Toward Understanding the Findability and Discoverability of Shading Gradients in Almost-Flat Design

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Prior usability studies have suggested that a raised appearance from shading gradients may improve the findability and discoverability of objects in a graphical user interface. The present research investigates this claim in the context of almost-flat design. A traditional visual search paradigm was implemented to examine the rate at which shading gradients are processed in the context of almost-flat design, and perceived depth ratings were collected to examine the magnitude and direction of depth emergent from simple shaded objects. Results indicated shading gradients were highly salient and processed preattentively amidst flat distractors, but if overused, they could be a considerable distraction when searching for a flat object. Perceived depth results confirmed that an emergent sense of depth differentiated shaded objects from flat objects during deliberate processing. These findings advocate the use of almost-flat design, but they also raise the need for further research and the development of design guidelines for the use of shading gradients.

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INTRODUCTION

In software applications and websites, findability and discoverability are key components of usability. Findability refers to how easily users can locate content they know exists, and discoverability refers to how easily users can encounter content of which they were previously unaware. Simply put, difficulties locating information and features necessary for task completion inevitably lead to poor efficiency, effectiveness, and satisfaction.

Findability and discoverability are often discussed in terms of information architecture, such as making content more accessible through search functions and menus (Morville, 2005). But they can also be a factor of visual design within an interface (Cardello, 2014). For instance, a user may not notice a button or not realize a button is clickable.

Almost-flat design is a style of visual design which attempts to improve findability and discoverability through the sparing use of depth cues, such as shading gradients, which give rise to three-dimensional shape and make important page elements stand out and appear actionable (Page, 2014). It is an amalgamation of its predecessors, realistic design and flat design, which embodied the extremes of completely three-dimensional and two-dimensional appearances, respectively.

Designers and usability practitioners have both advocated the superior usability of almost-flat design (Debus, 2015; Loranger, 2015; Meyer, 2015b; Moore, 2013; Sanchez, 2012), but only a handful of published research provides support for this claim. Most notably, usability studies have suggested that a raised appearance from shading gradients helps users find important items in an interface and thereby increases performance on navigation tasks, while a flat appearance often causes users to disregard actionable elements resulting in decreased performance (Nielsen, 1995, 2012; Usabilla, 2013).

The above findings indicate the presence of an interesting phenomenon but leave many questions unanswered about its exact nature. These studies did not separate the task of finding something on a page from the decision to click, nor did they verify that observed differences in performance were attributable to psychological differences in perception of shaded items. In particular, the interfaces studied lacked the control necessary to sufficiently demonstrate that shading gradients explained performance differences, rather than other aspects of modern design that often accompany almost-flat design, such as a more spacious page layout, fewer elements on a page, and larger page elements (Burmistrov, Zlokazova, Izmalkova, & Leonova, 2015).

In the present research, we begin the process of validating the benefits of almost-flat design identified in previous usability studies through the use of more tightly controlled stimuli and connections to established psychological theory. We also begin to examine some of the potential consequences from overusing shading gradients in an otherwise flat environment. Our hope is that through a detailed understanding of the instrumental perceptual processes involved in the use of almost-flat design, further research will be initiated and design guidelines will be formed.

Visual Search Theory

Visual search tasks, referring to the identification of a particular item amongst others in the visual field, can be described as a two stage perceptual process (A. M. Treisman & Gelade, 1980). First, a rapid preattentive phase detects the presence of certain features in the visual field, such as luminance values, colors, and shapes. When a particular item is uniquely identified by one of these features, it tends to stand out from other items in the visual field, making it easy to identify. This phase is said to occur in parallel because distinct items can be identified in virtually the same amount of time, regardless of how many distractor items are present. When the preattentive phase fails to locate a target, it is followed by a slow, attentive phase in which items are examined one-by-one until the target is found. This phase is said to occur serially because the amount of time to identify a target depends on the number of other items that have to be examined.

The speed of visual search is highly dependent upon visual features of the targeted item standing out in the preattentive phase, and this warrants further discussion of what exactly features are and how they influence the search process. *Features*, such as the individual colors red, blue, and yellow, are instances of their parent *dimensions*, *e.g.* color. When an item is distinguished by a feature from a unique dimension, relative to other items in the visual field, it is identified preattentively (A. Treisman & Souther, 1985). Likewise, when an item is distinguished by a discriminable feature within a common dimension, it is identified preattentively (A. Treisman & Gormican, 1988). However, when items are not distinguished in these ways, search proceeds slowly.

Among the non-ideal combinations of features, two are most notable. First is search for a target distinguished by the *absence* of a unique dimension, rather than the *presence* of a unique dimension. The former is slow, and the latter is rapid (A. Treisman & Souther, 1985). Second is search for a target that is absent altogether, *i.e.* not shown on the visual display. Target-absent searches are known to occur serially (A. Treisman, 1985) unless the target is familiar and highly salient (Rosenholtz, 2001). These two present-absent effects have been called asymmetrical effects and have been shown to be robust among interface clutter (Yamani & McCarley, 2011).

In regard to visual design, these discoveries highlight the importance of knowing what features are processed preattentively in which distractor contexts so they can be applied in a way that benefits the user. They also inform what types of experiments to perform when investigating the existence of a preattentive pop-out effect and the potential detriments of overusing a visual cue. This brings us to the application of visual search in the context of almost-flat design.

Shading Gradients

Designers change the way users view interfaces through different visual treatments, which can often be described in terms of low-level perceptual features. Shading in almost-flat design, for instance, is often accomplished through a vertical luminance gradient (Figure 1). When a raised (convex) figure is desired, the gradient typically transitions from light at the top to dark at the bottom. When a depressed (concave) figure is desired, the gradient transitions from dark at the top to light at the bottom. These treatments are consistent with the general tendency for the visual system to assume a single, top-down light source (Ramachandran, 1988).

Previous research has shown the human visual system can process these gradients rapidly, quickly identifying them amidst other elements in the visual field under certain conditions. For example, Kleffner and Ramachandran (1992) showed concave stimuli pop-out among convex stimuli, indicating concave stimuli can be identified rapidly and in parallel, i.e. virtually independent of the number of convex elements. Aks and Enns (1992) also replicated this result and suggested the effects were due to a preattentive processing of depth information.

These studies provide evidence that shading gradients can be useful tools for designers to highlight important interface elements, but the contexts in which these findings hold is uncertain and the potential dangers of overuse have not been examined. The aforementioned studies tested visual search rates of shading gradients among objects of opposing depth. That is, all objects were either convex or concave. They notably did not test search rates of shaded objects among flat objects, which have no apparent depth relative to the computer screen and are representative of modern flat interface designs.

In the present research, we set out to determine if luminance gradients could be processed preattentively in an otherwise flat interface. It was hypothesized that both a convex target and a concave target would be processed rapidly and virtually independent of the number of flat distractors, even though the difference in depth between the target and distractor would be less than in previous research (Kleffner & Ramachandran, 1992). We also aimed to determine if flat objects could be processed preattentively among objects with luminance gradients. It was hypothesized that a flat target would be processed serially, i.e. dependent on the number of convex or concave distractors. This was based on previous research suggesting asymmetrical effects are observed when stimuli differ greatly in salience (A. Treisman & Gormican, 1988; A. Treisman & Souther, 1985).

METHOD

In line with previous visual processing and attention research, a visual search paradigm was used to examine the visual processing speed of vertical luminance gradients in an otherwise flat environment. This approach allowed the differentiation of serial and parallel search and thereby the detection of preattentively processed cues (A. M. Treisman & Gelade, 1980).

Participants

Seventeen undergraduate students (11 male, 6 female) participated in a single 30 minute session for course credit. All participants had either normal (11) or corrected-normal (6) vision. All participants completed every trial of the experiment, and all but one finished the visual search task with a mean accuracy above 90%. The remaining participant, who responded correctly to only 78% of the trials, was not included in subsequent analyses.

Stimuli and Displays

Three types of target and distractor stimuli were used in this experiment (Figure 1), each a circle subtending 1° of visual angle. The convex stimulus was formed by a vertical luminance gradient ranging from 147 cd/m^2 (very light grey) at the top to 12 cd/m^2 (very dark grey) at the bottom. The concave stimulus was the same as the convex stimulus rotated 180°. The flat stimulus had an evenly distributed luminance value of 68 cd/m^2 (medium grey), which was the average luminance of the gradients.

Stimuli were grouped into four target-distractor pairs (convex-flat, flat-convex, concave-flat, flat-concave) and stimuli from each pair were arranged on a white background (159 cd/m^2) to form different displays. Displays were generated in three sizes: 1, 6, and 12 items, with items placed randomly in a 7° x 7° region without overlap. In half of the displays, one of the items was a target and the remaining items were homogenous distractors. In the remaining half of the displays, all items were homogeneous distractors. Examples

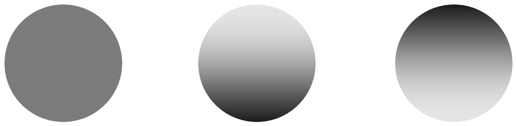

Figure 1. The three types of target and distractor stimuli: flat, convex, and concave from left to right.

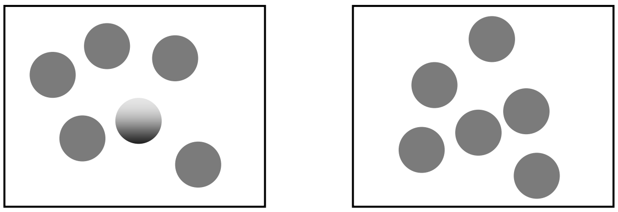

Figure 2. An example target present display (left) and target absent display (right) for the convex-flat target-distractor pair.

of the two target presence conditions (present, absent) are shown in Figure 2.

Procedure

Visual search task. Participants were seated approximately 0.7 meters away from a computer screen measuring 17 inches on the diagonal. Each trial began with a fixation symbol displayed in the center of the screen for one second. This was followed by a stimulus display to which the participant would respond either target present (left Ctrl key) or target absent (right Ctrl key). The stimulus display was visible until either the participant responded or three seconds elapsed, and then a feedback message of "correct" or "incorrect" was displayed in the center of the screen for one second. If a response was not received within three seconds, the trial was marked incorrect.

Trials were blocked by the four target-distractor pairs, and blocks were presented in random order within-subject. Within each block, displays were presented in random order without replacement until every combination of display size (1, 6, 12) and target presence (present, absent) had been seen. This was repeated 15 times in each block for a total of (3 x 2 x 15) 90 trials per block and (3 x 2 x 15 x 4) 360 trials over all four target-distractor pairs.

At the beginning of each block, participants were shown the upcoming target and distractor stimuli and given six practice trials, one for each combination of display size and target present condition. Participants were also instructed to remain fixated at the location of the fixation symbol and respond as quickly and accurately as possible.

Depth ratings. After completing the visual search task, participants were asked to complete a post-task survey which collected perceived depth ratings for each type of stimulus. Participants were shown each of the flat, concave, and convex stimuli, one at a time, and were asked to rate the perceived depth of the stimuli on a scale of -10 to 10. Participants were instructed that a negative value indicated the stimulus appeared depressed into the screen, a value of zero indicated the stimulus appeared flat, and a positive value indicated the stimulus appeared raised out of the screen.

This approach to depth ratings was notably different from previous research with similar stimuli (Aks & Enns, 1992) because it allowed participants to distinguish a stimulus that appeared depressed from one that appeared raised. The measurement of all three stimuli on a scale with both positive and negative values allowed (a) the perceived magnitudes of depth between concave and convex stimuli to be compared, (b) the relative perceived depth of a flat stimulus to be identified, and (c) the detection of participants who viewed concave stimuli as raised and/or convex as depressed, i.e. the opposite of what was intended.

RESULTS

Visual Search

Mean search times for correct responses in each target-distractor condition are shown in Figure 3. Search for a convex target amidst flat distractors yielded a slope of < 1 ms per item when both the target was present and absent. Search for a flat target among convex distractors yielded a slope of 6 ms per item when the target was present and 24 ms per item when the target was absent. Search for a concave target amidst flat distractors yielded a slope of 4 ms per item when the target was present and < 1 ms per item when the target was absent. Search for a flat target among concave distractors yielded a slope of 19 ms per item when the target was present and 39 ms when the target was absent.

A two-way repeated measures ANOVA ($\alpha = .05$) was performed to examine the effects of target-distractor pair and target presence on the slope of reaction time over display size. There were significant main effects of target-distractor pair, $F(3, 45) = 32.26$, $p < .001$, $\eta^2 = .47$, and target presence, $F(1, 15) = 14.81$, $p < .001$, $\eta^2 = .10$. There was also a significant two-way interaction of target-distractor pair and target presence, $F(3, 45) = 17.30$, $p < .001$, $\eta^2 = .17$.

Bonferroni *post hoc* tests revealed the slopes of target present and target absent searches were significantly different when searching for a flat target among convex distractors ($p = .003$) and when searching for a flat target among concave distractors ($p < .001$). However, the slopes of target present and target absent searches showed non-significant differences when searching for a convex target among flat distractors ($p = 1.00$) or a concave target among flat distractors ($p = 1.00$).

Depth Ratings

The impact of stimulus type on depth ratings was analyzed with a one-way repeated measures ANOVA. Overall, stimulus type had a significant impact on depth ratings, $F(2, 30) = 10.45$, $p < .001$, $\eta^2 = .37$. Bonferroni *post hoc* tests revealed depth ratings for the convex stimulus were significantly different from both the flat stimulus ($p < .001$) and the concave stimulus ($p = .01$). However, the difference in depth ratings between the concave stimulus and flat stimulus was non-significant ($p = .52$).

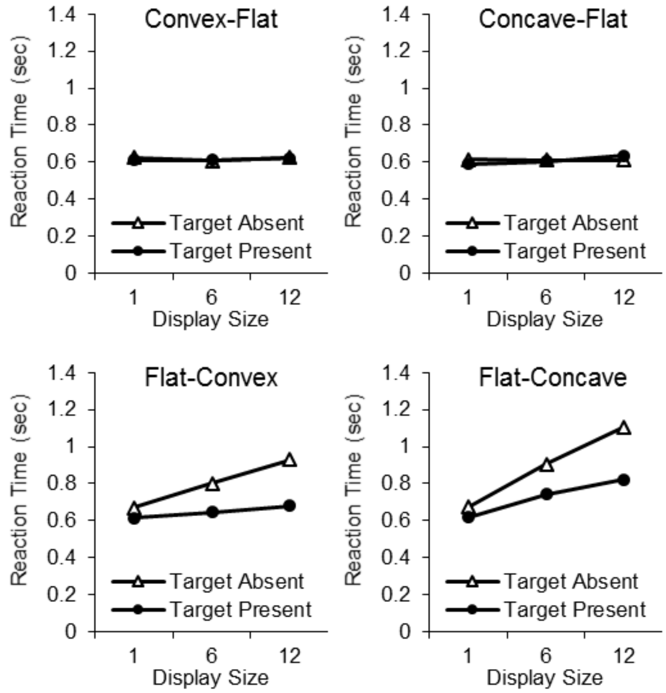

Figure 3. Mean response times for correct responses in the four target-distractor conditions: search for a convex target among flat distractors (top left), flat target among convex distractors (bottom left), concave target among flat distractors (top right), and flat target among concave distractors (bottom right). Target present and target absent conditions are plotted separately.

Given the concave stimulus was the exact opposite of the convex stimulus by design and the concave stimulus showed similar search patterns to the convex stimulus, it seemed logical for the magnitude of its depth to be approximately the inverse of the convex stimuli. Thus, further investigation was required to determine why a significant difference was not observed between concave and flat stimuli.

One possibility was the concave stimulus could have been interpreted differently between participants. For example, some participants might have perceived depth opposite the intended direction due to inversion of the light source (Ramachandran, 1988), e.g. seeing a concave stimulus as raised, which would cause positive and negative depth ratings to cancel each other out in an average.

To examine this possibility, depth ratings were categorized by perceived shape according to the instructions presented in the post-task survey. Stimuli given a zero depth rating were categorized as flat. Stimuli given a positive depth rating were categorized as convex. And stimuli given a negative depth rating were categorized as concave.

Counts and mean depth ratings for each combination of stimulus and perceived shape are shown in Table 1. All participants perceived the flat stimulus to be flat in shape, and all but two participants perceived the convex stimulus as convex. However, the concave stimulus was not consistently perceived as concave. A large number of convex perceptions had brought the overall mean for the concave stimulus closer to zero.

Table 1
Group Size and Mean Depth Ratings by Stimulus and Perceived Shape

Stimulus	Perceived Shape	*N*	Perceived Depth
Flat	Flat	16	0.00
	Convex	-	-
	Concave	-	-
Convex	Flat	-	-
	Convex	14	5.36
	Concave	2	-3.00
Concave	Flat	1	0.00
	Convex	6	3.83
	Concave	9	-5.67

Note. A dash indicates no participants were in that group.

DISCUSSION

Search for convex and concave targets showed similar results among flat distractors. Both yielded small slopes (4 ms or less per item) in target present conditions – far below the 10 ms cutoff for serial search (Cave & Wolfe, 1990; Enns & Rensink, 1991). This indicated convex and concave stimuli were processed rapidly and independent of the number of flat items in the display, signifying a pop-out effect. Further, small slopes for target absent conditions (< 1 ms per item) indicated convex and concave stimuli were highly salient to the point that their absence was notable without having to serially examine each item. This type of effect is typically observed when the target and distractor differ either drastically on a continuum in one feature dimension (A. Treisman & Gormican, 1988) or exist on separate feature dimensions (A. Treisman & Souther, 1985). These results confirmed the hypothesis that convex and concave stimuli can be processed rapidly in a flat context.

Search for flat targets showed similar results among both convex and concave distractors. Both yielded steeper search slopes than when concave and convex stimuli were targets. The flat-concave condition showed strong evidence of serial processing with a linear slope of 19 ms per item when the target was present and 39 ms per item when the target was absent. However, the flat-convex condition showed signs of rapid processing when the target was present - a slope of only 6 ms per item – in contrast to a slope of 39 ms when the target was absent. These results confirmed the hypothesis that flat items are found serially among concave stimuli, and rejected the hypothesis that flat items are found serially among convex stimuli. Though, convex stimuli were salient enough to prevent rapid identification of a missing flat target.

In regard to perceived depth, participants tended to view flat stimuli as having no depth relative to the computer screen and convex and concave stimuli as having depth relative to the computer screen. This confirmed an emergent sense of depth differentiated concave and convex stimuli from flat stimuli. Some participants interpreted the depth of convex and concave stimuli opposite the intended direction, e.g. they saw a concave stimulus as raised out of the screen, but these reverse interpretations were likely due to the presentation format of an

Figure 4. Example interface elements that have been emphasized with shading gradients: an icon, button, and toggle widget from left to right.

isolated stimulus during depth ratings and would be unlikely to occur when surrounded by contextual cues in an interface (Ramachandran, 1988).

CONCLUSIONS

This study demonstrates there are potential usability benefits to using luminance gradients amidst otherwise flat design in software interfaces. The process of visual search can be made quick and easy when a key element is distinguished by a convex or concave cue. Even as interfaces become more cluttered, convex and concave cues can still be detected quickly. Further, convex and concave stimuli are perceived to have depth during deliberate processing which likely explains increases in speed and accuracy in usability tests, relative to flat interfaces, due to conveyed affordances, or signifiers (Gaver, 1991; Norman, 2013).

This study also addresses some of the consequences of overusing perceptual cues like luminance gradients. Convex and concave stimuli are highly salient and attract attention, which pulls attention away from other elements on the page. Their overuse can make it more difficult for a user to find a flat element that is not readily distinguished by some other cue, such as color. Albeit, this salience could be used to the designer's advantage by drawing attention to an unexpected element, such as an alert.

These results advocate a hybrid approach between realism and flat design, which some have called almost-flat design, or flat 2.0 (Meyer, 2015a; Page, 2014). Convex and concave cues seem to work well when used sparingly to emphasize important interface elements, amidst an otherwise flat interface. This treatment is appropriate for a variety of key interface elements, including but not limited to those in Figure 4.

This research highlights the value of considering user perceptual and cognitive processes in design, but further research is required to establish concrete psychologically-driven guidelines for almost-flat design. For example, it would be useful to know the extent to which convex and concave cues can be used before search for flat elements is severely inhibited. It would also be useful to know how much contrast is necessary across a luminance gradient for an item to be discriminable and rapidly identified in visual search. And it would be helpful to know how convex and concave cues compare to and interact with other cues commonly used in flat design. With a better understanding of the processes behind the interpretation of shading cues, guidelines can be created to foster usability.

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