80 (.03)**	.76 (.03)**	.74 (.03)**	.69 (.03)**

Note. Standard errors of the proportions, averaged over observers, are shown in parentheses. Results of *t* tests ($df = 22$) are shown for comparisons of the baseline condition, one-object, dual-response (1O2R), with the dual-object, same-response (2OSR) condition and the dual-object, different-response (2ODR) condition. 1O1R = single-object, single-response condition.
$^{**}p < .01$.

thresholds (Table 1) by 57% for orientation judgments (contrasts of .30 vs. .47) and by 16% for phase judgments (.35 vs. .41); in no noise, the magnitude increased by 6% for orientation judgments (.038 vs. .039) and by 4% for phase judgments (.032 vs. .033). These results replicate the previously reported object attention effect for basic feature dimensions in a psychophysical task across the psychometric function. Previous researchers (Duncan, 1984, 1993a, 1993b; Duncan & Nimmo-Smith, 1996), who used poststimulus masks and one signal contrast level with performance typical of accuracies in the middle of a psychometric function, found object attention deficits on the order of an 8% reduction in percentage correct. The size of the current dual-object deficits average reductions of 11% correct for orientation and 8% correct for phase judgments for high-noise conditions in central regions of the psychometric functions.

The results showed that the size of the dual-object attention effect is substantially larger in masked conditions than in low-noise conditions, even when difficulty, as measured by performance accuracy, is matched. This suggests an important role of focused object attention in noise or mask suppression. Integration noise masking (e.g., Dosher & Lu, 1998; Lu & Dosher, 1998) and the poststimulus noise masking of previous studies (e.g., Duncan, 1984) seem to operate nearly equivalently in relation to object attention, which is consistent with the similarity between the two in other attention domains (Dosher & Lu, 2000b).

Comparison of the 1O2R and 2OSR conditions showed that accuracy was statistically equivalent in the two conditions or differed only slightly, whereas the 2ODR condition showed significant reporting deficits relative to the 2OSR condition. This pattern was especially obvious in the orientation judgments. The primacy of object attention as an explanatory principle implies an important corollary of analyzer independence (Duncan, 1984, 1993a, 1993b; Duncan & Nimmo-Smith, 1996). Substantial compatibility effects offset object attention effects in the judgment of basic stimulus dimensions of orientation and phase, counter to earlier claims.

Experiment 2, in which dual-report orders were counterbalanced across rather than within observers, simplified the response demands for any single observer. Discrimination accuracy (percentage correct) was measured only at the intermediate contrast level for zero and for high noise, for both orientation and phase judgments. The results (Table 3) closely replicate those of Experiment 1: Accuracy was significantly lower in the 2ODR condition than in the control 1O2R condition and in the corresponding 2OSR condition; accuracy in the latter two conditions was quite similar. This replication suggests that details of the response arrangements were not a significant factor in the results of Experiment 1.[4]

Full analyses of the contingency between first and second responses were carried out for the dual-response conditions of Experiment 1. The two responses were typically statistically independent, and this was equivalently so for the 2ODR and the 2OSR conditions. If there had been direct trade-offs on a trial-by-trial basis between performance on the first and second responses, one would have expected to see a contingency. If the 2ODR condition had been uniquely difficult and thus more susceptible to direct trade-offs, this should have generated dependencies in 2ODR trials. Neither effect occurred.

DISCUSSION

This study evaluated object attention effects using full psychometric functions in a psychophysical task with basic, low-level, stimulus dimensions. Two features for the same object were reported with little or no loss in report accuracy. Two features of two different objects were reported significantly less well than the same two features of a single object. This dual-report deficit reliably occurred only when two different features of two objects were reported. The dual-object deficits in the high-noise condition in these experiments was as large as or larger than the dual-report deficits originally reported with postmasks. Thus, substantial dual-report deficits occur even for basic visual features that are coded very early by the visual system (Graham, 1989). Critically, however, the object attention deficit was small or nonexistent in the case of identical judgments for the two objects.

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[4] The similarity of the size of the object attention effect in zero and high noise in Experiment 2 may reflect differences in the overall accuracy levels in the two conditions, which in turn reflect a selection of contrasts in the zero- and high-noise conditions that did not exactly match accuracy in the set of observers.

Previously, it has been argued that object attention limitations themselves are paramount, and that judgment similarity is not functionally important in object attention effects. In studies (Duncan, 1993a, 1993b; Duncan & Nimmo-Smith, 1996) that explicitly contrasted same judgments and different judgments, however, the same judgments were never identical. Instead, they involved different tokens on the dimension, often requiring different reference frames, different judgment criteria, or different response mappings. For example, Duncan (1993a) had observers report the location of the stimulus in a surrounding box or the orientation of a stimulus—and explicitly compared cases with two orientation judgments or two location judgments with cases with one orientation and one location judgment. However, the two location judgments required a horizontal reference in one case (up/down) and a vertical reference in the other (left/right), and the orientation judgments were made relative to a horizontal axis (clockwise/counterclockwise of horizontal) in one case and a vertical axis (clockwise/counterclockwise of vertical) in the other. Thus, two location judgments and the two orientation judgments both required judgments relative to different reference frames and used different response mapping. Duncan also asked subjects to make dual-shape judgments, discriminating, for example, *E* and *F*, and *G* and *C*. Therefore, although both letter judgments were labeled shape judgments, the judgments themselves were not the same (*E* vs. *F* and *G* vs. *C*).

In other cases, when apparently equivalent feature values were used, we nonetheless believe that different judgment frames were required. In Duncan's (1993b) Experiment 1, for example, they judged whether two letters were in the same font size, but although the font sizes were nominally the same, the judgments involved different letter stimuli (*C* vs. *G* and *E* vs. *F*); in other cases, the same nominal length judgments were required, but one length was horizontal and the other vertical. Indeed, our review of the literature suggested that the current study is the first case in which the dual-report deficits in object attention have been evaluated using strictly equivalent judgments. The critical result that identical judgments about different objects show very small to nonexistent object attention effects suggests a foundational reframing of object attention deficits.

An argument that dual-object deficits are eliminated in same-judgment conditions because the two objects are perceived as a single object appears to be circular. Furthermore, the theoretical position that capacity limitations operate with simultaneous demands on a given feature processor (Allport, 1971; Wickens, 1971) does not apply, because this predicts that the different-judgment conditions should be the more accurate. Instead, the observation that dual-report deficits are largely restricted to dual-object, different-judgment conditions may be related to recent reports that rule activation associated with switching between different tasks has a measurable cost within an executive processing model (Rubinstein, Meyer, & Evans, 2001, see also Sperling & Melchner, 1978; Tse, Lu, & Sperling, 2000).

We suggest that reduced dual-object report deficits in same-judgment cases may constitute a fundamental boundary condition on object attention effects with substantial practical implications. Further work should extend this finding beyond the domain of judgments of basic visual features. Because we did not find robust dual-object report deficits in same-judgment conditions for spatially separated objects in the present study, we speculate that dual-object report deficits would also not occur for object features or object parts, rather than the objects themselves (Vecera et al., 2000, 2001).

Another major finding concerns the phenomenology of the deficits. Previous studies of object attention dual-report deficits (e.g., Duncan, 1984) used a high-contrast postmask. The role of the mask was presumably to reduce performance with the high-contrast stimuli to a measurable level. In our psychophysical task, contrast reduction can calibrate performance even in the absence of noise (masks), and can equate performance (accuracy) for both zero-noise and noisy conditions. Several recent theoretical frameworks have proposed that attention may serve a special function in the elimination of noise or masks (e.g., Dosher & Lu, 2000a, 2000b; Enns & Di Lollo, 1997). The current results suggest that focal attention to a single object indeed plays a key role in the exclusion of noise, and has a small effect in the absence of noise masks. The average magnitudes of the (different-judgment) dual-report deficits, when measured in terms of contrast threshold reduction, ranged from 16 to 57% in high noise, and from 4 to 6% in zero noise. These results have special significance within a recently developed perceptual template model of perceptual attention (Dosher & Lu, 2000b; Lu & Dosher, 1998). This model distinguishes between two independent mechanisms of attention: template retuning to exclude external noise (reduce the effect of masking) and stimulus enhancement (improvements in the absence of masks). The current results suggest that both these mechanisms operate in object attention, and that external-noise exclusion is the dominant mechanism. A related parametric manipulation of external noise and quantitative model evaluation, reported elsewhere (Han, Dosher, & Lu, 2001), supported this analysis.

Certain theorists might prefer to reframe the current results in relation to dual-task limitations in sharing attention across distal regions of space. Under such a framework, an analogous set of conclusions would hold: The existence of dual-report deficits for features from distal regions of space, a critical reduction or elimination of dual-report deficits for the report of the same features from two distal regions, and the larger effects in high-noise (masked) conditions than in no-noise conditions suggest that focalized attention has an important function in the exclusion of noise. However, it has been argued that object attention effects are similar when the objects occupy close or overlapping regions of space and when the objects occupy distal regions of space (e.g., Baylis & Driver, 1993; Vecera & Farah, 1994). In contrast, Davis, Driver, Pavani, and Shepherd (2000) reconceived the dual-object report deficit as reflecting the spatial distribution of attention, controlled by object boundaries. Our conclusions could be restated in terms of the costs of sharing attention over two distal locations instead of the costs of sharing attention over two objects, if a spatial-attention interpretation is preferred to an object attention interpretation.

Further investigation of this point requires more complex hierarchical definitions of spatially extended objects in which spatial factors are equated (e.g., Watson & Kramer, 1999). In this study, we focused on object stimuli that are matched to the hypothesized analysis of visual inputs by the early visual system. Davis et al. (2000; see also Davis, 2001) have claimed that dual-report deficits may be eliminated when the regions of spatial attention of a single object and dual objects are equated; this may provide another boundary condition on dual-object deficits.

For the basic visual judgments studied here, the magnitudes of the object attention deficits are determined by the division of attention over two objects and the nature of the reference frame, judgment criteria, or response mapping, as well as the amount of external noise masking the display. Division of attention over objects is not sufficient to yield large dual-report deficits if the judgments are identical, and judgments of quite different properties are not sufficient to yield dual-report deficits if attention is not divided over objects.

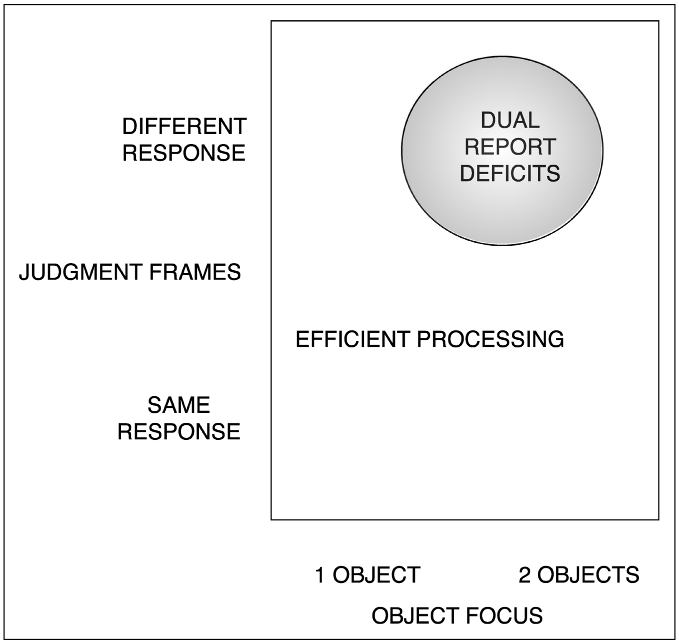

Fig. 3. Boundary conditions on dual-report deficits. Dual-report deficits may occur only when two objects are judged for two different response features. Two responses to a single object or the same response to two objects may not necessarily reduce performance relative to a single judgment about a single object.

Both factors are important in determining the magnitude of a dual-report deficit (see Fig. 3). The larger magnitude of object attention limitations in high-noise, or masked, conditions than in no-noise conditions implies a functional role of object attention in noise or mask suppression.

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