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THE ROLE OF HIGHLIGHTING IN VISUAL SEARCH THROUGH MAPS

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An experiment was conducted in which participants performed a simulated vehicle dispatching task using a map display with two information domains. The intensity of one information domain was varied to examine the effect on processing the information in a cluttered display. Response times were recorded for questions either requiring focused attention on a particular information domain or divided attention between the two information domains. The results of the present experiments indicate that it is possible to "declutter" a display without erasing any information. By "lowlighting" one information domain and keeping the other domain at a fairly high intensity level, performance on tasks requiring divided attention is optimal, as is performance on tasks requiring focused attention to one domain exclusively. These results are also discussed in conjunction with a computational model of the effects of discriminability and salience on performance in a cluttered display with variable intensity codings used to visually segregate different domains of information.

Maps are often subject to perceptual challenges related to clutter. When viewing a map to extract explicit information necessary to answer a question, it can become difficult to parse out the relevant information—to extract what is needed from the clutter. In fact, when more information is present in the display, the time it takes to find even a single element in the display increases linearly with the amount of clutter (Kroft & Wickens, 2003; Yeh and Wickens, 2001), in a manner consistent with serial models of visual search. However, many investigations of visual search in basic research have ignored search in the map domain, even though most map usage involves some kind of visual search to extract the necessary information (Kroft and Wickens, 2003; Remington, Johnson, Ruthruff, Gold, & Romera, 2000); Wickens 2000; Yeh & Wickens, 2001).

When extracting information from a map to answer such questions as "where is Z" or "how far is it between X and Y" or "will I need to cross a river to get from A to B", the focus of attention may be on a particular "domain" of information within the display, or attention may need to be divided between two separate information domains if mental integration or comparison is required, as with the latter two questions above.

One obvious way to reduce the penalty of increased clutter in a map search is to increase the visual salience of particular domains of information when they are required for processing. Increasing the salience of certain items can result in the direction or "capture" of attention to those items in a very rapid manner, providing an immediate benefit to search if the salient item(s) happens to be a search target (Fisher & Tan, 1989; Posner & Snyder, 1975). In addition, the use of salience to create items that are more discriminable from non-salient ones can also serve to help "segregate" the display and aid in the pre-attentive grouping of similarly-featured items (Treisman 1988; Treisman & Gelade, 1980). These "grouped" items can then aid search, as users can then search only the group likely to contain the target as well as use the feature grouping to serve as landmarks to mark items or locations in the display which have already been searched (Fisher & Tan, 1989).

Our current research is based on the hypothesis that intensity coding, of information in a map display (e.g., backgrounding, highlighting, lowlighting) can aid in map processing by imposing a dual influence on attention and information processing. First, intensity **differences** between classes of information can accomplish the above-mentioned segregating/organizing function (although intensity similarity between classes may disrupt the segregating function due to perceptual confusion). Second, increasing intensity will increase the **salience** and attention-capturing properties of items. Very few studies have examined these issues in an applied context. Yeh and Wickens (2001) found only a marginally-significant trend for brighter items among dim items to be found faster than dimmer items among bright items. Johnson and colleagues (Johnson, Jordan, Liao, & Granada, 2003; Johnson, Liao, & Granada, 2002) found that the discriminability of dim items was hurt in a bright context compared to a dim context, but the discriminability of bright items was equivalent across both contextual intensities. From these results, we hypothesize that search among a highlighted (brighter) class of items will be more efficient than search among lowlighted (dimmer) class of items. However, no study has systematically investigated the interaction of intensity differences and salience in a map search task, nor are there apparent efforts to capture the joint influences of salience and discriminability on information processing in a map display, in a manner analogous to approaches by Fisher and his colleagues on searching through highlighted menus (Fisher, Coury, Tengs, & Duffy, 1989).

The studies mentioned above have examined only the issue of focused attention within a class of items. If attention must be *divided* between two classes of information, one highlighted and one lowlighted, in order to answer a question, two competing predictions can be offered. The proximity compatibility principle (Wickens & Carswell, 1995), which states that mental integration of items is aided by their perceptual similarity (defined by location, color, contrast, organization, etc.), would predict that responses to such divided attention questions would be hindered by segregated displays and performance would be best when the two groups are presented at a uniform intensity. This prediction was upheld when similarity was created by spatial proximity for the to-be-integrated items (Kroft & Wickens, 2003, O'Brien and Wickens, 1997), but not when it was created by intensity similarity (Yeh & Wickens, 2001). A contrasting prediction is that the *benefits* gained from reducing clutter through segregation of the items in the display into different groups would overshadow any penalties of these differences for integration. Furthermore, as both classes (highlighted and lowlighted) of information are utilized in answering a divided attention question, the salience benefit for the highlighted class can offset the low-salience cost of the lowlighted class, producing an effect dependent only on the inter-group discriminability, an effect favoring intensity differences

In the current experiment, we examine the effects of intensity coding (highlighting and lowlighting) in a simulated vehicle dispatching task involving two disparate domains of information. One domain is always presented at a constant intensity level, while the other domain is presented at varying intensities. The latter is displayed in four conditions: two "lowlighting" conditions with intensities much below and slightly below the constant level, a control "clutter" condition in which the intensity of both domains is equivalent, and a fourth "highlighting" condition where the intensity of the varied domain is brighter than the intensity level of the constant domain. Figure 1a provides a schematic representation of the four intensity levels.

A COMPUTATIONAL MODEL

We predict that performance on tasks which depend on these domains of information will be an aggregate function of the two influences described above, **discriminability** and **salience**, whose influence varies with the intensity of the varied domain of information.

The role of **discriminability** in aiding the focus of attention on one domain of information will aid search to the extent that the particular domain is perceptually discriminable from the other. So, the cost of low discriminability to the response time on tasks requiring focused attention on one particular domain of information should resemble the inverted V-shaped function shown in Figure 1b. To the extent that discriminability is a continuous function of intensity differences, this cost will be greatest when both domains are presented at equal intensities and should decrease with an increasing difference between the two intensity levels.

The discriminability cost should be born equally on tasks requiring focused attention on either the constant or the varied domain. However, the effect of **salience** should result in opposing functions for tasks requiring focused attention on the constant and varied domains, as the ability to focus attention on the constant domain should decrease as the intensity of the varied domain increases, resulting in an increasing penalty to reaction time, as the varied domain information captures attention due to its increasing salience (see Figure 1c). Intuitively then, the increasing salience of the intensity domain should result in a better ability to focus attention on that domain, producing a downward trend in reaction time, as the intensity level increases (see Figure 1d).

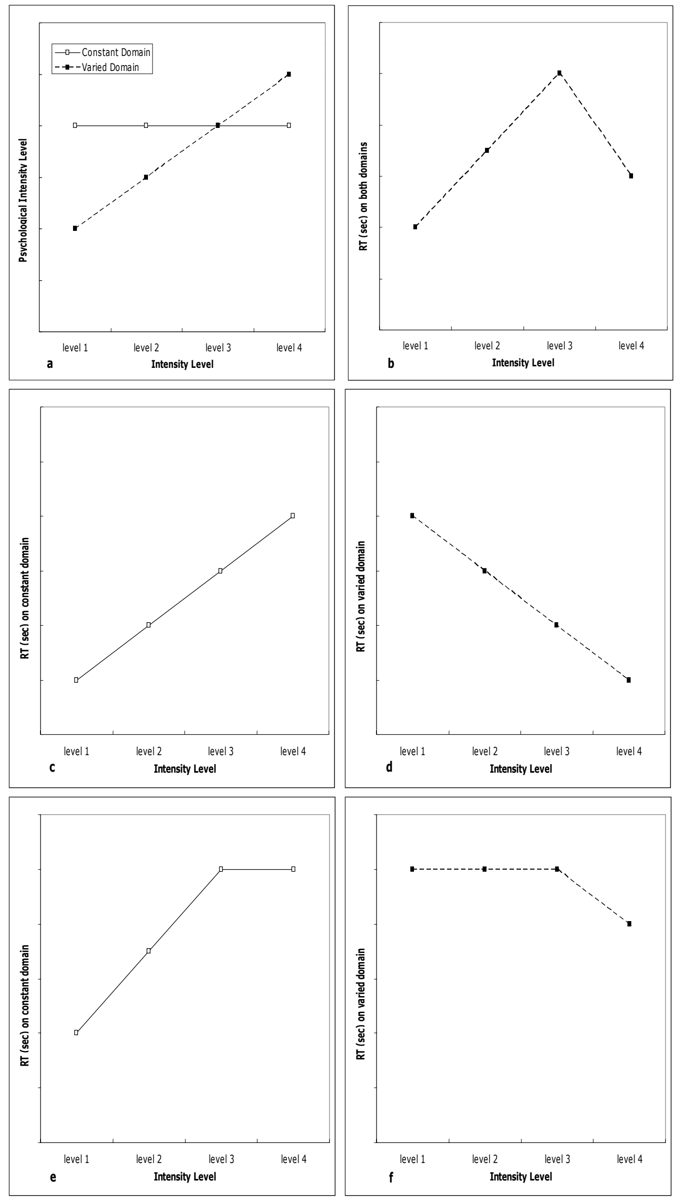

Figure 1. All graphs depict an effect (measured in RT) across the 4 intensity levels used in the studies. (a) The psychological intensity levels used in the experiment, where the open boxes (and solid lines) depict intensity of the constant domain, and the black boxes (and dashed lines) depict that of the varied domain. (b) The expected cost function for the influence of discriminability on both the constant and varied domains. (c) The expected cost function for the influence of salience on the constant domain. (d) The expected cost function for the influence of salience on the varied domain. (e) The combined cost function for the two influences on attention on the constant domain. (f). The combined cost function for the two influences on attention on the varied domain.

An aggregate of the two functions described should produce a pattern of results of focused attention to the constant and varied domains shown in Figures 1e and 1f respectively, assuming that there is an equal and additive relationship between the two psychological influences. However, the actual pattern of results may not be this simple for two reasons. First, the effects described may not be linear—smaller differences in intensity (i.e., between levels 2 and 3) may be sufficient to reach ceiling on the guidance of attentional focus and thus, no further difference will produce a benefit. Second, it is difficult to determine ahead of time whether or not the two influences will have an equal impact on processing (e.g. equal slopes in the figure) as the intensity level is varied. If the two influences are not equal in their impact, it will be hard to ascertain their true net effect when they are working in opposite directions, as is the case for the two brightest intensities for the constant domain task in Figure 1e, and for the three lowest intensities for the varied domain task in Figure 1f. A beneficial outcome of these uncertainties, however, is that it is possible to find an optimal intensity difference which can maximize performance on one task while providing a minimum cost to performance on the other.

In the current experiment, we examine how well users can answer questions about dispatching vehicles (by estimating distances between objects) within a grid-like map structure. The questions either require focused attention to either of two domains (**vehicles** or **destinations**) within the map or require the integration of information (divided attention) across both domains. In this experiment, the vehicle intensities varied at the 4 levels while the destinations were always presented at intensity level 3.

METHODS

Participants

Participants were 24 undergraduates with normal or corrected-to-normal vision who were paid $5 for their participation.

Apparatus

A Silicon Graphics IRIS 4-sight Window System was used to produce the simulation of a city map on a 16" monitor. The four intensity levels, used for the varied domain, measured with a photometer were: 3.28 x 10-2 fL for intensity level 1, 8.09 x 10-1 fL for intensity level 2, 1.74 fL for intensity level 3 and 3.89 fL for intensity level 4. The intensity level of the constant information domain was the same as that of level 3 (1.74 fL). All information was projected on a completely black background.

Task

The task simulated the task of a vehicle dispatcher. A map presented various domains of information--streets, buildings, destinations (the destination domain information) and vehicles (the vehicle domain information), that were to be dispatched to different destinations. Subjects were asked to infer distances between various items on the map (see Figure 2 for example maps used in the study). The distances to-be-inferred either dealt only with vehicles or destinations (focused attention questions) or required some integration of information from both the vehicle and destination domains (divided attention questions).

The vehicles were symbolized by circles and the destinations by squares. Each trial had 9 target vehicles, labeled 1 through 9, and 9 target destinations, labeled A through I. The map also contained 12 non-target vehicles, represented by circles containing the letter X instead of a number and 12 non-target destinations, represented by squares containing an * instead of a letter. The 24 non-target items were not task-relevant and were simply present to provide additional visual clutter in the display.

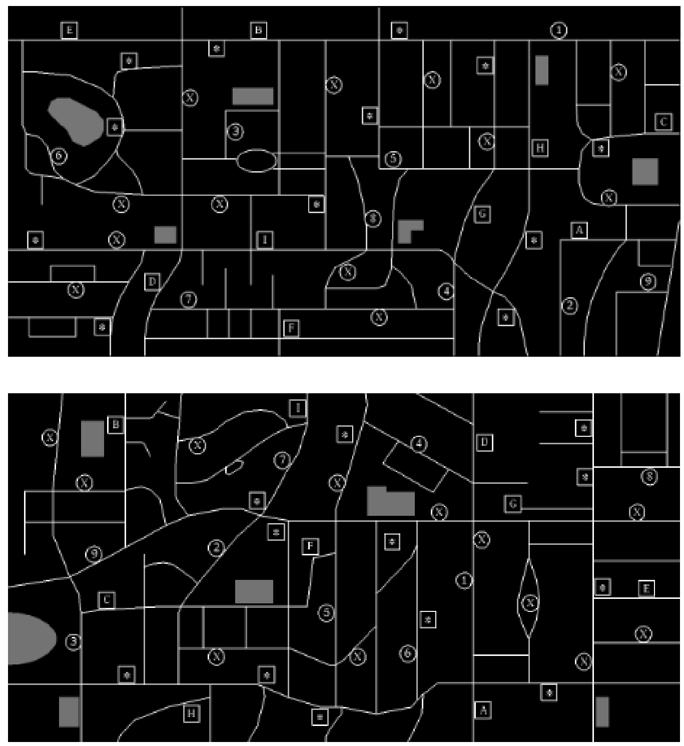

Figure 2. The two maps with each an example of the way vehicles (numbers in circles), destinations (letters in squares), their distractors (X's in circles and∗'s in squares respectively), and the buildings could be presented on the map. In these figures, characters are presented as negative, meaning that the dark items were light in the display and vice versa. In these particular renderings, the both vehicles and destinations are presented at the same constant intensity (level 3).

Each subject participated in a total of 24 blocks of trials. These were defined by 2 maps which were crossed with the 4 intensity levels, created by modulating the brightness of the varied domain, and the 3 question types: focused attention on the constant domain, focused attention on the varied domain, and divided attention between these two domains. Focused attention questions were of the form "which vehicle is closest to vehicle 1" or "which destination is closest to destination E" while divided attention questions were of the form "is vehicle 3 closer to destination C than to destination D." Each block contained between 6-12 questions of the appropriate type.

The constant domain was always displayed at the second highest level of intensity: level 3. Subjects were instructed to respond as quickly and accurately as possible.

RESULTS

Our analysis of the results asked 3 distinct questions. First, what effects, if any, were there across intensity levels for each of the 3 question types? Second, did the qualitative pattern predicted by the additive model, match the actual pattern of results, as both predicted and obtained data sets are presented in figure 3? And finally, how well does the obtained data match any version of the model?

ANOVAs performed on response time for the three difficult question types, revealed a significant main effect of intensity on focused attention for the constant domain ($F(3, 21) = 3.45$, $p = .03$; Figure 3a), on focused attention for the varying domain ($F(3, 21) = 9.53$; $p = .02$, Figure 3b) and on divided attention ($F(3, 21) = 3.40$, $p = .04$, Figure 3c). As predicted, performance for the focused attention questions on the constant domain declined (RT increased) with increasing intensity level. However, the results obtained for performance on the focused attention questions on the varied domain did not match the model predictions as well, with performance on intensity levels 1 and 2 better (faster RT) than expected. That is, in the predicted tradeoff between intensity and discriminability, the better discriminability of levels 1 and 2, more than offset the costs of the lower intensity. Finally, performance on the divided attention questions matched the predicted pattern of results fairly well. There were no effects of intensity on accuracy, so the pattern of results did not reflect a speed accuracy tradeoff between conditions, and as such, there will be no further discussion of the accuracy results.

There was a reasonable match between the model predictions (discussed above in the introduction), and the obtained, significant variance in the measured RT. Analysis of the data, however, revealed several distinct differences between the predicted and observed patterns of results. For the constant domain questions, there were smaller benefits than predicted at intensity level 1. For the varied domain questions, there were also smaller costs than predicted at intensity levels 1 and 2, as the model had predicted equally poor performance for these questions at all intensity levels but the highest. The final discrepancy lies with the divided attention questions where there is no benefit (as predicted) at level 4 compared to level 3, when the model predicts a benefit.

To quantify the model's performance, we correlated the predictions from the equal-weighting (of both the intensity and discrimination functions) model with the obtained data. These correlations, each based upon 4 data points, are shown as the bold faced numbers in the leftmost column of Table 1.

Further examination of the data suggested to us that performance might have been more influenced by discrimination than by the visual salience of the intensity. As one example, for the varied domain questions, while the equal

Table 1

Correlations of Model Predictions with Obtained RT Data

Weighting:	Equal	2:1
Focused constant	**+0.96**	0.92
Focused variable	+**0.08**	0.56
Divided Attention	+**0.99**	0.97

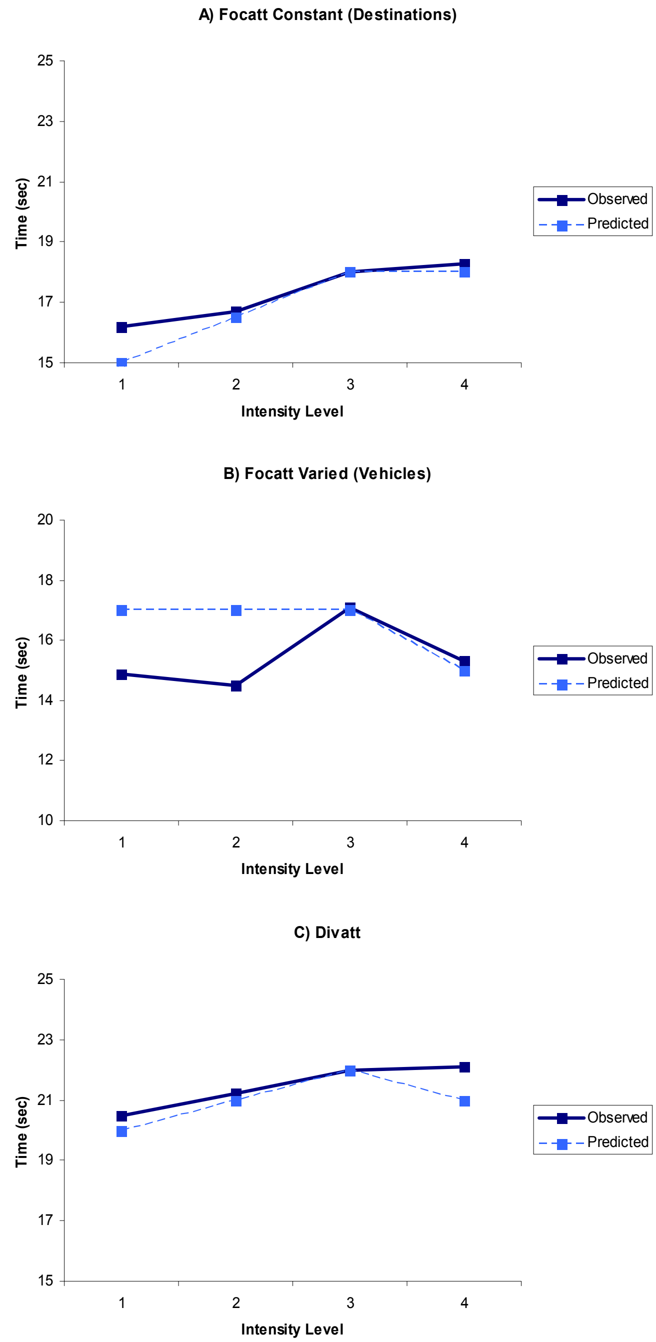

Figure 3. a) Observed vs. predicted values for the focused attention questions on the constant domain. b) Observed vs. predicted values for the focused attention questions on the varied domain. c) Observed vs. predicted values for the divided attention questions

weighting model would predict an offsetting effect of a discrimination advantage and a salience cost for levels 1, 2, and 3, as noted above the data revealed that the discrimination benefit dominated the salience cost (producing the better than predicted performance at intensity levels 1 and 2, where a discrimination benefit could be observed, compared to level 3, where there is no segregation of the two domains). Hence the model fits were repeated with a weighting of 2:1 for discriminability relative to salience (intensity), and these correlations are shown lowlighted, in the right columns of Table 1. We noticed that in the weakest case predicted by the model (the focused attention questions on the varied domain), the model fit was improved substantially under this new weighing scheme, and the correlations for the other two models diminish only slightly. Hence, it appears that discriminability/confusability is a more powerful influence than salience on performance in a task requiring integration between or focused attention on multiple domains of information in a display.

CONCLUSION

From an applied perspective, the present data suggest that it may be possible to achieve the "best of both worlds" in design, by using intensity coding to support focused attention, since intensity differences appear to support both focused and divided attention in a map display. The model fit offered by the 2:1 weighing of discriminability relative to salience also supports the hypothesis that intensity differences between domains of information are key to producing optimal performance, counteracting the hypothesis that adherence to the proximity compatibility principle, when display proximity is defined by similarity of intensity, will result in more favorable performance (See also Kroft and Wickens, 2003).

Furthermore, the data are informative to designers in suggesting that the intensity difference does not need to be too large to achieve adequate levels of discriminability: the difference between intensity levels 2 and 3 is at least as effective as the difference between levels 1 and 3. Thus, participants in the current paradigm apparently processed any dissimilarity between intensities as a categorical difference, not a continuous difference in which a greater intensity difference is better. In addition, the fact that the level 2-3 distinction provided a greater advantage than the level 3-4 distinction reveals that the highlighted information domain should not be made "too bright"; otherwise, it might lead to distraction issues, capturing attention due to its extreme salience, when processing the dimmer member of the pair is required. Therefore, if task analysis can clearly reveal differences in the general importance and frequency of use of different information classes, then an intensity-coding scheme, in which more important information is highlighted, would seem to produce a highly effective display design, capable of supporting tasks which require both focused attention on individual information domains and the integration of information between domains.

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