Exploratory Discoveries from Eye-Tracking Tests of Wertheimer’s Gestalt Patterns

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In this study, the authors use a novel eye-tracking technology to determine how viewing behavior complies with Wertheimer’s descriptions of Gestalt principles of similarity, proximity, continuation and closure. The results show that viewers respond predictably to most Gestalt principles and that there are nuances to note when it comes to better understanding the role of visual attention in the closure principle and competing principles. In addition, the results reveal a fundamental distinction between visual attention and visual perception. By grasping this critical difference between attention and perception, designers may become more successful in applying Gestalt principles to their design.

Max Wertheimer’s findings from the “dot study” [1] shaped the Gestalt principles of similarity, proximity, continuation and closure, and were refined through works by Wolfgang Köhler [2], Kurt Koßka [3] and Wolfgang Metzger [4]. As the Gestalt psychologists’ research was translated into English, artists and designers increasingly spoke of visual art in terms that were, in part, derived from these same organizing principles. Of particular influence in the application of Gestalt in design education were works by György Kepes [5] and Rudolf Arnheim [6]. In subsequent years, artists and designers have increasingly made references to Gestalt principles as fundamental to viewers’ engagement in visual communication.

Even though designers have learned Gestalt principles as fundamental laws, the measurement limitations have prevented us from developing a good way to test how viewers respond to designs that apply the knowledge of Gestalt principles (see Wagemans et al. [7] and Jäkel et al. [8] for more in-depth literature reviews of Gestalt principles). To deliver intended messages to an audience, designers should know how the audiences “read” their design: where they start, how they “follow” and what they concentrate on. Therefore, examining viewers’ visual focus and attention order is critical for designers to apply Gestalt principles in their designs. To address this gap, we designed an eye-tracking study with the goal of understanding the connection between visual attention and perception using classic patterns in Wertheimer’s original paper. Focusing on original, basic patterns ensures us to more effectively control for other factors often appearing in complex designs (color, size, faces, familiarity, competing principles, etc.) that deploy some aspects of Gestalt principles.

Driven in part by the “eye-mind hypothesis” [9], eye tracking is considered effective in assessing a user’s attention, as it reveals how the user reads and scans information by capturing users’ eye fixation–based metrics [10]. Fixations, or time spent looking at specific locations [11], have been linked to cognitive processes indicating various forms of attention and cognitive load [12]. Eye tracking–based metrics have been used across many disciplines to understand and improve design in architecture [13], information visualization [14], mechanical design [15] and art [16]. Our study adopts this novel eye-tracking technology to discover if participants “read” patterns as Wertheimer anticipated.

METHODS

Our experiment included 49 participants (all undergraduates, 22 women, 27 men, median age = 21) from a midwestern U.S. university. Each participant had normal or corrected-to-normal vision. All participants were naive to the aims of the study and had no previous knowledge of Gestalt visual principles. The participants were asked to view the images freely; we did not give them a task, since that would strongly bias their eye movements.

Our study included 10 visual stimuli: eight reproduced from original patterns in Wertheimer’s 1923 paper and two additional patterns we created to study the closure principle. A survey question followed each stimulus to specify how a participant interpreted that image. After eye-tracking calibration, a participant looked at each image (randomly) for six seconds and then answered a survey question.
Eye movements were recorded with a Tobii Pro X3-120 desk-mounted eye tracker (120 Hz). A nine-point calibration procedure occurred before each recording to ensure the accuracy of the eye-tracking metrics. Visual stimuli appeared on a 27-inch monitor with a screen resolution of 1920 x 1080 pixels. We used iMotions software to collect and analyze data. The software allowed us to create two types of heat maps: One summarizes the participants’ cumulative fixations, and the other, a series of 12 heat maps (small multiples heat map), provides us with participants’ eye-fixation sequences in 0.5-second increments. (More detailed experimental setup information—protocols, further equipment specification and task/process description—is available upon request.)

RESULTS
Similarity
Wertheimer introduced the similarity principle as follows: “the tendency of like parts to band together—which we may call the factor of similarity” [17]. Using the patterns in Wertheimer’s paper (Fig. 1), we expected viewers to group the black dots and white circles to read horizontal lines and vertical lines.

In Fig. 1, the summarized similarity (horizontal) heat map shows an irregular horizontal shape indicating that viewers “read” horizontal lines rather than vertical lines; we observe the opposite result in the summarized similarity (vertical) heat map, where an irregular vertical shape reveals that viewers read vertical lines rather than horizontal lines. Using the survey question, 46 out of 49 participants indicated they “read” horizontal lines in similarity (horizontal), and 44 out of 49 “read” vertical lines in similarity (vertical).

In addition, the small multiples heat maps reveal the attention order. In the small multiples similarity (horizontal) one, participants started to spot three black-dot lines on the top of the pattern for 1.5 seconds, then extended to black-dot lines and white-circle lines for one second and then jumped back and forth between black-dot lines across the pattern. This indicates participants first grouped same-color dots as lines (black-dot and white-circle lines) and then grouped same-color lines.

The small multiples similarity (vertical) heat map indicates that in the first 2.5 seconds participants focused on black-dot lines up and down. Then they looked across lines horizontally. For the last 1.5 seconds, they looked at black-dot lines up and down again. This suggests that participants focused on black-dot lines first and spent most of their attention on them based on similarity. In summary, most participants grouped elements based on color, which is in line with the Gestalt similarity principle.

Proximity
While describing the principle of proximity, Wertheimer wrote this about the dots pattern in Fig. 2 [18]: “Quite obviously the arrangement B as abc/def/ghi is greatly superior to ceg/hij/ikm” [19]. After reviewing other patterns (Fig. 3), he concluded: “In each of the above cases that form of grouping is most natural which involves the smallest interval. They all show, that is to say, the predominant influence of what we may call The Factor of Proximity” [20]. In short, Wertheimer

![Fig. 1. Similarity (horizontal) and similarity (vertical). (© Xinran Hu)](image-url)
Fig. 2. Proximity. (© Xinran Hu)

Fig. 3. Proximity and similarity. (© Xinran Hu)
believed people tend to group closed elements based on the proximity principle.

The summarized heat map in Fig. 2 suggests that participants focused on the second three-dot diagonal line and then moved to the third and fourth diagonals. Furthermore, 45 out of 49 viewers stated that they grouped three dots as one unit and “read” the pattern as six short diagonals.

In addition, the small multiples heat map in Fig. 2 indicates participants focused back and forth on the second and third short diagonal lines during the first three seconds and then expanded to the fourth, fifth and sixth diagonal lines. This suggests that participants treated three dots as a unit based on proximity and then connected units.

In this study, we also considered a scenario where the pattern included competing principles. Using Fig. 3, Wertheimer stated, “An illustration of opposition [occurs] in which similarity is victorious despite the preferential status given to proximity” [21]. However, the summarized heat map is not conclusive if similarity or proximity dominates the pattern.

When we looked at their verbal responses, 21 participants grouped three dots to make a diagonal and read the entire pattern as short diagonals; 22 grouped black dots and white circles; five saw three horizontal lines; and one indicated they read diagonals first and black dots later. Our survey results suggest, therefore, that neither similarity nor proximity dominates.

The small multiples heat map in Fig. 3 also shows that focus started on diagonals for the first two seconds, indicating that proximity dominates. In contrast, in the next four seconds, the focus area includes either two or three same-color dots (black or white) from different diagonals, indicating viewers grouped dots based on similarity. When proximity and similarity groupings happen simultaneously, either grouping by proximity is reinforced by similarity or is opposed by similarity [22]. In this case, grouping by proximity was opposed by similarity.

In another test of proximity (Fig. 4), the summarized heat map reveals that viewers focused on a three-dot unit and the adjacent five-dot group, resulting in a large, cocoon-like shape as the focus area. Among those tested, 44 out of 49 viewers indicated they had grouped three (bcd) dots, then five (efghi) dots and then seven (jklmnop) dots.

In addition, the small multiples heat map in Fig. 4 provides a detailed fixation sequence. Participants grouped close dots as a unit and read back and forth among these units: three-dot, five-dot and seven-dot, suggesting a reliance on the proximity principle.

Continuation
Wertheimer noted:

Taken individually, the points in B are in closer proximity to the individual points of A (or C) than the points of A and C are to each other. Nevertheless, the perceived grouping is not AB/C or BC/A, but quite clearly “a horizontal line and a vertical line”—i.e. AC/B... We are dealing now with a new principle which we may call The Factor of Direction [23] [Fig. 5].
From the heat map in Fig. 5, we observed that the participants' focus area was centered on B to make a vertical line. Yet, when asked, "How do you read this pattern?", 26 participants chose AC/B, 21 chose AB/C or BC/A and the remaining two chose "others." That means 53% of viewers supported Wertheimer's statement about Fig. 5. The small multiples heat map in Fig. 5 also indicates the participants' focus was on vertical line B, looking up and down.

For the dots pattern shown in Fig. 6, Wertheimer explains, "The direction may still be unequivocally given even when curved lines are used is of course obvious" [24]. He believed that we read AC and add the diagonal B afterward [25]. The heat map in Fig. 6 reveals that the primary focus was on the short diagonal on the top of the arch. Responding to the survey question "How do you read the pattern?", 41 out of 49 viewers chose "Read AC as the main part with B as a smaller part attached to it." Again, survey responses supported Wertheimer's assumption: The majority finished the arch AC and then kept their focus on B. However, the small multiples heat map in Fig. 6 indicates that participants consistently and mostly focused on diagonal line B.

Now we found a disjunction between heat map results and viewers' survey responses. The heat maps indicate participants' attention stayed on vertical line B (Fig. 5) and diagonal line B (Fig. 6), but those heat maps fail to show that participants significantly recognized a horizontal line or an arch. Therefore, we know that while the heat map provides an accurate record of viewers' attention, it does not fully indicate the viewers' perception.

Closure

Wertheimer used the geometric pattern shown in Fig. 7 to explain the factor of closure: "If A, B, C, D are given and AB/CD constitute two self-enclosed units, then this arrangement rather than AC/BD will be apprehended" [26]. Wertheimer believed that viewers would perceive two completed shapes: AB, an eye shape, and CD, a square. He contended that viewers would not read AC and BD together.

The heat map in Fig. 7 reveals that participants mostly attended to the conjunction of the two shapes, not the separate shapes themselves. The small multiples heat map indicates that participants' attention started at the conjunction area of AB, an eye shape, and CD, a square, and then moved around the eye area. After that, attention moved between the conjunction area and the square. At the last second, attention went back to the conjunction area. Survey questions revealed that all 49 participants perceived AB and CD as two separate shapes.

However, perhaps this pattern is not the best example of the closure principle. Discussing this principle, Gregg Berryman [27] states that human beings have a natural tendency to close gaps and complete an unfinished form. Therefore, we designed our own graphics in a follow-up experiment with 28 participants to test the principle of closure using closed/unclosed shapes. We used a simple full circle and contrasted it to a circle with two gaps (Fig. 8). The heat map of the full circle shows a focal point at the top-center, while the heat map of the circle with gaps indicates that the two gaps con-
Fig. 6. Continuation curved. (© Xinran Hu)

Fig. 7. Closure. (© Xinran Hu)
sttute two focal points. This phenomenon might mean that because viewers “tend to close the gap,” they spend more time looking at the gap and examining the spot. This discovery surprised us because, in perception, viewers ignore gaps to complete the form; therefore, the gap seems unimportant. However, it is the gap that draws attention and thus becomes the focus. In practice, a designer should wisely make use of the gaps instead of ignoring them.

In the survey responses, all 28 participants read a completed circle as “a circle” and a circle with gaps as “a circle with two gaps.” These results indicate that, as human beings, we tend to close gaps, to complete an unfinished form; even with two gaps in Fig. 8, we still see it as a circle instead of two curves.

**IMPLICATIONS**

This is, to our knowledge, the first study to empirically assess the link between Gestalt principles, viewers’ visual attention and their perception using eye-tracking technology. As such, this study is one of the steps needed in bridging the gap between Gestalt theory and design practice and addressing criticism of Gestalt principles based on their lack of measurement and precision [28,29]. More specifically, our study offers five key findings. First, from eye fixation–based heat map analyses and survey responses, we concluded that, except in one case, participants in our study responded to Gestalt principles as Wertheimer expected. Second, we found that although eye tracking can monitor where, when and at what viewers look, this technology cannot reflect whole intellectual processes—it cannot tell us how the brain reads and thinks, since the direction of gaze can be either coupled or uncoupled to visual attention [30]. Therefore, when we use an eye tracker to test design work, we must realize that the result is only a partial, although meaningful, record of how a viewer received visual information.

Third, our study supports the critical insight that visual focus and attention order do not always match the visual perception. For example, even though we know that viewers close gaps in incomplete forms, we may fail to realize that the gap itself is a focal point. Our study suggests that users will exert visual effort and focus on those gaps to facilitate the perception of the complete form. Therefore, designers should take a careful, nuanced approach when applying the closure principle to design work.

Fourth, despite our assumptions that viewers read the way we design based on Gestalt principles, sometimes eye-tracking tests reveal the difference. For example, in Fig. 7, Wertheimer’s assumption differed from the eye-tracking test results and survey responses: Our results did not show that similarity dominated. The third and fourth findings reflect a gap between Gestalt principles and design practice, which leads us to the next stage of the study.

Fifth, despite some of its limitations, our study introduced a novel method of empirically evaluating visual attention and perception in the context of design application of Gestalt principles. This method includes triangulation using (1) eye fixation–based cumulative heatmaps, (2) small multiples heat maps to capture attention order and (3) perception interpretation through survey questions. Only through this triangulation approach was it possible for us to confirm and identify Gestalt principle nuances. This contribution is significant in the context of existing Gestalt-focused literature that currently does not deploy this method, thus minimizing a potential misinterpretation of Gestalt visual principles and their application.

Every study has limitations and resulting opportunities. Our study is no different in that respect. We encourage further studies to replicate these findings using a larger sample and including more varied participants. Similarly, we focused on relatively simple patterns as we purposefully limited the scope to minimize potential confounding factors often present in more complex designs. Lastly, this was an exploratory study, with an appropriate focus on visual and descriptive result interpretation. Encouraged by our findings, we believe more confirmatory empirical tests of each principle using formal hypothesis and statistical analysis are needed.

**CONCLUSION**

Visual sensation is a core part of design perception. Studying the impact (perception and the resulting cognitive processes) of Gestalt visual principles without understanding and measuring visual focus and attention order can limit our knowledge of the practical application of Gestalt principles. Our use of eye-tracking technology is, to our knowledge, the first attempt to connect the relationship between visual attention and perception in the Gestalt context. We will continue this research by adding more design work to study viewers’ responses and measure how Gestalt principles impact visual communication. In the end, perhaps we can learn how better to apply theory to design practice and thereby achieve more efficient and effective communication.
References and Notes


18 All patterns in Figs 1–7 without superimposed eye gaze heatmap come from Wertheimer's original work. Images with eye gaze heatmap represent the authors' adaptation of the original work and collected eye tracking data.


22 Koffka [3].


25 Wertheimer [1].


28 Wagemans et al. [7].

29 Jäkel et al. [8].


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