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Workload is Bad, Except when it's Not: The Case of Avoiding Attractive Distractors

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Abstract

Increased cognitive workload is typically considered to hinder task performance. The current study presents an example where increased workload *aided* a visual search task. Increased workload, via a secondary task, provided participants extra time to avoid distracting stimulus configurations. Furthermore, initial fixations on distracting densities occurred at higher frequencies when initial saccades lasted less–than 400 milliseconds. We conclude that the combination of the primary visual search task and the secondary task create an environment where the secondary task was *beneficial* to the visual search task.

Introduction

There is a rich literature demonstrating how visual stimuli affect visual search patterns (Findlay, 1982, 1997; He & Kowler, 1991; McCarley, Kramer, & Peterson, 2002; Pomplun, Reingold, & Shen, 2003; Rayner, Liversedge, White, & Vergilino-Perez, 2003; Wolfe, Cave, & Franzel, 1989; Zelinsky, 1996). However, few studies have focused on how *stimulus configurations* influence eye movements. An example of a stimulus configuration is differences in inter-stimulus distance, or *density*. Stimulus density can be easily manipulated. Increasing the inter-stimulus distance decreases density, and vice-versa. There is also little research describing the effects of increased workload on visual search. Do visual search strategies change as a function of workload? In this paper, we address workload and stimulus configuration effects on visual search.

Previous research suggests that saccades are programmed and targeted in an automatic, data-driven fashion. Data-driven processes shape overt behavior via environmental factors, and are typically considered unconscious processes. There are two striking examples that suggest data-driven processes determine saccadic endpoints. The first example is the *global effect* (Findlay, 1982, 1997). The global effect occurs when saccadic endpoints land at intermediate target positions during abrupt onset tasks containing at least two stimuli. That is, when two stimuli appear to the right or left of an initial fixation point, saccadic endpoints tend to be located between the stimuli. The global effect provides evidence that global target configurations influence saccadic amplitude. It appears that saccadic processes use stimulus attributes such as spatial properties in determining endpoints.

The second example is the *center–of–gravity effect* (He & Kowler, 1991). The center–of–gravity effect indicates that saccades directed toward a shape land at consistent locations near the center of the shape, and that the shape's contour information is all that is necessary for consistent saccades. The two effects taken together suggest that the saccadic mechanism relies on spatial properties of stimuli when determining saccadic endpoints.

The amount of influence deliberate, top-down strategies have on saccadic endpoint location is still unclear. However, it is unlikely that humans solely rely on purposeful, top-down strategies when determining saccadic endpoints. He and Kowler (1991) propose a serial, two-stage process for determining saccadic endpoints that incorporates both automatic processes and intentional strategies. The two-stage process involves an initial intentional target selection, followed by an automatic weighted averaging of the shape or stimuli to determine the saccadic endpoint.

Shen, Reingold, and Pomplun (2000) demonstrated that in a conjunctive search task visual search is also affected by the cost structure of the search environment. When few same-color distractors were present, saccadic selectivity was biased towards color. However, as the number of same-color distractors increased, saccadic selectivity shifted from same-color to same-shape stimuli. This suggests that visual search may be sensitive to the soft constraints of the search space. Hard constraints arise from the types of stimuli built into the search environment, and the types of interactive behavior permitted (such as searching by color or shape). Hence, hard constraints determine which microstrategies are possible (Gray & Boehm-Davis, 2000). In contrast, soft constraints determine which of the possible microstrategies are *most likely* to be selected (Gray & Fu, 2004). When selection is non-deliberate or automatic the least effort microstrategy is chosen. Searching same-color targets when they are the majority distractor leads to higher movement latencies, higher manual response times, and more fixations than searching the minority, same-shape distractors (Shen et al., 2000).

Our research has focused on where a participant is likely to initially fixate. Initial fixations are the dwells located at the endpoint of the initial saccade. This work has uncovered an effect of stimuli density on initial fixation locations, or the *pro-density effect* (Myers, Gray, & Schoelles, 2003, 2004). As the density of stimuli increases (inter-stimulus distances become smaller), the probability of initially fixating the dense group also increases. Our work in conjunction with Shen et al. (2000) makes it apparent that stimulus features are not the only aspects of the search space considered. Rather, we have found that stimulus configurations are also important. It is likely that the results of Shen et al. (2000) and Myers et al. (2003; 2004), are solely attributable to neither data–driven nor purposeful, top–down search strategies, but are attributable to a combination of both processes.

If the determination of saccadic endpoints and initial fixation locations are not the exclusive result of top-down, purposeful processes, then taxing top-down processes in order to eliminate any purposeful search strategy will allow automatic, data-driven processes greater influence in overt behavior. Our research has demonstrated that the pro-density effect is heightened with increased workload. The pro–density effect *doubled* with an added auditory task (Myers et al., 2004). This result suggests a data–driven component when determining where to initially fixate or saccade.

In the studies conducted by Myers et al. (2003; 2004), target and density locations were completely orthogonal; as a result, dense clusters of stimuli provided no useful information of the target's whereabouts. Therefore, there was no incentive to *avoid* dense clusters of stimuli.

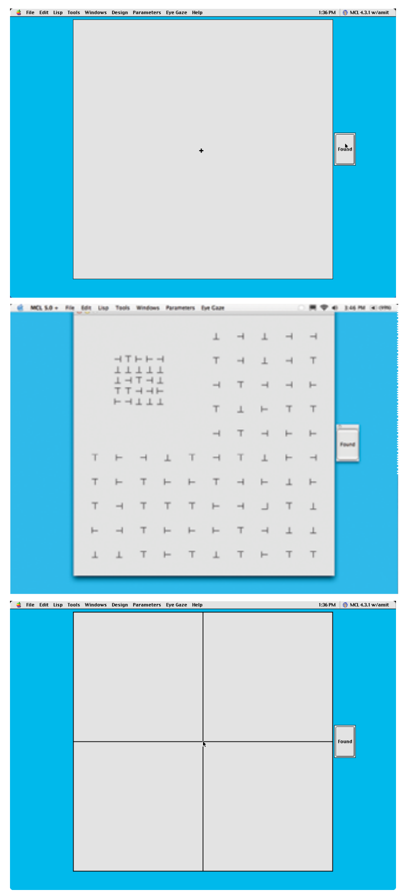
Having found a pro-density effect in previous work, the current study attempted to determine the robustness of this effect by establishing a negative correlation between dense clusters and the probability of a target being located in a dense cluster. If initial fixations still land on the dense cluster, this would suggest that the effect is determined by low–level, bottom–up process that are drawn to certain configural properties. On the other hand, if initial saccades resist the dense cluster or show an *aversion* to the dense cluster, this "anti-density" effect would suggest target location information provided by dense clusters might be incorporated into a conscious, top–down strategy such as deliberately avoiding the dense cluster. However, Myers et al. (2003; 2004) demonstrate that dense clusters are initially fixated more than chance and the number of initial fixations increases with the degree of density and added workload. Therefore, a dense cluster of stimuli is an *attractive distractor* in the current study. Workload was manipulated between participants as a dual task condition and a single task condition. Participants in the dual task condition performed two tasks simultaneously, thereby increasing cognitive workload. The single task group performed one task.

If participants were able to resist initially fixating a dense cluster, the pro-density effect would drop to at most chance levels in the single task group. This would suggest that deliberate processes are overriding the influence of unintentional, data-driven processes on overt behavior in the task environment. We also predicted no effect of degree of density (moderate vs. strong) in the single task group. For the dual task group, we predicted an increase in the pro-density effect as demonstrated in Myers et al. (2004). This would suggest that data–driven processes begin to peer through deliberate strategies in dual task, high load situations. We did not predict the pro-density effect to increase two–fold, rather that it would increase to levels significantly greater than chance. Finally, we predicted that there would be a significant effect of degree of density in the dual task condition, specifically that strong densities would be initially fixated more often than moderate densities.

Method

Participants

A total of thirty-three undergraduate students volunteered to participate. All participants had normal, or corrected–to–normal vision. Participants were randomly assigned to one of two groups. The single task group performed a visual search task, and the dual task group simultaneously performed the same visual search task and an auditory letter classification task. There were 16 participants in the single task condition and 17 participants in the dual task condition. The study lasted approximately 1 hour, and participants were run individually.



1. Fixation
2. Stimulus
3. Test

Figure 1. One visual search task trial, presented in order of from top to bottom.

Apparatus

The data collection apparatus consisted of a PowerMac G4 Apple computer running MacOS Jaguar, a 17-inch flat panel display with the resolution set to 1024 x 768, a chinrest, and an Eyegaze eye-tracking system developed by LC Technologies that measured gazepoint at a 60Hz rate.

Visual Search Task

The visual search task was composed of three different displays, each presented sequentially and in a fixed order. Each display was composed of a window and a *Found* button. An example of the task is depicted in Figure 1. The initial display was composed of a single cross hair located in the middle of the window. The cross hair was used as an initial fixation point for each trial (top, Figure 1). Once the eye tracking system determined cross hair fixation, the stimulus display appeared. The stimulus display (middle, Figure 1) contained a target (e.g., L) and distractors (e.g., T) that were randomly rotated about their axes on each trial. The stimulus display consisted of a 10x10 stimuli matrix, enabling the display to be divided into four equal quadrants of stimuli. The L was placed at the center of a randomly chosen quadrant that did not contain a dense cluster of stimuli.

The within-subject independent variable, stimuli density, varied on 3 levels: strong, moderate, and weak with an inter-stimulus distance of 0.54°, 0.97°, & 1.94° of visual angle, respectively. Each density level occurred on 33% of all trials, with quadrant location randomized for each trial. Quadrants not containing a dense cluster had an inter-stimulus distance equal to weak. (Hence, on weak density trials, all four quadrants were of equivalent density.) The L was *never* located in a dense cluster of stimuli.

Participants were instructed to find the target as quickly as possible and were aware there were only four possible target locations. On target discovery, participants clicked the 'found' button. After clicking 'found', the test display appeared (bottom, Figure 1). The test display was divided into four visible quadrants with the mouse pointer located at the quadrants' intersection. Participants were instructed to click on the quadrant where the target was discovered. Once the participant clicked on a quadrant, the pointer was automatically relocated to the 'found' button and the fixation display reappeared, beginning a new trial. Each participant performed 4 blocks of 48 trials.

Auditory Letter Classification Task

Participants in the dual task condition were acoustically presented random letters of the alphabet in four-second intervals via the speaking software *Victoria*, developed by Apple™. For each letter presented, the participant pressed X if the current letter came before the previous letter or C if it came after. For example, if the subject heard 'A' followed by 'G' she would press C signifying 'G' occurs *after* 'A' in the alphabet. If after four more seconds 'B' was presented, she would press X signifying 'B' occurs *before* 'G'. Letter presentation occurred every four seconds throughout each block of 48 trials. Participants were instructed to simultaneously perform both the visual search task and the letter classification task to the best of their ability. Each dual task participant received accuracy feedback on the letter classification task at the end of each block. No subject scored below 85% accuracy in the last three blocks. Single task participants did not participate in the letter classification task.

Dependent Measures

Our dependent measure was the initial fixation location for each trial, where the initial fixation is the second dwell on the stimuli display. The first dwell was a *residual fixation* resulting from fixating the cross hair on the fixation display. Fixations were determined using the eye tracking software's default fixation analysis. Initial saccades were defined as the eye movement from the residual fixation to the initial fixation.

Results

Comparisons are between the *actual* number of initial fixations on a dense cluster and the number expected by chance. Since there were four possible quadrants to fixate within, there is a 25% chance that an initial fixation would occur on the dense cluster. All t-tests reported are two-tailed and measured at a 0.05 significance level. The first block was removed to reduce any variance attributable to task familiarization. Trials in which all four quadrants were of equivalent density (weak density trials) were excluded from the analyses.

Single Task Condition

The dense cluster was initially fixated on 23.63% of the trials when a dense cluster was present. This rate of initial fixation does not differ from chance [$t(15) = -0.71$; $p = 0.485$]. The planned comparison of degree of density (moderate vs. strong) was not significant ($p = 0.95$). This supports our hypothesis that for the single task there would be no pro-density effect.

Dual Task Condition

The dense cluster was initially fixated on 17.44% of all trials. The rate of initial fixation significantly differs from chance [$t(16) = -2.88$; $p = 0.01$]. There was a marginally significant effect between degrees of density [$t(16) = 1.962$; $p = 0.067$] when comparing moderately dense clusters ($M = 15.14$, $SE = 2.51$) to strongly dense clusters ($M = 19.86$, $SE = 2.72$).

In the dual task condition, we predicted a positive effect of density on initial fixation locations. Instead, we found a negative effect. Initial fixations on dense clusters of stimuli, under dual task conditions, were less than would be expected by chance. We term this the *anti-density effect* and explore it in the following sections. We also found the strong density was initially fixated more often than the moderate density.

Initial Saccade Latencies (ISLs)

Initial Saccade Latencies were defined as the amount of time the participant continued to fixate the cross hair location *after* the stimuli display appeared. The eye tracker used in the study sampled the eye position every 16.67

milliseconds. Each sample in the residual fixation was counted and multiplied by 16.67 in order to determine each subject's ISL for each trial.

ISL Analyses

Before analyzing the ISL data we removed outliers from the data set. Outliers were identified for each group by calculating the mean and standard deviation for each group and removing any data point that exceeded the mean by +/– 3 standard deviations. This procedure resulted in removing 27 data points from the single task group and 41 data points from the dual task group. All blocks were included.

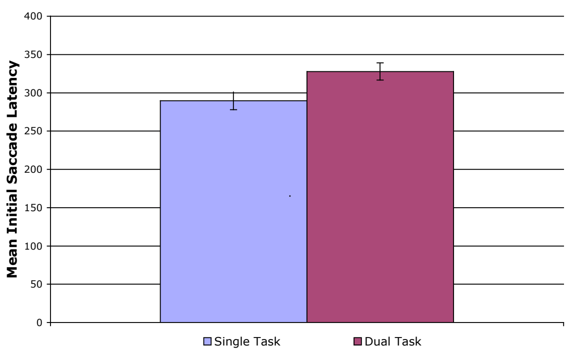


Figure 2. Comparison between dual and single task ISLs. The error bars represent standard error.

An independent groups t-test was performed between the dual and single task conditions on mean ISL. The dual task group had longer ISLs on average (M = 327.79, SE = 11.5) when compared to the single task group (M = 289.53, SE = 11.3), and this difference was significant, $t(31) = 2.37$; $p = 0.024$ (see Figure 2). This result signifies that there was a difference between the groups average ISL.

Discussion of Results

The single-task manipulation worked as predicted: the density effect occurred at chance levels. However, our dual-task manipulation exhibited an anti-density effect. This result is quite startling in the face of previous research that consistently demonstrated dense clusters *attracting* initial fixations (Myers et al., 2003, 2004). We also found a marginally significant effect of degree of density in the dual task condition.

When unintentional processes associated with dense clusters are not producing an effect, dense clusters should only be initially fixated at chance levels. However, if participants were using implicit information provided by the dense cluster (that the target was not located there), then participants should avoid dense clusters. However, 23.63% of initial fixations are located on a dense cluster of stimuli. The results do not support dense cluster avoidance for the single task. In the single task condition it is apparent that the unintentional attraction of dense clusters has been overridden by a different, possibly deliberate, strategy.

Perhaps participants learned to avoid the dense cluster in the single task condition, but were unable to reduce the effect below chance levels. However, in the dual task condition, the pro-density effect is reduced to below chance levels (17.44%, depicted in Figure 3). This was a significant reduction from chance, and suggested the dense cluster was avoided. It is apparent that something was aiding participants to avoid dense clusters in the dual task group. Initial saccade latencies provided a clue. Due to longer ISLs, participants might have more time to implement a conscious, deliberate strategy. We explore this possibility in the upcoming sections.

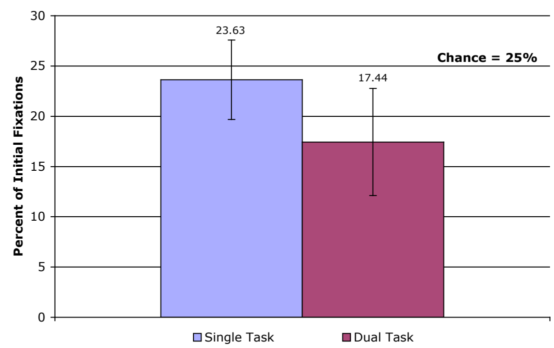


Figure 3. Effects of density by task compared to chance, error bars indicate 95% confidence interval.

Post-Hoc Analyses

Our initial analyses suggested the letter classification task aided dual task participants. Extra time might allow participants to avoid dense clusters. Added time could result from performing some aspect of the letter classification task at stimuli display onset, such as making a comparison, pressing a keyboard key, or even retrieving a memory of the previous letter presented. Extra time was apparent in participants' initial saccade latencies (ISLs). Specifically, dual task participants had significantly longer ISLs compared to single task participants. Further analyses were performed to determine if short ISLs led to a stronger pro-density effect and longer ISLs led to a weaker pro-density effect (anti-density effect). All four blocks were included in the analyses.

To determine if the pro-density and anti-density effects occurred at different rates for different ISLs, we divided our data into 5 bins. Each bin spanned 150 ms, and ranged from 100 ms to 550+ ms. The number of pro-density initial fixations was derived for each bin and divided by the total number of initial fixations for the same bin, creating a percent of pro-density fixations (see Figure 4).

Figure 4 shows a reduction in the pro-density effect as ISLs increase in duration. Figure 4 also shows that single task participants followed the same general trend. The separation between the single task curve and the dual task curve is a result of the single task having a greater number of pro-density fixations.

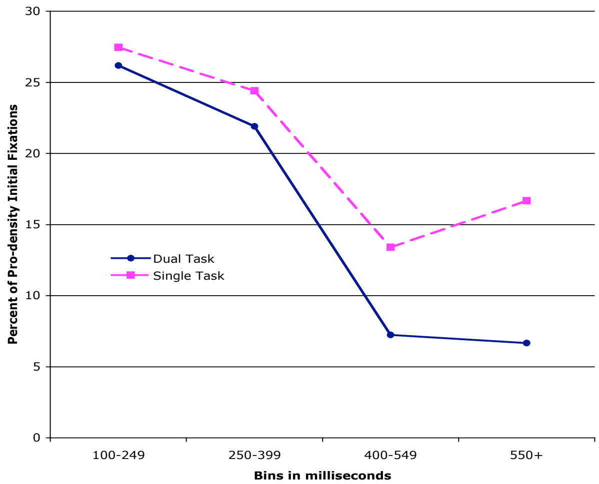


Figure 4. Pro-density effect as a function of initial saccade latency, by task.

It is important to note that the 550+ bin does not contain much data, especially for the single task condition. In fact these data points may be considered aberrant for the single task condition, however they fell within the outlier cutoff. Very few single task participants had ISLs that were 550 ms or greater, as demonstrated in Figure 5.

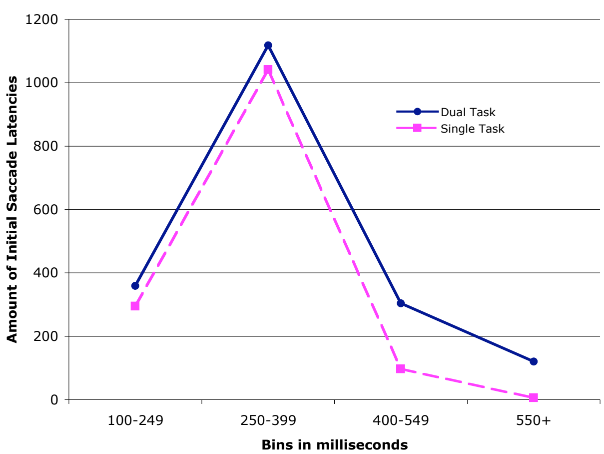


Figure 5. Frequency of initial saccade latencies for each bin, by task

Figures 2 and 4 provide evidence that there was a difference in mean ISLs between the dual and single task conditions. Figure 4 demonstrates that as ISLs increased, the likelihood of initially fixating a dense cluster reduced dramatically. In order to test for significance, a 2 (single task, dual task) x 3 (bins 100–249, 250–399, & 400–549) repeated measures ANOVA was performed. The 550+ bin was removed from the analysis due to insufficient data in the single task group, as demonstrated in Figure 5. Results indicate that there is a significant interaction [$F(1,2) = 3.292$; $p = 0.045$)] between the presence of the letter classification task and ISLs (see Figure 6). There was also a main effect of ISL on the percent of initial fixations on a dense cluster [$F(1,2) = 31.275$; $p < 0.0001$)].

Summary and Discussion

The results of our post-hoc analyses revealed a surprising effect. Participants were *aided* in the dual task condition via the auditory task. Generally, aid came in the form of not initially fixating distracting dense clusters. As a result of increased ISLs, the visio-cognitive system gained the opportunity to acquire and use information relevant to the task at hand. This analysis suggests that low-level strategies are chosen based on the soft constraints inherent in the task environment (Gray & Fu, 2004).

In previous research (Myers et al., 2003, 2004) dense clusters were *uninformative* and we found that dual task situations increased the pro-density effect. In the current study, dense clusters were made *informative* and the information was somehow used in a beneficial manner. When dense clusters are uninformative, they should always be considered as a possible target location. However, when a dense cluster provides target location information, then it becomes possible to reduce your search costs, and is akin to differences in saccadic selectivity as a function of distractor ratios discussed by Shen et al. (2000). Costs attributable to the current experiment's search space begin at very low levels. However, when the opportunity arose to reduce cost, providing benefit by reducing the search space, both dual *and* single task participants seized the opportunity. This occurred at greater rates as ISLs increased. It appears that the visio-cognitive system is extremely sensitive to cost-benefit tradeoffs, even when the cost is an average of one extra fixation. Our data suggests a limit: enough time must be provided in order to achieve a reduction.

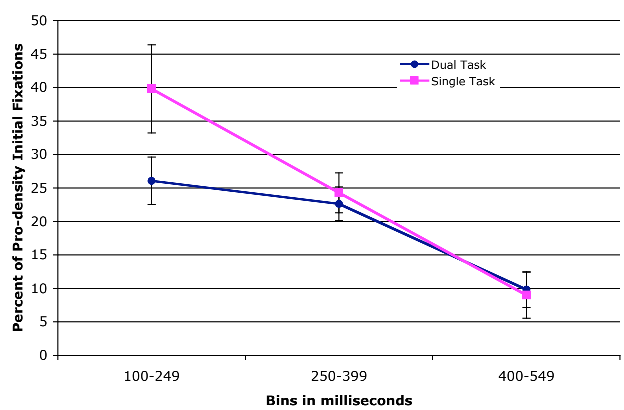


Figure 6. Interaction of initial saccade latency and task condition. Error bars represent standard error.

The reasons for and ways in which purposeful, top-down strategies interact with automatic, data-driven processes are unclear; however our analyses do shed some light. The data suggest that the pro-density effect is an automatic, data–driven process. This is attributable to short ISLs leading to high percentages of initial fixations on dense clusters. This was observed in both task conditions when ISLs were relatively short (see Figure 6). Dense clusters were avoided on roughly 90% of all trials in both task conditions when ISLs were ≥ 400 ms. This suggests more time is necessary to impose deliberate, top–down strategies. In addition, dense clusters were initially fixated more than chance levels for short ISLs. This indicates that automatic, data–driven processes have more influence in overt behavior when ISLs were relatively short, and as ISLs increased the ability to impose top–down strategies on the search task increased. Soft constraints theory suggests that after initially adopting a least-cost strategy, such as avoiding the dense cluster, the number of initial fixations on dense clusters should be reduced as the new microstrategy gains in success over time. It is likely that participants do reduce initial fixations from block 1 to block 4 for all ISL bins, and this reduction would be an example of a learned, unconscious, data-driven strategy.

Further support comes from the planned comparisons between moderate and strong densities in the dual task condition. When top-down processes are sapped by added workload, there are differences between strong and moderate densities. However, there was no difference in the single task condition. When deliberate top–down strategies are taxed, it is likely that bottom-up processes have an opportunity to exert more control on overt behavior.

Pomplun, Reingold, & Shen (2003) have developed a computational model (Area Activation Model) that predicts where saccadic endpoints will be located. These locations are based on information in the search space such as color and shape. The current study points to areas in the model where more work is needed; namely, that stimuli configuration and cognitive workload are important aspects of visual search that must be considered when developing models of saccadic selectivity.

Although the experiment revealed surprising effects, we did not design the experiment with these effects in mind. We see this as a possible limitation in our study and feel that more studies such as the one presented here need to be completed to understand the true nature of the effects that stimuli configurations and high levels of cognitive workload have on visual search.

Acknowledgments

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