2014

THE EFFECTS OF ALTERNATE-LINE SHADING ON VISUAL SEARCH IN GRID-BASED GRAPHIC DESIGNS

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THE EFFECTS OF ALTERNATE-LINE SHADING ON VISUAL SEARCH IN GRID-BASED GRAPHIC DESIGNS

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Arts & Sciences at the University of Kentucky

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2014

ABSTRACT OF THESIS

THE EFFECTS OF ALTERNATE-LINE SHADING ON VISUAL SEARCH IN GRID-BASED GRAPHIC DESIGNS

Objective: The goal of this research was to determine whether alternate-line shading (zebra-striping) of grid-based displays affects the strategy (i.e., "visual flow") and efficiency of serial search. **Background:** Grids, matrices, and tables are commonly used to organize information. A number of design techniques and psychological principles are relevant to how viewers' eyes can be guided through such visual works. One common technique for grids, "zebra-striping," is intended to guide eyes through the design, or "create visual flow" by alternating shaded and unshaded rows or columns. **Method:** 13 participants completed a visual serial search task. The target was embedded in a grid that had 1) no shading, 2) shading of alternating rows, or 3) shading of alternating columns. Response times and error rates were analyzed to determine search strategy and efficiency. **Results:** Our analysis found evidence supporting a weak effect of shading on search strategy. The direction of shading had an impact on which parts of the grid were responded to most rapidly. However, a left-to-right reading bias and middle-to-outside edge effect were also found. Overall performance was reliably better when the grid had no shading. Exploratory analyses suggest individual differences may be a factor. **Conclusion:** Shading seems to create visual flow that is relatively weak compared to search strategies related to the edge effect or left-to-right reading biases. In general, however, the presence of any type of shading reduced search performance. **Application:** Designers creating a grid-based display should not automatically assume that shading will change viewers search strategies. Furthermore, although strategic shading may be useful for tasks other than that studied here, our current data indicate that shading can actually be detrimental to visual search for complex (i.e., conjunctive) targets.

KEYWORDS: Visual Flow, Visual Search, Grids, Perceptual Grouping, Zebra Striping, Edge Effect

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Dedicated to Janet Sue Faraci Lee, D.M.D.

ACKNOWLEDGMENTS

I would like to thank the members of my committee, Ramesh Bhatt, Ph.D., Gerry Swan, Ph.D., and Melody Carswell, Ph.D. More specifically, I would like to thank Dr. Bhatt for his lectures on perceptual grouping which inspired exploration into applications in graphic design. I would like to thank Dr. Swan and his previous research on tabular displays in application in the field of education. And I would like to thank Dr. Carswell for her continued support, inspiration, and guidance over the last three years in researching applications of basic psychological principles in technology and design.

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Chapter 1: Visual Flow in Art and Graphic Design

"Any competent designer can craft a layout and design to elicit any specific entry/focus behavior on the page," Andy Rutledge, Graphic Designer, 2008

When designing in a visual medium, it is often the case that the designer will attempt to guide the viewer's eyes through their work by arranging elements in specific ways. From the cognitive psychologist's perspective, this phenomenon relates directly to principles that have been researched extensively over the past century, including those related to perceptual grouping and visual search. Similarly, from the human factors / usability perspective, these basic psychological principles find applications in various displays to increase the ease with which users can access information. All three fields are discussing the same phenomenon, but they are approaching it in slightly different ways. This phenomenon has been called "visual flow," but this terminology is not consistent across domains. Designers try to create visual flow; they will manipulate their work with the intention to guide the viewer's eyes through it. Conversely, psychologists, whether they are basic or applied, will focus on viewer response. They might attempt to operationalize the concept of flow as achieving low variability in viewers' scan paths during serial search through the work (not to be confused with J.J. Gibson's optical flow). To put this another way, from the designer's perspective, a piece can have visual flow without it ever being viewed or used. From the psychologist's perspective, it is only after multiple viewings can a piece be said to have, or lack, visual flow.

Designers claim they can influence basic, low-level visual search processes by tweaking various design features to change the perceptual organization of a display, but their designs are rarely tested to truly see how effective they are at achieving the designer's goals. One example where features are assumed to direct visual flow is in graphic designs using a grid format by shading alternating columns or rows to create a "zebra striping" effect. However, the effects of such shading in tables, particularly in how perceptual groupings can affect eye movements and performance in a visual search task, have not been thoroughly researched. The purpose of this thesis is to investigate how this shading of horizontal rows or vertical columns in grids can affect performance in a visual search task, as well as to compare these designs to a grid with no shading.

Defining Visual Flow in Design

While visual flow techniques have been used in applied settings, such as with the design of tables or websites, their foundation originated in classical works of fine art. Although these various media often use similar principles and techniques, the terminology is often inconsistent. In fine art, the attempt to guide is often called "visual movement," but in graphic design, as well as this thesis, it is called "visual flow," (Cox, 2011). The goal of a designer's visual flow is to carry "the viewer's eye through the document in a way that all the important elements receive prominence, and nothing snags the vision or causes the viewer to lose sense of the piece," (Kyrnin, n.d.). Designers attempt to manipulate various design elements, such as line, color, size, and shape, to achieve this goal.

Design Elements in Practice

While grid-based formats will sometimes utilize certain design techniques to create visual flow, many of these techniques were initially practiced in fine art, such as sculpture and painting. Similarly, the same elements are purposely used in modern artistic media such as photography and cinema. Photographer Ian Plant emphasizes the importance of guiding a viewer's eye through a composition by "using a progression of elements, tonal transition, and color," (2013). Plant stresses that if a photo, like a painting, only receives focus in one location, then it will likely only procure fleeting, short-term interest. In cinematography, the need for effective progressions is exacerbated because these works have the added dimension of time as they create transitions and frame many individual shots. However, while editors, directors, and camera crews have been able to develop skills over the last century to effectively direct attention, their techniques are largely a craft based on experience and convention. Underlying theories and empirical evidence are lacking to support the skills (May & Barnard, 1995).

Graphic design

Framing photographs and cinematic shots may create a certain visual flow, but photographers and cinematographers are often able to manipulate their elements relatively freely, at least compared to many works in graphic design. By its very nature, graphic design encourages adherence to a number of rules while artists are largely able to make their own rules, according to the American Institute of Graphic Arts (Elimeliah, 2006). Graphic designs must often communicate specific information and therefore they are subject to empirical evaluations. The focus on viewer outcomes may be responsible for the development of best practice guidelines in graphic design. For example, designers will often utilize a grid layout (Bokil, 2009 for overview of grids in design). In creating columns and rows by using weighted lines or by creating empty "gutters," designers can organize information in a consistent structure. While this technique has been utilized in newspapers for many decades, grids have been translated extensively for website design (Vinh, 2005). Websites can become incredibly complex so the need for effective organization of the information is increasingly important. While aesthetics and design trends change, the grid layout seems to persist whenever large amounts of information need to be organized and presented. And if rows and columns are being created, then a visual flow may be created as well. Gutters appear between columns to direct the viewer's scan path down rather than across. Heavy lines between rows can direct the viewer's scan path across rather than down.

Grid (Table) Design in Microsoft Office

Grids and tables are so prevalent for organizing and presenting information that the Microsoft Office Suite of programs allows for them to be easily created and inserted into documents and presentation slides. They also provide many design options. In MS Word, the default table is a simple grid (all cells white with uniform, black borders between). The alternative design templates, however, frequently include various types of "zebra striping," where the design manipulates the background color of every other row. In MS PowerPoint, the default table setting includes such zebra striping with similar alternative templates (Figure 1.1). This zebra striping attempts to create visual flow across the table. However, we should look at the cognitive psychological research foundations to explore how these design techniques might actually be affecting scan paths.

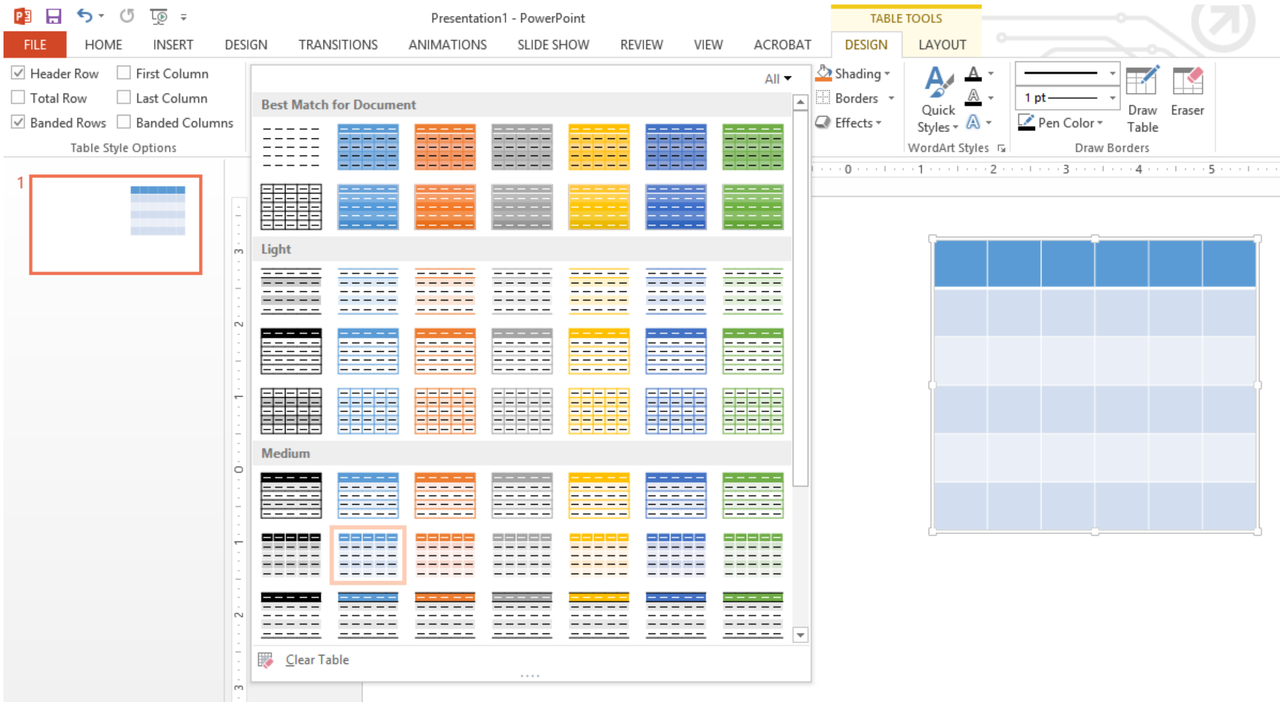


Figure 1.1 – Screenshot of MS PowerPoint default to zebra striped table design, with more alternatives

Designer's Assumptions

In having zebra striping in a grid-like layout, or any other instance where a designer attempts to create visual flow to direct search by manipulating design elements, designers seem to assume that they can rely on influencing early, even pre-attentive, processes to guide search (i.e., bottom-up processing). However, search strategies are greatly influenced by other factors, such as patterns developed after years of reading ("reading bias"), or the tendency to focus on the center of an array when searching for targets when their location is unknown and assumed to be equally likely throughout the array ("edge effect"). Designers seem to ignore that this top-down processing can impact search tremendously. In the next section we will discuss the basic psychological principals associated with visual flow, including how they relate to top-down and bottom-up processing.

Chapter 2: Cognitive Processes in Visual Flow

Perceptual grouping

"Design is essentially the opposite of chance," Lauer and Pentack, 1995

The reason a grid layout has been used so prolifically is due to its efficacy at presenting great amounts of information. A grid is effective because it organizes information into smaller, more manageable groups. Many of the techniques used by designers to create these groups relate directly to the concepts researched extensively in Gestalt psychology over the last century (see Wagemans et al, 2012, for review). The seminal work on perceptual grouping is attributed to Max Wertheimer in 1923, with Willis D. Ellis' translation to English from the original German in 1938 contributing greatly to its influence. Wertheimer articulated principles (Figure 2.1) which predicted the perceptual grouping of visual elements, some of which are outlined here. Rather than a line of independent visual elements (Figure 2.1a), Wertheimer created the impressions of unified pairs by altering the space between dots

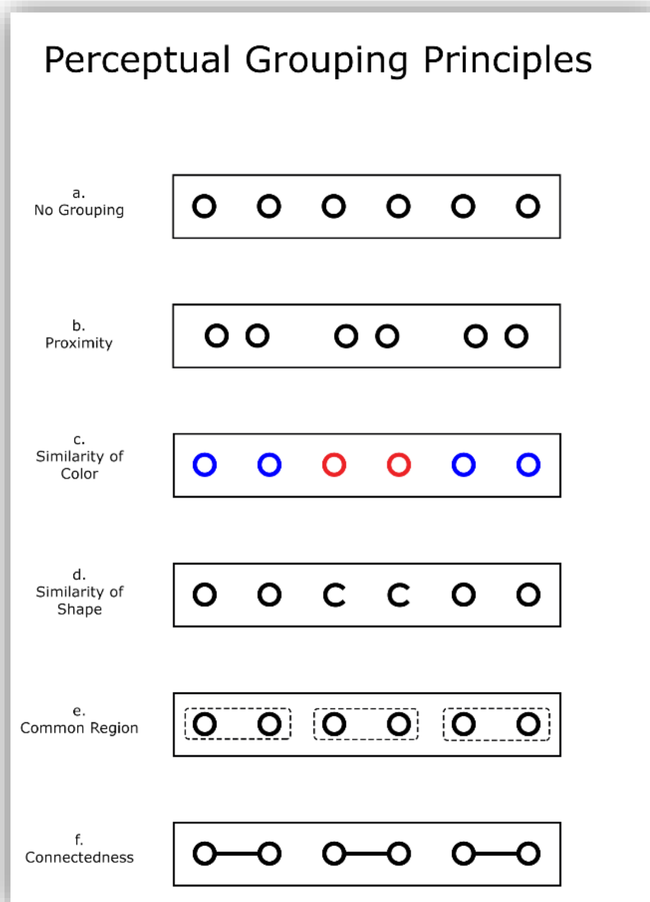


Figure 2.1 - Perceptual Grouping Principles

(Figure 2.1b). This has come to be known as the law of *proximity* and has been researched extensively, including applications in analog display design (Wickens and Carswell, 1995). In grids, the gutters between columns in grids and tables are created by manipulating proximity. Another principle is that of *similarity*, where groups are based on similarity in size, color (Figure 2.1c), shape (Figure 2.1d), orientation, and other attributes. In grids, shading can visually integrate backgrounds that are the same color. While many of these grouping principles are derived from Wertheimer's classic work, some newer principles have been developed. *Common region* (Figure 2.1e) groups elements together when they lie in the same bounded area (Palmer, 1992). In grids, common region can be created by adding vertical and/or horizontal lines to create or differentiate columns and/or rows. If both orientations of lines are used simultaneously, then common regions will be created in the form of specific cells. *Connectedness* (Figure 2.1f) groups elements together when a common border is shared (Palmer & Rock, 1994). In grids, connectedness is often seen when adjacent cells will share a common border. It is important to note that multiple perceptual grouping principles can be used together to create the designer's desired level of visual integration among elements.

Bottom-up & Top-Down Processing

Scan paths, whether they are through photographs or websites, are subject to two major influences: bottom-up and top-down processes. Perceptual grouping begins at a rather low level (Treisman, 1982) to define objects that can then be the subject of higher-level search processes. Designers attempt to influence this low-level, bottom-up search by manipulating design elements to create perceptual groupings. However, there are other factors that can influence scan paths. In top-down search, a person will create generalized schema after repeated exposure, and these schema will be used in new instances to determine where specific information might be located. An example of this can be seen in the "F" layout for website designs (Nielson, 2006). Years of reading practice results in relatively automated "scanning programs" that guide the eye across the top from left to right. After the end of the line is reached, the eye automatically jumps back to the left and down to move across a new line of text. However, if a viewer finds that the most important information for their task is consistently placed on the left-hand side of the page or screen (such as a navigation menu), then the initial scan path of the user when presented with a new instance of the page or screen will be down that left side. These scan paths may be predicted based on the potential task as well as the viewer's previous experience.

Like the "F" layout seen in websites, top-down influences in visual search has been found in the research of radar displays. Baker, Morris, and Steedman (1960) found evidence of an "edge effect," where the targets in the outer edge of the display take longer to be found than targets in the middle, assuming the target location is unknown and has an equal likelihood throughout the display. While this effect is one of the more robust effects in visual search (Monk, 1981), it may also put into question the fundamental claim by designers that they can guide viewers' eyes through a work. Designers fail to acknowledge that these learned strategies, as shown in the edge effect, are influential in visual search beyond the early processes they try to manipulate. This can be seen in tables, where information is organized in a grid, but graphic implementations can be used to create perceptual groupings. These implementations certainly influence early processing in visual search, but top-down influences are usually left out of the discussion. However, designers claim they can elicit whatever specific behavior they want, independent of the task or experience (Rutledge, 2008). In reality, both top-down (e.g., schema) and bottom-up (e.g., grouping) processing are likely to influence visual flow.

Visual search – Feature Integration Theory

While perceptual groupings may make it easier to sort through information, the key to visual flow is often to lead the eyes of a viewer to one particular end point, or, often, through a succession. Visual search research has explored the cognitive and perceptual mechanisms that influence such phenomena. Treisman's feature integration theory (FIT) takes a largely bottom-up approach by suggesting "that attention must be directed serially to each stimulus in a display whenever conjunctions of more than one separable feature are needed to characterize or distinguish the possible objects presented" (Treisman & Galade, 1980). However, when perceptual groups of similar features were created, search appeared to be serial between groups rather than between items when searching for stimuli defined by feature conjunctions. In line with earlier work, conjunctive targets produced serial self-terminating searches, while targets defined by a unique feature require only parallel search processes. While parallel searches were not affected by manipulation of groupings, the serial search time was affected by the groupings and their sizes. When there were a few, large groups, the search time for a conjunctive target was faster than when there were many smaller groups, or no groups at all (Treisman, 1982).

Treisman's findings have been explored elsewhere, including applied areas such as the work of Niemelä & Saarinen in 2000 where they found grouping similar icons on a computer interface to be beneficial to visual search. Basic research continued and tested other grouping principles as well, such as clustering by proximity (Xu, 2010). FIT and visual search were also researched in the presence of groupings created by common regions (Nakashima and Yokosawa, 2013). Groups were created by enclosing elements in boxes (Figure 5). When there were a few, larger boxes, the search time decreased, but this effect was weakened as the number of boxes increased and sizes decreased, leading to a table-like grid. Thus, in grouping to-be-searched stimulus elements, designers should consider that there is an optimal group size and number.

Visual Search – Guided Search

Triesman's FIT has been shown to have its shortcomings. Wolfe (1989, 2007) presented his guided search (GS) concept, suggesting that not all searches for conjunctive targets have to be exclusively serial searches, but rather, they can be guided by a number of parallel processes. While FIT suggests people will search in a serial manner for a conjunctive target, GS suggests a more "sequential filtering" approach, where a broad, fast parallel search can eliminate distractors based on one feature (i.e., eliminate groups with the similar feature) and then, assuming an effective transfer of that information, a slower, more exact, serial search is conducted on the remaining stimuli. So the initial parallel search "guides" the serial search. Furthermore, when a triple conjunctive search is conducted (i.e. searching for a target sharing one feature with three different distractors), FIT would predict a serial search would be conducted, when, in fact, a parallel search is utilized, as proposed by GS. Thus, both top-down and bottom-up processes guide visual search.

Chapter 3: Information Visualization and Tables

"Getting information from a table is like extracting sunlight from a cucumber," (Farquhar & Farquhar, 1891).

Grids organize information into columns and rows according to gestalt principles. Tables, a familiar grid-based format, are often used when it is important to find and "read out" a specific piece of information, similar to serially searching for a target. However, the graphic design of tables has not often been experimentally explored, even though tables have been used throughout much of our civilized history, dating all the way back to the Sumerians utilizing a tabular format for accounting purposes in the 18th century BCE (Marchese, 2011). Great strides in information presentation occurred around the time of the scientific revolution, as seen in the most famous table in science, the periodic table of elements by Dmitri Mendeleev in 1869. The Nineteenth Century also included the work of William Playfair, who created and popularized many visualization techniques, including some still used today such as the pie chart, line graph, and bar chart (Wainer, 1990). These graphical means of presenting information have been shown to have advantages over tables when viewers need to perceive general trends and make a quick comparison (Wainer, 1992). Modern, interactive graphs have even been able to address some issues, which were once strengths for tables, by allowing users to locate specific data points and the extract and manipulate the information associated with it. By clicking on a specific point on a line graph, for example, the actual value it represents can appear, precise information that was once more easily accessible in a table than a graph.

However, there is one presentation function at which tables, compared to graphs, always excel: the presentation of qualitative information. Tables can easily present both qualitative and quantitative information, as is often the case in educational settings or in healthcare charts (it is difficult to communicate a patient's medications and allergies through a graph alone). The combination graph-tables known as a "grables" can be utilized as well, with graphs embedded within a surrounding table (Figure 6; Bradstreet, 2012).

Guidelines for Tabular Information

While tables have been around for millennia, the design of them has frequently left people confused and frustrated (Farquhar & Farquhar, 1891). To alleviate this confusion and frustration, a series of guidelines have been developed over the years to help design tables with in intent to ease the extraction of information presented in a tabular format. Unfortunately, many of these guidelines, such as the number of decimal points the designer should use, address issues related to the presentation of quantitative information which may be better represented by graphs. These principles often derive from Ehrenberg (1977) who equated this extraction and integration of tabular quantitative information as a mark of "numeracy." One such set of guidelines, developed by Menon and Nerella (2000), uses the acronym of ORACLE to provide six rules for designing tables. However, only one of these guidelines addresses anything graphic in nature: "L: Lay out the table to facilitate comparisons," and even then it does not provide particularly substantive guidance. Wainer (1992, 1997) also has a series of guidelines for using tables to present information. However, again, only one of the guidelines addresses the actual layout of the table, by suggesting using space to aid perception (in accordance with gutters created when manipulating proximity).

Bradstreet (2012) presented guidelines for grable designs which should parallel many of the same guidelines developed for table layouts. One of his guidelines is particularly relevant to the present discussion: “Horizontal and vertical lines, and also gaps of white space, should be used sparingly, to parse major divisions in a table. Occasional regular gaps can help guide the eye and emphasize patterns. Single spacing with occasional gaps is an easy rule to adopt,” (Bradstreet, 2012, pg 48). Tufte (1990) also provides guidance on graphic design, but his focus is not so much what to add but rather what to remove from tables and graphs. He claims that most graphical devices in tables and graphs, such as horizontal or vertical lines or shading, are considered “chartjunk” that only impede information extraction. This is in accordance with his “data-ink ratio” principle where visualizations should limit the amount of non-data related ink. However, this guideline may be less important than the compatibility achieved between the types of design element used in the display and the task for which the display will be used (Carswell, 1992). Unfortunately, evidence specific to the use of design elements such as shading in tables is sparse.

Table Design Research

While graphical treatments are frequently used in the design of tabular displays, oftentimes to create perceptual groupings, the effect of such treatments and groupings have not been thoroughly researched. Tabular design was investigated by manipulating the weight of anchoring and alignment lines in nutrition labels (Goldberg, Probart, & Zak, 1999). Participants’ eye movements were measured while they searched for specific nutritional information (Figure 7). The data showed that less experienced users would fixate on the first, thickest anchor while more experienced users would bypass the anchor and land closer to the target. The data also showed that smaller and absent alignment lines proved to worsen performance relative to the heavier lines used in the current nutrition label design. When thinking in terms of perceptual grouping, the anchoring lines are used to create common regions and the alignment lines predominantly groups elements using connectedness. However, the smaller and absent alignment lines do not appear to create these groupings. These findings suggest that Tufte's data-ink ratio may not apply to tabular design as decreasing the non-data ink lead to decreased performance. Contrary to the focus on creating flow through perceptual organization alone, the differences found between less-experienced and more-experienced users suggests top-down influences also come into play.

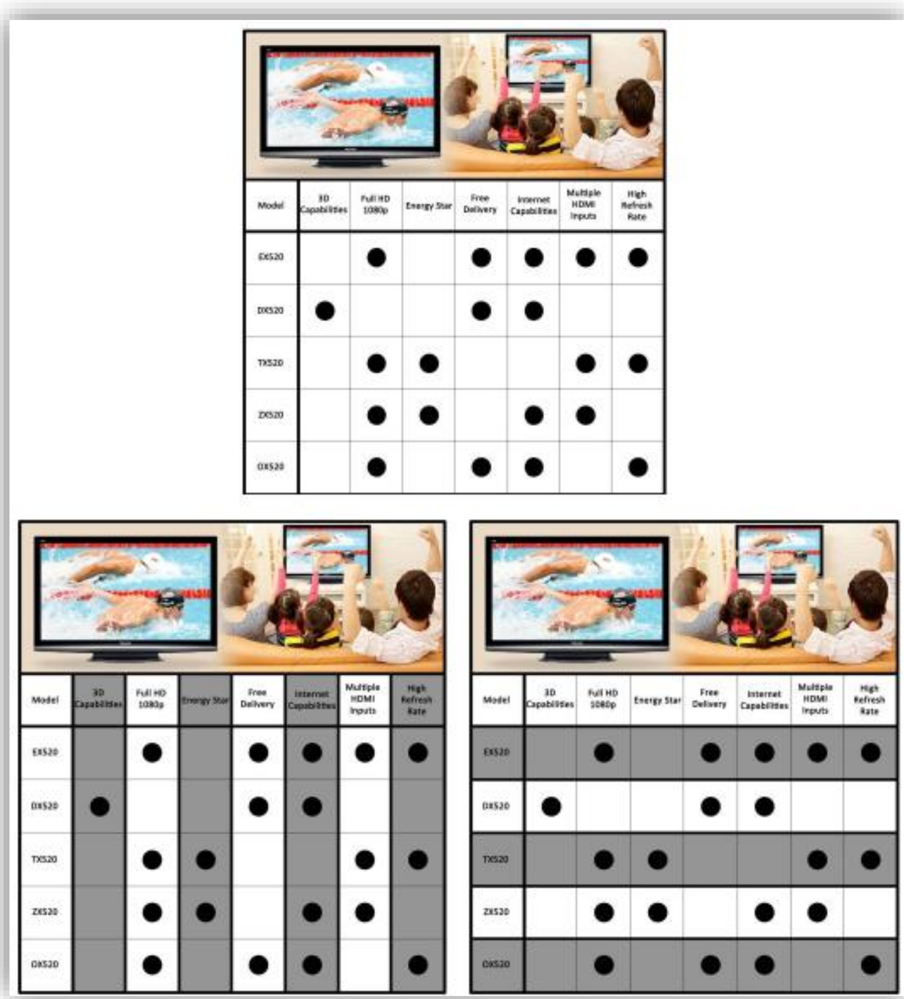
There has been a small amount of empirical work on the design of product comparison tables. Resnick in 2004 researched how providing numerical rankings and/or color-coded highlights affected users performance in focused tasks and integrative tasks when comparing cars. The focused task was basically a visual search task (i.e., what is the base retail price of Model 4?), while the integrative task required more numeracy skills in the aggregation of information about multiple car attributes (i.e., which model has the most head and shoulder room?). For both tasks, the data showed faster performances when either highlights or rankings were used, but when both were present, performance efficiency was not as strong as when each treatment was used alone. While this study focuses on the design of particular cells in a table rather than whole columns or rows, it is still important to note that the design of the table did affect performance on both focused and integrative tasks.

One study (Enders, 2007) did actually address the value of zebra striping, although it only used tables with horizontally shaded rows. Enders presented online participants with a table (15 rows x 9 columns) either with no shading or with horizontal shading and asked 6 questions about the information presented in the table. Here, tabular entries were grouped by creating common regions through common, contiguous background shading. Perceptual groupings were created vertically down the columns by using proximity to create gutters, although these were not discussed in the article. The data showed no significant difference in accuracy between shaded and unshaded tables. There was evidence of a learning effect as later questions were answered more rapidly. There were no significant differences in speed between the shading and no shading conditions, except for the final question where shaded tables were faster. In this way, after repeated exposure, the shading seemed to help bridge the gutters created between each column, which used to slow down the search. These effects, however, again illustrate the impact of top-down processing on the impact of "flow" manipulations.

Some preliminary work has been done comparing no shading designs and designs with both horizontal and vertical shading orientations by our lab (Lee et al, 2012). We asked online participants to complete a decision making task with product comparison tables with varying shading orientations (horizontal, vertical, and no shading). Perceptual groupings resulted from the use of common regions with the thicker borders between the white and the grey, with similarity in background color, and connectedness with shared borders (Figure 3.1). Unlike other studies where the cells were rectangular with a horizontal orientation, all the cells were equilateral. A main effect was found where the horizontal shading orientation led to the fastest response time, perhaps due a reading effect.

Based on the studies of tabular design described above, it seems that common graphic design practices, such as zebra-striping, can influence performance of several types of tasks. However, none of the studies explicitly related table design to the concept of visual flow. Furthermore, with the exception of the Lee et. al study, all of the stimuli contained information in rectangular formats with horizontal orientation, which could

Figure 3.1 - Example product comparison tables for decision making task from Lee, 2012.



bias visual flow horizontally to follow that orientation, or could bias visual flow vertically to avoid the gutters between columns. In the current study, visual flow is explicitly addressed by using RTs to different target locations to infer the search path of participants. The study also controls for spatial proximity effects between groups defined in other ways (e.g., shading).

Chapter 4: Research Questions and Hypotheses

There were two primary questions addressed by this research. First, does an attempt to manipulate visual flow through the use of shading actually influence visual search strategy? Second, does the presence of shading have positive or negative effects on overall search task performance?

1*) Search strategy.* We attempted to determine if shading created visual flow as operationalized by patterns of RT benefits that conformed to the direction of shading. Specifically, we analyzed the interaction of target location (upper right vs. lower left) and shading direction (horizontal vs. vertical). Our hypothesis was that horizontal shading would be associated with faster responding in the upper right relative to the lower left corners of the grid, and that this pattern would be reduced or reversed with vertical shading. We also looked for evidence of "flow" by analyzing the impact of shading on the tendency to sample the middle portion of arrays more frequently than the edges when searching for targets (the edge effect). We hypothesized that shading would reduce the edge effect by creating flow across the entirety of each column (or row, depending on the direction of shading).

2) *Search efficiency.* In order to see if having shading enhances performance in the search task overall, the RT and error rate of grids with shading and grids with no

shading were compared. We hypothesized that the horizontal shading condition would have the most efficient search performance, based on the previous Lee et. al research. We also checked for any effect of contrast between targets and backgrounds that might confound the effect of shading on performance.

In addition to these primary questions, we also explored potential individual differences by creating "flow scores" for each participant. These scores summarized the size of the effect of shading on search strategy.

Chapter 5: Method

The purpose of this experiment was to determine whether shading affects visual flow search strategy in a grid, specifically looking for visual flow, and overall search efficiency.

Participants

This study used 13 students at the University of Kentucky (7 female, mean age=24.5) who were recruited by word of mouth and paid $20 for their participation.

Stimuli

All stimulus grids contained six rows and six columns with 36 equilateral square "cells." This grid size allowed for equal amounts of shaded and unshaded cells throughout the grid (18 each) in the shaded conditions (Table 1) and for 4 cells in each corner to be analyzed as grouped target locations of interest with buffer spaces in between (Figure 11). The 6x6 grids were also big enough to allow analysis of edge effects by dividing the middle 16 cells and the 20 edge cells (Figure 15). There were three grid designs (Table 5.1):

1) No shading (control) – no shaded cells

2) Horizontal shading – every other row is shaded (use common region, similarity, and connectedness to create perceptual groupings for alternating rows)

3) Vertical shading – every other column is shaded (use common region, similarity, and connectedness to create perceptual groupings for alternating columns)

Table 5.1: Example of the grids in the three shading conditions (Target is red C).

No Shading	Vertical Shading	Horizontal Shading
C O C C O C	C O C C O C	C O C C O C
O O C O O O	O O C O O O	O O C O O O
O C O O C C	O C O O C C	O C O O C C
C O C C O C	C O C C O C	C O C C O C
C O O C O C	C O O C O C	C O O C O C
C C C O C O	C C C O C O	C C C O C O

Two graphic designers were interviewed to determine an ecologically valid shade of grey to be used in the two types of shaded grids. The items used to fill the grids as distractors and targets were O's and C's in either red or blue (Table 5.2). On trials when a critical target was present, grids contained 2 types of distractors and one target of conjunctive features from the two distractors. The O's and C's were in the Century Gothic typeface due to its consistent stroke width and degree of curvature for both O and C. The O's and C's were 50 pixels in diameter (visual angle 1.89^{o} assuming participant was sitting approximately 63 cm from the display) with horizontal and vertical spacing of 20 pixels in each grid, allowing for a cell width of 60 pixels where the center of the O or C is located in the center of the cell with 10 pixels on all sides. A fixation stimulus preceded each stimulus grid. This stimulus consisted of black Xs in Century Gothic (Table 5.3).

The Xs were composed of two line segments, each of which could be short (53 pixels) or long (66 pixels).

Table 5.2: Target and distractor stimuli			
C	O	C	O
C	O	C	O

Table 5.3: Fixation stimuli		
Same	Different	
X	X	X

Thirty-six grid stimuli were created, one for each of the 36 possible target locations. To fill in the remaining cells with distractors, MS Excel's random number generator was used for randomization. Each of these grids were duplicated for the target-absent tables, where the target was replaced by a distractor. In all, there were 36 target present grids and 36 target absent grids, for a total of 72 stimulus grids. All 72 grids were rendered in the 3 shading conditions, yielding a total of 216 stimuli to be presented in a given block of trials.

Task & Apparatus

In a given trial, participants completed two tasks: a fixation task and a search task in a single grid. First, the fixation stimulus, an "X" (Table 5.3), was presented. Participants pressed either the "m" key or the "z" key depending on whether the diagonals making up the X were the same or different, respectively. An incorrect response led to a 3-second delay, and then a new fixation stimulus would be presented.

After a correct response, the search task began with the presentation of a grid at an interstimulus interval (ISI) of 30 ms. The upper left cell in the grid was in the same location on the display as the fixation, so that the cross of the X was in the center of that corner cell. For the search task, participants searched for a target and responded if the target was present by pressing “z” or absent by pressing “m.” After each response, the participant was shown a feedback slide, stating if they were correct on the previous trial, as well as presenting cumulative percent accurate and running average response time. After this feedback, the trial ended, and the next trial began with the next fixation stimulus.

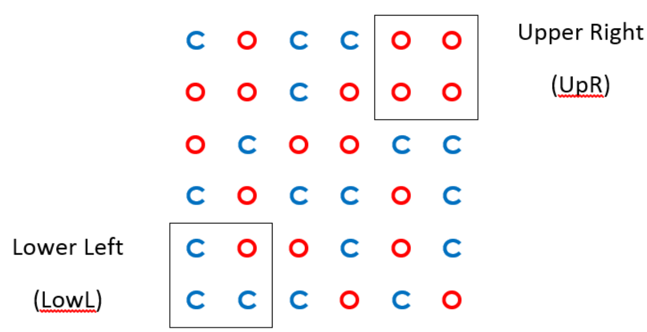
The stimulus grids were presented in a random order without replacement using ePrime 1.2, which also recorded responses and measured response time. All stimuli were presented on a 17” LCD monitor with 1280 x 1024 resolution and a 600:1 contrast ratio. The experiment was conducted in a closed, private room used specifically for running human subjects.

Procedure

After providing informed consent, the participants were given instructions for the visual search task. These instructions also included directions for performing the fixation task. Participants were instructed to respond as quickly as possible while maintaining an accuracy above 90%. After participants indicated that they understood the instructions, the experimental blocks began. Each participant completed 4 blocks, where each block had a different target (i.e., red C, blue C, red O, or blue O). Each block began with a description of the specific feature conjunction target and the 2 distractors. Participants then had 3 practice trials at the start of each block. If the participants felt comfortable with the fixation and search tasks, then they continued on to the experimental trials. At the end of the block, they were given a break. Presentation of the 216 grid stimuli was randomized within each block and the order of the 4 blocks was randomized across participants.

Of the 36 target locations, the stimuli of most interest were the four cells in the upper right (UpR) and the four cells in the lower left corners (LowL), as shown in Figure 5.1. Our assumption was that a horizontal scanning strategy would lead to faster detections in the upper right compared to lower left corner, and a vertical scanning strategy will result in faster detections in the lower left compared to upper right. This analysis assumes that participants began their search in the upper left corner (the position of the fixation stimulus).

Figure 1 - Demonstration of the 2 groups of 4 target locations used for the primary visual flow analysis.



Chapter 6: Results

Data Visualization: Heat Maps

Figure 6.1 contains “heat maps” representing individual means for response times (only correct responses) for each target location in the 6x6 grid. Cells have been color coded with 36 distinct colors for each cell. The darkest red is the lowest mean response time. This dark red gradually gets lighter as RT slows down until it is white, which is the median of the mean RTs. Then, light shades of blue gradually get darker until the darkest blue which represents the highest mean RT. These heat maps allow us to visually explore trends in RT as a function of cell location, providing insight into potential visual search strategies. Formal statistical analyses of these data based on our hypotheses about the effects of shading on visual flow are presented in subsequent sections.

We can see faster responses when the target location was in the quadrant of the grid closest to the fixation point. They were generally progressively longer as the target moved further away. This pattern provides some support for our assumption that the search process was serial, with visual sampling beginning in the upper left part of the grid. Responses to targets in the upper right corner were also generally faster than those in the lower left, with the exception of the vertical shading condition, perhaps supporting the presence of a left to right and top to bottom reading strategy.

The heat maps also present a possible edge effect, where RT is faster for the middle of the grids and slower for the edges, at least in the upper half of the grids. Although the fixation was located in the upper left corner, this cell and the immediately surrounding cells were not the fastest. Rather, search strategies, as inferred from RTs, seemed to initially focus on the upper-mid portion of the grid. This pattern appears to be particularly true in the no shading condition.

No Shading

1047	1044	1140	1052	1111	1172
1046	974	797	816	1173	1164
1114	988	919	1077	1126	1271
1177	1248	1124	1158	1343	1181
1354	1233	1330	1550	1307	1392
1380	1583	1454	1651	1356	1559

Vertical

1079	995	939	1066	1198	1480
973	943	893	1069	1217	1420
1075	1008	956	1134	1208	1278
1314	1155	1255	1152	1345	1413
1295	1387	1432	1501	1389	1378
1385	1347	1451	1595	1398	1375

Horizontal

944	970	1042	1049	1275	1332
1098	945	888	987	1002	1236
1047	981	1041	1112	1151	1366
1153	1121	1283	1185	1310	1362
1332	1382	1361	1483	1313	1409
1488	1553	1487	1577	1357	1539

Figure 6.1 - Heat map data visualizations of the mean RTs (ms) for each of the 36 cells, broken up by shading condition. Cells have been color coded so that the lowest RT is the darkest red, the median is white, and the highest RT is the darkest blue.

Overview of Analyses

A 2 (shading direction – horizontal or vertical) x 2 (target location – upper right or lower left corner) repeated measures analysis of variance (ANOVA) was implemented for response time (RT) collected in milliseconds (ms) and for error rate, both of which are metrics for search efficiency. A 2 (shading vs. no shading) x 2 (edge vs. middle) repeated measures ANOVA was also implemented on RT and error rate to see if there were edge effects. An ANOVA was also done to compare search efficiency of the three shading conditions (horizontal, vertical, and no shading).

For the primary analyses, data were submitted to a repeated measures mixed model analysis with standard least squares (STS) personality and restricted maximum likelihood (REML) methodology. JMP statistical software was used for all tests. STS can model the variance of both random effects (i.e., subject) and fixed effects, and REML handles unbalanced data better than traditional expected mean squares methods (Wolfinger, Tobias, and Sall, 1994). All pairwise comparisons were done using Tukey's Honestly Significant Difference (HSD) test to adjust for multiple comparisons.

Analysis 1: Search Strategy

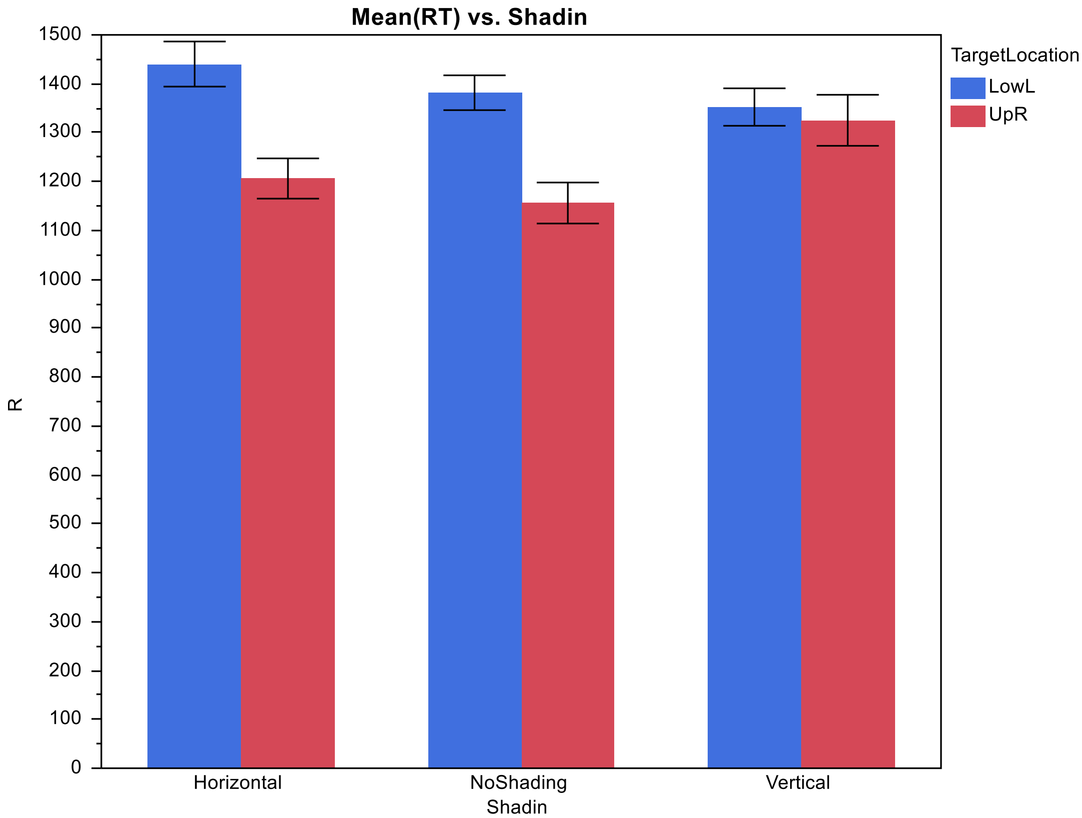
Visual Flow Analysis

We first focused on data from two corners of the grids – the upper right and lower left – to determine if there was an interaction of shading direction and target location on performance. Analysis was performed only on correct responses (86.5% were correct for these conditions). For the RT data (Table 6.1, Figure 6.2), a reliable interaction was found ($F(2,801.1)=3.85$, $p=0.02$, power=0.88), as well as a reliable main effect of target location ($F(1,801.3)=23.77$, $p<0.0001$, power=0.80). No main effect of shading direction was found (F(2,801.1)=1.53, *p*=0.22, power=0.07). The main effect of target location shows a reading bias as UpR was overall reliably faster than LowL. For the interaction, pairwise comparisons showed that both H and V with the target location in the LowL were reliably slower ($p<0.06$) than H with the target location in the UpR, but no other comparisons were reliable ($p>0.20$). This means that there was a difference between corners favoring the UpR for the horizontal condition, but not for the vertical condition. This interaction supports the hypothesis that search strategy follows visual flow by indicating that horizontal shading may reinforce the left-to-right reading bias, while the vertical shading may attenuate the reading bias.

Table 6.1 - Response time data (in milliseconds) for the primary visual flow analysis. Mean (SE)

		Target Location	
		LowL	UpR
Shading Direction	H	1440 (46.13)	1206 (41.15)
	N	1382 (35.60)	1156 (41.93)
	V	1352 (38.31)	1325 (52.20)

Figure 6.2 - Graph of mean RT (ms) comparing the shading direction and the target location (primary visual flow interaction). Error bars represent standard error.

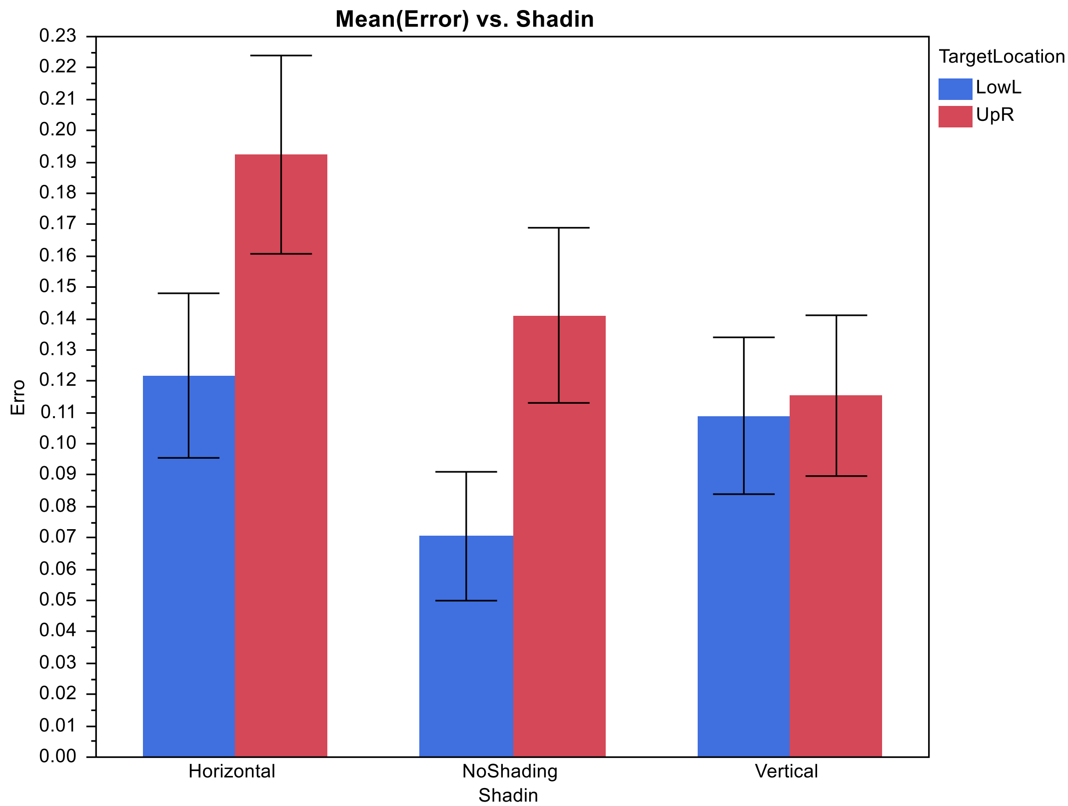


For the error rate (Table 6.2; Figure 6.3), the interaction was not reliable (F(2,918)=1.03, *p*=0.36, power=.52). The main effect of target location is a reliable difference (F(1,918)=5.43, *p*=0.02, power=0.29) and the main effect of shading was trending towards a reliable difference (F(2,918)=2.34, *p*=0.10, power=0.43). The H-UpR condition had the most misses, which seems to contradict the benefit of decreased RT we found for this condition. It appears as though when targets are in the UpR corner within a horizontally shaded grid, participants respond quickly, but are prone to missing the target as well compared to the other locations.

Table 6.2 - Proportion of errors for the primary visual flow analysis. Mean (SE)

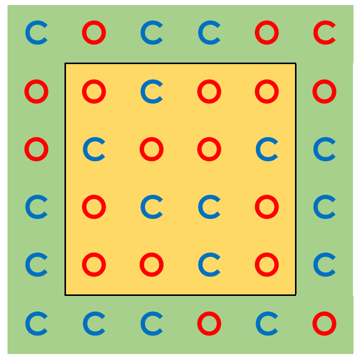
		Target Location	
		LowL	UpR
Shading Direction	H	0.1218 (0.0263)	0.1923 (0.0317)
	N	0.0705 (0.0206)	0.1410 (0.0280)
	V	0.1090 (0.0250)	0.1154 (0.0257)

Figure 6.3 - Graph of mean error comparing the shading direction and the target location (primary visual flow interaction). Error bars represent standard error.



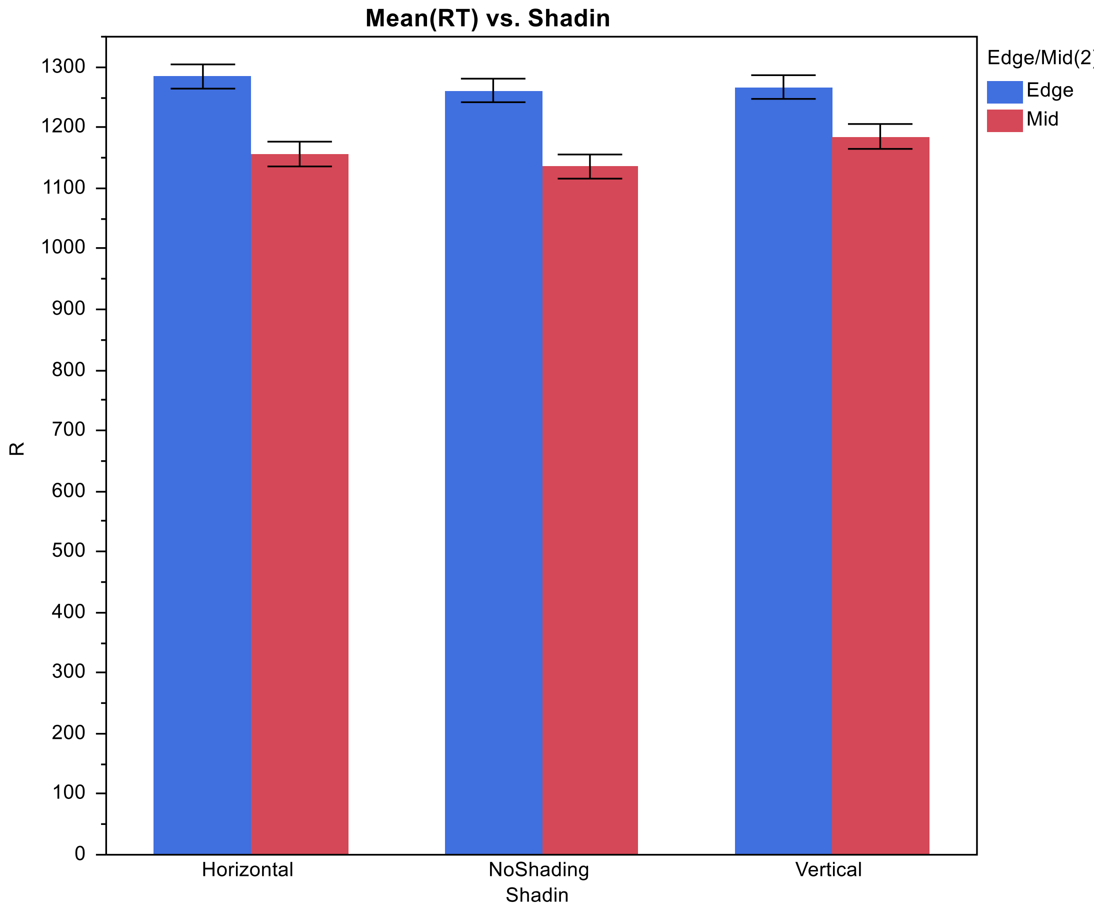
Edge Effect Analysis

Figure 6.4 - A demonstration of the 16 cells analyzed as "middle" (in orange) and the 20 cells analyzed as "edge" (in green) for the edge analysis.



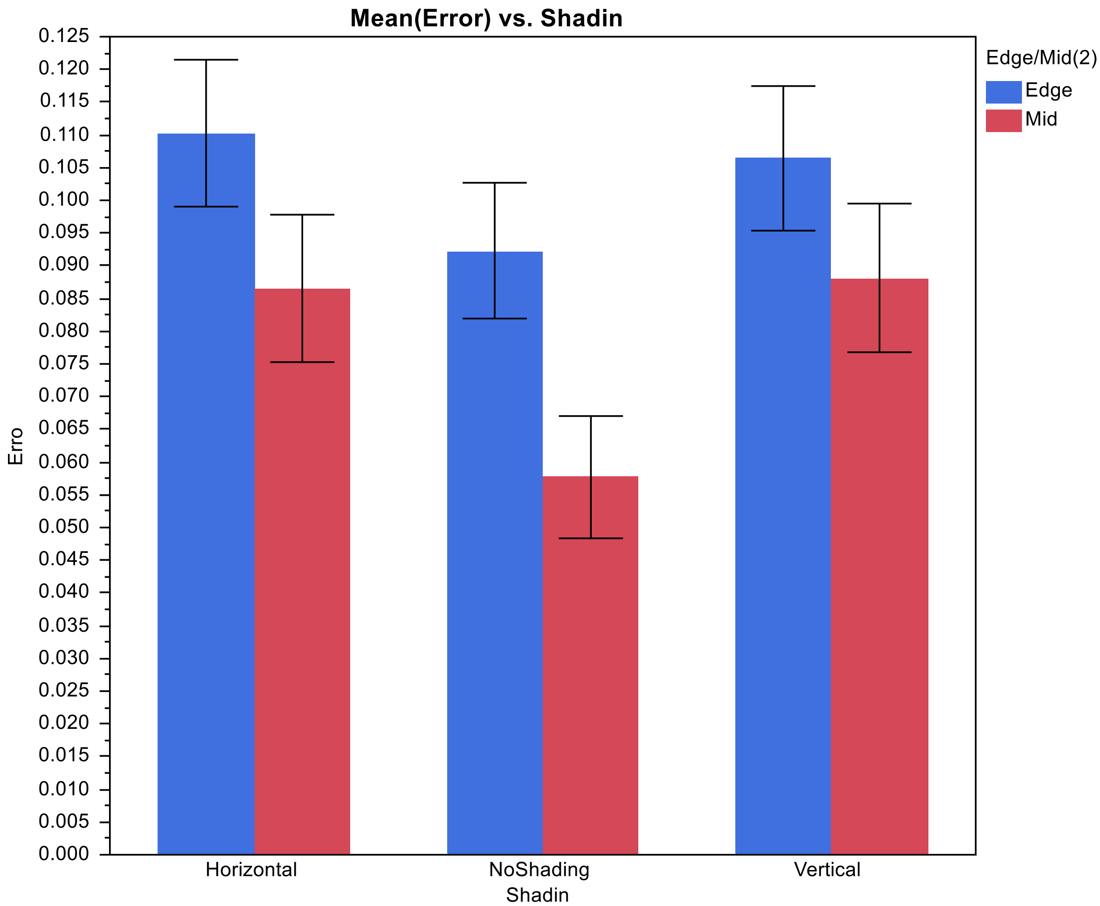
The second possible effect of shading on search strategy was its possible influence on any “edge effects.” The pattern evident in the heat maps was supported by an analysis of RTs and error rates in the centermost 16 cells versus the 20 edge cells (Figure 15). Analyzing correct responses (90.84% correct), we found evidence of an edge effect, where search times were longer for the targets in the edges (M=1271 ms; SE=11.35) than when the targets were in the middle (M=1159 ms; SE=11.72; $F(2,3808)=53.68$, $p<0.0001$, Figure 6.5). The interaction between shading and the target location (i.e., edge vs. middle) was not found to be reliable ($F(2,3808)=0.86$, $p=0.42$, power=0.18). The difference between the middle and the edge RT for the grids with no shading (M=123 ms) is slightly greater than for the grids with shading (M=106 ms), though it is not a statistically reliable difference.

Figure 6.5 - Graph of mean RT (ms) comparing the shading direction and the target location (middle vs. edge). Error bars represent standard error.



The error rate data analysis found similar results (Figure 6.6). There is evidence of an edge effect, where the error rate was reliably greater in the edge (M=0.1030; SE=0.0132) than the error rate for the middle (M=0.0775; SE=0.0135; $F(1,4194)=8.33$, $p=0.004$). The interaction between shading and the target location (i.e., edge vs. middle) for error rate was not found to be reliable ($F(2,4194)=0.30$, $p=0.74$, power=0.33). The difference in error rate between the middle and the edge for the girds with no shading (M=0.0346) is slightly greater than for the grids with shading (M=0.0210).

Figure 6.6 - Graph of mean error comparing the shading direction and the target location (edge vs. middle). Error bars represent standard error.

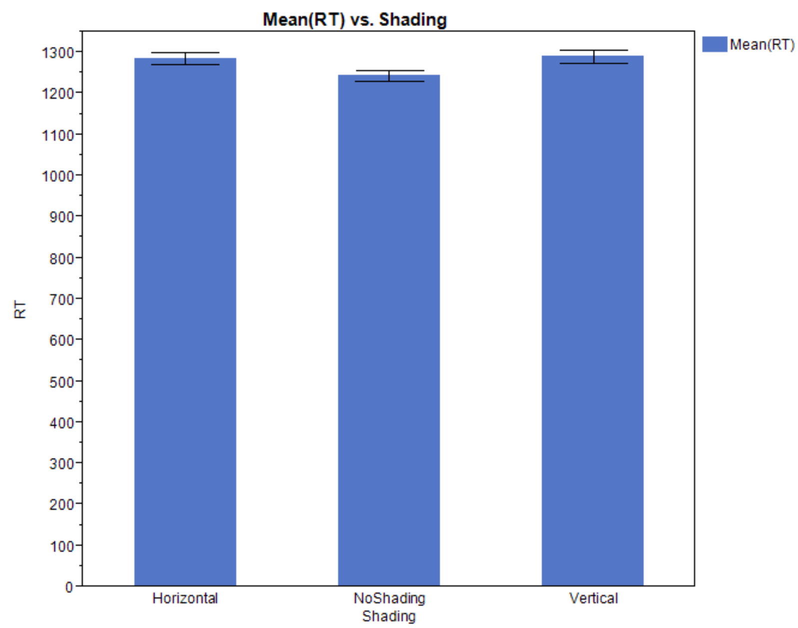


Analysis 2: Search Efficiency

Shading vs. No Shading

Next, the overall effect of shading was analyzed using only the correct responses (90.84% correct). For the present conditions, a reliable effect of RT was found (F(2,4197)=3.65, *p*=0.03; power=0.60; Figure 6.7) where the no shading condition (M=1244 milliseconds, SE=63.56) was reliably (*p*<0.07) faster than the Vertical (M=1290, SE=63.56) and the Horizontal (M=1285 milliseconds, SE=63.56). The difference between V and H was not reliable (p=0.81, power=0.06). A similar effect was trending for accuracy (F(2,4197)=2.81, p=0.06; Figure 6.8) where no shading (M=0.08, SE=0.007) had lower error rates than both horizontal (M=0.10, SE=0.008, p=0.09) and vertical (M=0.10, SE=0.008, p=0.12) conditions. The difference of error rates between vertical and horizontal was not statistically reliable (p=0.99). These results support the notion that adding shading to a grid will actually hurt rather than help search performance.

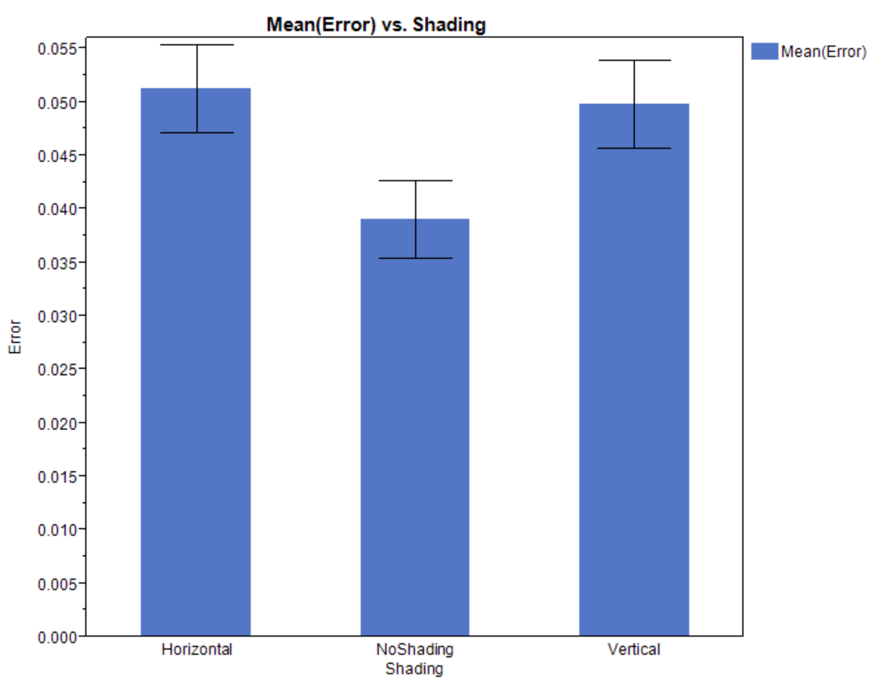
Figure 6.7- Graph of mean RT (ms) comparing the shading conditions. Error bars represent standard error.



Contrast Effect

One reasonable explanation for this effect in favor of no shading could be that the reduced visual contrast between the stimuli and background in half of the cells in the shading conditions caused the difference in performance. That is, are our targets simply easier to discern on a white background rather than a grey background? There was no reliable difference in RT for targets with a grey background (M=1211 ms; SE=56.95) and those with a white background (M=1233 ms; SE=56.18; $F(1,3812)=1.79$, $p=0.44$, power=0.35). In looking at accuracy, there is no reliable difference in error rate for targets with a grey background (M=0.0919; SE=0.0141) and targets with a white background (M=0.0915; SE=0.0130; $F(3,4198)=0.002$, $p=0.97$, power=0.05). The cost of shading on search efficiency does not seem to be due to difference in stimulus contrast across conditions.

Figure 6.8 - Graph of mean error rate comparing the shading conditions. Error bars represent standard error.



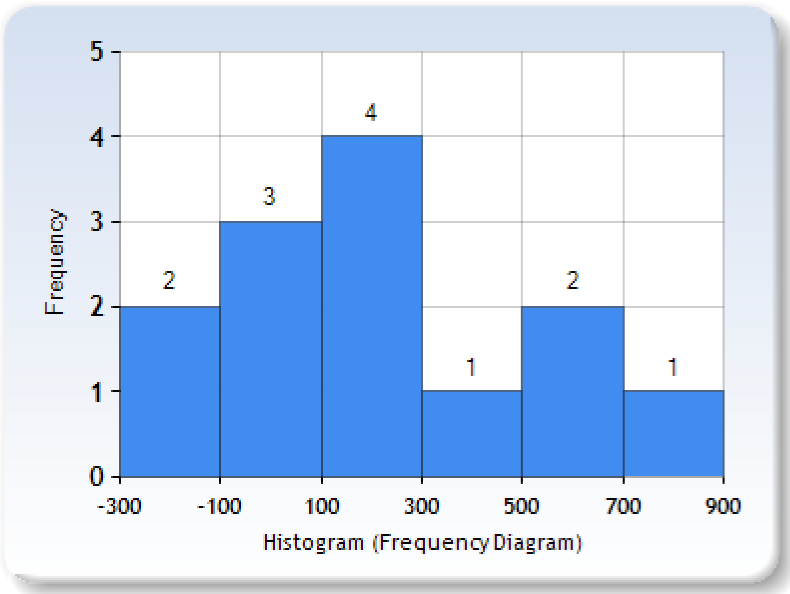
Exploring Individual Differences: Flow Score

A flow score was calculated for each participant using the means of correct responses for the grouped locations in the UpR and LowL for the horizontal and vertical conditions. To calculate flow score, the formula was the difference between the lower left and upper right for the horizontal condition, plus the difference between the upper right and lower left for the vertical condition, or:

$$\text{Flow Score} = (\text{LowL}_H - \text{UpR}_H) + (\text{UpR}_V - \text{LowL}_V)$$

With this flow score, a value close to zero supported the pattern of location effects we have attributed to "reading biases." A large positive flow score indicated that a participant's responses were consistent with the proposed effect of visual flow (i.e., searching followed shading). A large negative value was evidence of that shading affected search strategy, but in the opposite direction proposed for visual flow. Eleven of the 13 participants had positive flow scores. The mean flow score (218 ms, SE=80.44) was reliably higher than 0 based on a one-sample test ($t(12)=2.61$, $p=0.02$). Thus, searching appears to follow shading for most participants. Looking at the distribution of scores (Figure 6.9), it appears that three of the participants were affected more by shading than the rest. Demographics of these three participants are somewhat varied: a male social psychology graduate student, a female elementary school teacher, and a recent male bachelor's graduate in merchandising, apparel, and textiles (MAT) where he studied fashion. It is interesting to note that this MAT graduate likely has had the most schooling in design, and the other participant with a background in design (a male from landscape architecture) had the fourth highest flow score. Although the number of participants in this study preclude a detailed individual difference analysis, it is possible that the impact of shading on search performance is bimodal and that factors such as design training may determine susceptibility to flow manipulation.

Figure 6.9 - Histogram of the flow scores, showing that there may be individual differences to create a bimodal distribution.



Chapter 7: Discussion & Conclusion

Visual Flow

The primary purpose of this thesis was to explore the effects of shading direction on a visual search task in stimulus grids, specifically looking at whether the speed of detecting targets in different quadrants was a function of shading alternate rows or columns. A reliable interaction of shading direction and target location was found, with search being aligned with the direction of the shading. In this same analysis, the reliable main effect of location demonstrates a reading bias, as the upper right corner was faster than the lower left, regardless of shading condition. However, with vertical shading there was no reliable difference in RT between the upper right and lower left corners, suggesting that vertical shading attenuates the reading bias. This matches previous research as the vertical shading creates many groups to search across, if a participant is trying to use a reading strategy, which slows down response time (Nakashima and Yokosawa, 2013). This is not, however, strong evidence for visual flow, where shading would direct the eye downward, making targets in the lower left faster to find than those in the upper right.

Edge Effect

Further analyses showed the presence of an edge effect, where participants' searches were fastest with the target in the center of the grid. Slower RTs and higher error rates were found for the edges, regardless of shading. This search strategy is expected based on previous research (Baker, Morris, and Steedman, 1960). However, this edge effect is not addressed in prior research on the effects of perceptual grouping on visual search. In this middle-out search pattern, participants would need to scan across numerous perceptual groupings from the point of initial fixation to get to the center of the grid. They would then scan back to the edge, crossing still more perceptual boundaries, even in cases where the target was located in the same perceptual group as the fixation point (where the search should begin). It appears as though the top-down influences of learning this search strategy over time are more powerful than the bottom-up influences of perceptual grouping in determining search strategy.

So what do these findings mean for shading and visual flow? The interaction can be considered evidence that search will follow shading in accordance to visual flow, particularly if shading is consistent with typical reading scan paths. However, the edge effect is stronger than the effect of flow. Search will still be faster toward the middle of the grid, regardless of shading. However, before concluding that shading or other "flow" manipulations have no effect on the edge effect, it would be interesting to test a shading pattern that might better draw the eye to the edges, for example a bulls-eye pattern of shading.

Shading vs. No Shading

The other major analysis in this thesis was the comparison of performance obtained with unshaded vs. shaded grids. While we have evidence that visual flow is created, albeit rather weakly, this does not mean that the shading, nor flow, influences the overall efficiency of visual search through a grid-type layout. Our analysis comparing the shading conditions to the no shading condition found that adding shading slows down search. It also decreases accuracy. This supports Tufte's data-ink ratio design principle, in which minimalist designs are favored over those with "more ink" (Tufte, 1990). It is critical to note that the disadvantage for shading was not due to reduced contrast between targets and backgrounds in the shaded grids. Possible reasons for this decrement in performance may include disruption of normal sampling strategies. Such disruption could stem from the size and shape of the perceptual groups formed by shading.

Assuming shading effectively groups targets in a row or column, the finding of reduced efficiency in the shaded grids is inconsistent with visual search research demonstrating that the presence of perceptual groups improves performance (Treisman, 1982). This may suggests that not all groups are equally beneficial. This could be due to the oblong shape of the groups created in the grid stimuli studied here. The visual search research most commonly manipulates grouping by similarity (Niemelä & Saarinen, 2000) or by using equilateral boundaries (Nakashima and Yokosawa, 2013). In the present study, however, the distance from the center of the group (the space between the 3rd and 4th row or column) to the edge of the group (where the grey meets the white) varies greatly, from half a cell length to three full cells away. In tables, there are frequently similarly shaped, oblong groups, but they also often have strategic spacing to create gutters, using both principles of proximity and common region for rows and columns. Our stimuli used consistent spacing, so that common regions created by shading were the primary perceptual grouping principle present.

Flow Score

When analyzing the flow score data, some participants' search patterns matched a reading bias, a few went against the flow hypothesis, and a few had particularly high flow scores. The group as a whole searched following the direction of the shading, beyond just the reading bias, although the individual differences suggest the possibility of a bimodal distribution. Preliminary analysis of the individual differences suggests that having a background in design may yield results supporting visual flow, as the two participants with the most formal design training had two of the four highest flow scores.

Limitations

In this study, one of the limitations is particularly pertinent to the finding of a disadvantage for shading. The present task and stimuli may not be typical instances where shading could be of more use. Larger grids may benefit more from shading by serving as a reference while scanning across the longer distances, particularly in typical tables where rows and columns contain headings that must be referenced. Also, shading may be beneficial in helping bridge gutters seen commonly in tables.

In analyzing the flow score data, there appears to be a cluster of individuals who are strongly affected by shading in the manner predicted by visual flow. Such individual differences could be due to a number of demographic and psychographic factors, such as participants’ familiarity with design principles, their familiarity with visual search tasks, academic or professional background, primary language (for different reading biases), or many other factors. A much larger, strategically sampled group of participants would need to be tested to begin to investigate the importance of individual differences in reactions to different flow manipulations. In the present study, we failed to collect much demographic data, and the number of participants was too low to firmly conclude anything about the nature of the distribution of flow scores.

Design Implications

These research findings provide limited evidence of visual flow, a phenomenon proposed by many designers. However, perceptual grouping meant to guide serial search through a display actually decreased performance. The no shading condition was associated with the fastest and most accurate performance. This suggests that using shading in a grid is not always beneficial to performance. At any rate, the findings may indicate that graphic designers are not able to direct search patterns as well as they would like to believe.

Future Research

Future research should look for instances where shading can improve performance in grid-like formats. For example, with a larger number of rows and columns, or in cases with gutters, shading may be beneficial as a reference point across the longer distances. This benefit may be particularly true if there are headings for the rows or columns that must be referenced as seen in many tables. Overall, using shading in conjunction with other perceptual grouping principles should be explored. Other shading patterns could also be used to selectively influence certain top-down search strategies such as the edge effect.

Because “flow” refers to the predictability of viewers’ scan paths through a display, it is critical for future research to use eye-tracking as a more direct measure. Such data could be used to strengthen conclusions inferred from response times, such as the presence of a reading bias and middle-out search strategies. Looking at the direction of the first saccadic movement at the onset of the grid would be particularly interesting.

Future research should also compare individuals from different demographics, particularly exploring those with a background in design fields, specifically graphic design. Does familiarity with design principles affect susceptibility to visual flow manipulations? Or, perhaps, are those drawn to design professions more likely to have particular perceptual characteristics that make it more difficult for them to ignore or override design elements that foster grouping elements? Do designers feel so strongly about visual flow because it affects them, personally, very strongly? Finally, having graphic designers create grids with the goal of creating particular patterns of visual flow, would allow up to see whether such stimuli are more effective than the ones studied here, and to determine what manipulations of flow designers prefer.

Closing Thoughts

In this thesis, we have found weak evidence of visual flow using zebra striping in a grid format. However, the effects of visual flow are attenuated by reading biases and are overridden by the edge effect. Furthermore, when there is no shading at all, thusly no explicit visual flow, performance improves. These findings contradict the claims designers make about being able to guide attention through their work by manipulating design elements to create perceptual groupings, when, in fact, such groupings inhibit performance.

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Michael Patrick Lee

Education

University of Kentucky:

- B.A., Psychology, May 2012, Summa Cum Laude
- M.S., Experimental Psychology, August 2014 (expected)
- Human-Technology Interaction Certificate (expected)

Selected Awards and Honors

2012 Graduation- Departmental and University Honors

2012 Outstanding Psychology Major Award

2012 Oswald Research and Creativity Award

2012 Maurice A. Clay Award for the Outstanding Graduating Senior in the College of Arts & Sciences

2011 Summer Research and Creativity Grant

Professional Experience:

Internships

2014 (fall)- present	Human Factors Intern General Electric – Appliances and Lighting Manager: Will Seidelman, M.S. (will.seidelman@gmail.com)
2012 (summer)	Human Factors Intern General Electric – Appliances and Lighting Manager: Cathy Emery, Ph.D. (cathy.emery@uky.edu)

Research Assistant

2011- present	University of Kentucky Center for Visualization and Virtual Environments Adviser: C. Melody Carswell, Ph.D. (melody.carswell@uky.edu)

Teaching Assistant

2014 (spring & summer)	Applications of Statistics in Psychology (PSY 216). University of Kentucky. Professor: Steven Arthur, Ph.D.
2013 (spring & fall)	Cognitive Processes Advance Lecture/Lab (PSY 427). University of Kentucky. Professor: Jonathan Golding, Ph.D. (spring); Larry Gottlob, Ph.D. (fall)

2012 (fall) Introduction to Psychology (PSY 100). University of Kentucky. Professor: Jonathan Golding, Ph.D.

Peer-Reviewed Publications

Lee, M. P., Carswell, C.M., Seidelman, W., & Sublette, M. (In Press). A Case Study of Human Factors Issues with Environmental Control in a New Energy-Efficient Building. *Ergonomics in Design*

Lee, M. P., Kent, T., Carswell, C.M., Seidelman, W., & Sublette, M. (In Press). Zebra-Striping: Visual Flow in Grid-based Graphic Design. *Proceedings of the 2014 International Annual Meeting of the Human Factors and Ergonomics Society,* Chicago, IL

Lee, M., Carswell, C.M., Seidelman, W., & Sublette, M. (2013). Green Expectations: The Story of a Customizable Lighting Control Panel Designed to Reduce Energy Use. *Proceedings of the 2013 International Annual Meeting of the Human Factors and Ergonomics Society,* San Diego, CA: The Human Factors and Ergonomics Society

Lee, M., Carswell, C.M., Seidelman, W., & Sublette, M. (2012). The design of product comparison tables and its effects on decision making. *Proceedings of the 56th Annual Meeting of the Human Factors and Ergonomics Society,* Boston, MA: The Human Factors and Ergonomics Society

Seidelman, W., Carswell, C. M., Kent, T., Lee, M., Fu, B., & Yang, R. (In Press). Development of a Hybrid Reality Display for Welders through Applied Cognitive Task Analysis. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting*. Chicago, IL: Human Factors and Ergonomics Society.

Seidelman, W., Carswell, C. M., Kent, T., Lee, M., Fu, B., & Yang, R. (2014). User Centered Design of a Hybrid-Reality Display for Weld Monitoring. *CHI '14 Extended Abstracts on Human Factors in Computing Systems.* Toronto: ACM.

Sublette, M., Carswell, C.M., Seidelman, W., Lee, M., & Seals, W.B., (2013). Further Explorations of the “White Space” Bias in Users’ Anticipation of Task Workload. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting*. San Diego, CA: Human Factors and Ergonomics Society.

Crouch, J., Lee, M., Carswell, C.M., Patrick, T., Seidelman, W., & Sublette, M., (2013). The Impact of Aesthetic Design on Bus Shelter Usability. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting*. San Diego, CA: Human Factors and Ergonomics Society.

Graduate Course Work

University of Kentucky:

CE 635	Highway Safety	Nick Stamatiadis / Reg Souleyrette
AAD 600	Arts Administration Technologies	Jessica Shields
PSY 621	Proseminar in Learning	Chana Akins
PSY 623	Proseminar in Sensation and Perception	C. Melody Carswell / Ramesh Bhatt
PSY 611	Psychological Research (Regression)	Peggy Keller
PSY 610	Psychometrics (ANOVA)	Saul Miller
EDC 726	Mixed Methods Research	Joan Mazur
PSY 562	Human Technology Interaction	C. Melody Carswell