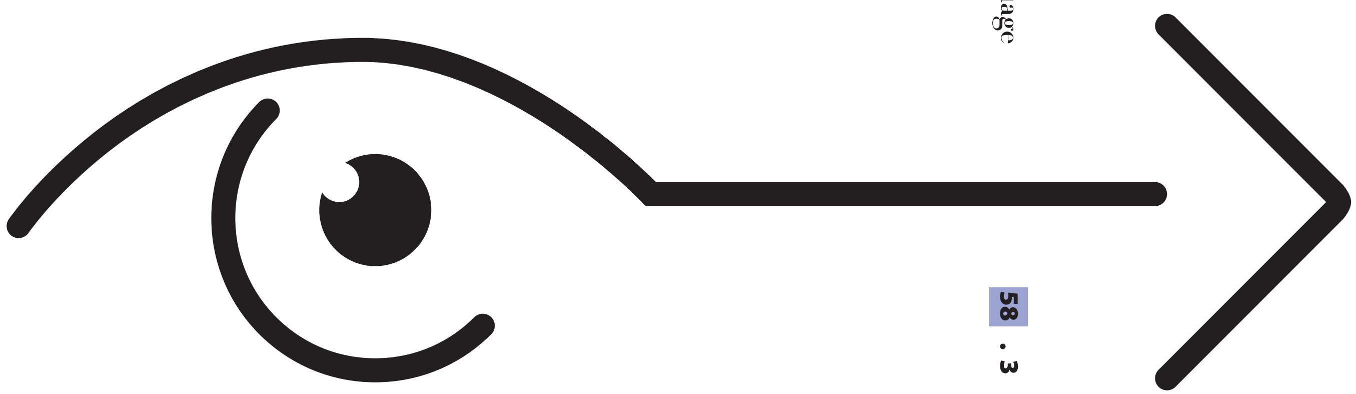

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a study exploring visual crowding within the frame of a pictogram, measuring the effect of spacing between two icons and between icons and an outline frame on icon recognition, concluding that the most limiting factor for recognition is two icons overlapping or placed in close proximity to each other

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Crowding Impairs Recognition of Framed Icons

Pia Pedersen
Chiron Oderkerk
Sofie Beier

Abstract

Pictograms are graphic symbols designed to function within limited space. They are characterized by overlapping elements within a frame, which can lead to visual crowding, where neighboring objects merge and become indistinguishable. While visual crowding has been extensively studied in reading and vision research, its impact on pictograms remains underexplored.

This study aimed to measure the effect of spacing between two icons and between icons and an outline frame on icon recognition. Using Auckland Optotypes to construct fictive pictograms, we conducted an experiment within an object recognition experimental paradigm, involving 25 participants. Results showed significant interaction between the effects of icon-frame distance and the spacing between the two icons, with the most limiting factor for recognition being two icons overlapping or placed in close proximity to each other. Strategic spacing adjustments within framed pictograms can reduce the impact of crowding on recognition, particularly when icons are not overlapping.

Keywords
icons
crowding
psychophysics

1. Introduction

Pictograms are positioned within the broader category of graphic symbols and are defined by their capacity to visually echo the ideas, concepts, or objects they intend to convey through the use of simple, stylized, and figurative designs (Ota, 1987, s. 18; Tijus et al., 2007; Zender & Mejía, 2013). Functioning as efficient communicative tools, pictograms play a role in democratically disseminating information across diverse places and contexts, such as for wayfinding (Lee et al., 2014; Rousek & Hallbeck, 2011), warning (Roca et al., 2018; Waterson et al., 2012) and providing medical information (Merks et al., 2019; Ng et al., 2017; Pedersen, 2019) ii. Consider pharmaceutical pictograms, exemplified in Fig. 1, which convey significant messages about medications that are complicated or closely related. In such scenarios, the addition of specific details and information becomes essential to enable patients to distinguish and comprehend the nuanced meanings embedded in the pictograms (Pedersen, 2019, p. 75).

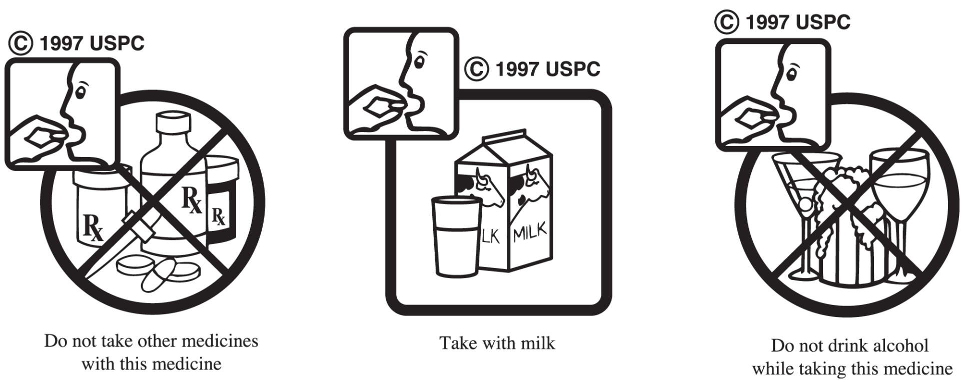


Figure 1.

Examples of United States Pharmacopeia (USP) pictograms, representing a large set of easily accessible pictograms that are frequently found in the research literature. The three examples provided, each concerning how to take medicines, illustrate the level of detail and information that may be necessary to inform patients.

It is well known that the design of pictograms can influence recognition, particularly in small visual sizes (Pedersen et al., 2022), visual search, and comprehension (Rousek & Hallbeck, 2011). The visual elements within the pictogram must be selected and combined to form the intended meaning and drawn in a way that is easily comprehensible (Strauss & Zender, 2017; Zender & Mejía, 2013) and legible (Pedersen, 2019). Whether the intended meaning of a pictogram is understood involves an interplay of these and other factors.

The present study focused on the legibility of pictograms and the spatial relationship of their elements. Strauss & Zender (2017) have developed a taxonomy that distinguishes between graphemes, icons, and pictograms, which will constitute the use of terminology in this study. Graphemes are small visual elements that do not necessarily have a meaning of their own; icons consist of graphemes and represent a simple concept or object; and pictograms typically represent more complex concepts or ideas, as depicted in Fig. 2. Thus, depending on the referent they represent, pictograms can either consist of one or a combination of icons. This distinction is relevant for evaluating pictogram legibility because it provides a framework for isolating elements and controlling stimuli.

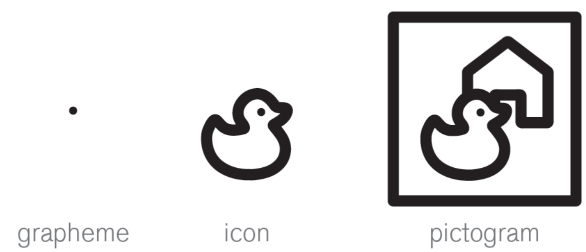


Figure 2.

The distinction between grapheme, icon, and pictogram according to the taxonomy by Strauss & Zender (2017).

Pictograms must function in different sizes, and because of the limitation of space, icons within the pictogram often overlap (exemplified in Fig. 1). In addition, they are often placed within a surrounding shape which is either indented to communicate a specific meaning or to protect and further separate a pictogram from surrounding elements. The surrounding shape is known to be an important component of warning signs specifically (Ma et al., 2018). As the 'ISO 7010 – Graphical symbols — Safety colours and safety signs — Registered safety signs' demonstrate, the square is used to provide information, the triangle for warnings, and the circle for prohibitions and requirements (see also Kepes, 1966). Despite the purpose of the background shape, we are yet to fully understand how to optimize the spatial relationship between the frame and the placement of icons within a pictogram. In this study, we used the square as a background shape because it is used for many types of pictograms and typically for framing the pictogram elements if not for conveying a specific meaning.

1.1 Frame and crowding

One fundamental limitation of visual perception is the phenomenon known as crowding, where individual objects placed in close proximity tend to perceptually merge. Research indicates that object framing increases the risk of crowding (Herzog et al., 2015). Crowding is strongest between objects with similar features, while between objects with, for instance, different shapes, crowding is reduced (Levi et al., 1994). Crowding has been found in the visual periphery (Bouma, 1970), at small visual angles in the center of vision (Coates et al., 2018), and with short exposure to stimuli (Lev et al., 2014), suggesting that most reading situations involving pictograms will be affected by some level of crowding between individual elements.

There is a consensus within vision research that object recognition is a two-stage process of first detecting individual features and second integrating features into an image (Levi, 2008; Pelli & Tillman, 2008). Crowding does not appear to affect the first stage of feature detection; however, it affects the second stage, where the feature integration can be disproportionately large so that separate neighboring parts appear connected (Pelli et al., 2004). In other words, the smaller features (graphemes and icons) of a pictogram can be individually identified; however, when the perceptual system tries to integrate these features into a whole pictogram, the features might perceptually merge, leading to failure of recognition or misinterpretation.

To avoid this crowding effect, placing objects at considerable spatial distances is recommended (Pelli, 2008). However, this isn't always feasible in pictogram design, where multiple icons frequently need to coexist within a relatively confined spatial area. Consequently, the intentional overlap of icons is frequently adopted in the design of complex pictograms.

1.2 Legibility of graphic symbols

From a broad perceptive, graphic symbols (including pictograms and icons) have been extensively studied across subjects and contexts. However, only a few studies have explored approaches for enhancing their legibility. One possible explanation for this gap could be the tradition of testing graphic symbols at larger sizes, where comprehension is less affected by visibility issues (Pedersen, 2019, p. 88). Some studies that investigate visibility make use of a blurring filter to clarify how to redesign a graphic symbol effectively.

For instance, research addressing the visibility of symbolic highway signs demonstrated improvement through shape modification. This involved maximizing contour size and increasing contour separation within a fixed diamond-shaped frame (Kline & Fuchs, 1993). Additionally, symbol signs with high levels of blur tolerance—meaning symbols not heavily reliant on high spatial frequencies to convey critical information—prove more legible at greater viewing distances (Schieber, 1994). This suggests that the deliberate manipulation of negative space within a frame could be an effective strategy for optimizing the visibility of graphic symbols.

Other studies address the challenges posed by overlapping elements within limited space, particularly in the recognition of prohibitive symbols, a scenario influenced by the interaction between the negation slash and the pictorial (Murray et al., 1998; Shieh & Huang, 2004). In conditions of reduced luminance contrast or limited exposure time, the size of the graphic symbol within the circle and the thickness of the negation have been found to significantly impact glance legibility (Shieh & Huang, 2004). In our previous study (Pedersen et al., 2022), we demonstrated an effect of skeleton simplification on the recognition of USP pictograms, indicating that pictograms with crowded and overlapping elements performed significantly worse. Building on this, the current experiment aimed to optimize the use of space within the pictogram frame by minimizing the effects of crowding.

1.3 Optotypes as stimuli

Compared to letters, testing the effect of crowding in pictograms poses a challenge due to their diverse shapes, strokes, areas, varying numbers of elements, and variations in the complexity levels of the shapes. Using controlled stimuli rather than "real-life" pictograms becomes essential to determine the crowding effect.

Several validated methods exist for measuring visual acuity (VA) through pictures, such as LEA symbols, Kay Pictures, and Auckland Optotypes. The LEA symbols (Hyvärinen et al., 1980) are commonly employed for pre-literate children, featuring four objects, a square, an apple, a house, and a circle. Similarly, the Kay Picture test of VA (Kay, 1983; Milling et al., 2015) includes six picture optotypes – a house, a car, a star, an apple, a shoe, and a duck. In this experiment, we utilisized the Auckland Optotypes (Fig. 3) as stimuli because it is an open-access set with 10 icons designed for more consistent assessments. Developed with considerations for uniform stroke width, a 1:1 aspect ratio, perimetric complexity, and mean overlap, each Auckland Optotype has been designed to be adequately unique to ensure easy and unambiguous identification (Hamm et al., 2018). With more items than common pictorial VA methods, the Auckland Optotypes achieve higher reliability, particularly concerning the percentage of guessing answers (Ibid.). Using two Auckland Optotypes as icons surrounded by a frame, we constructed fictive pictograms.

While the Auckland Optotypes still await testing in crowded settings, the recommended practice of using Lea symbols in visual acuity tests for preschool children involves flanking each optotype with four bars. This specifically creates a crowding rectangle, enhancing the detection of lazy eyes (amblyopia) (Cotter et al., 2015, p. 9).

Our hypothesis suggests that as the distance between two icons decreases, while maintaining a consistent distance between the icons and the frame through a proportional frame size, the crowding effect is expected to increase, resulting in a decline in recognition rate. Conversely, if the distance between icons decreases but the distance between the frame and the icon increases due to a *uniform frame size*, either the proximity of the frame to the icons or the closeness between the icons themselves will amplify the crowding effect, resulting in a decline in recognition rate. Whether it is the frame surrounding the icons or the icons themselves, the crowding effect is anticipated to be equally significant. Moreover, the cumulative impact of crowding both between icons and between icons and frames is likely to contribute to a more pronounced decline in recognition rates.

2. Experiment

2.1 Respondents

The experiment included 25 participants aged between 18 and 36 years (M_{age} = 25.25 years, *SD* = 4.36 years, 14 women). Participants were recruited through a recruitment website (Forsoegsperson.dk), and all received a gift card of DKK 300 for their participation. The experiment took place at The Royal Danish Academy and adhered to the rules of the Declaration of Helsinki and The Danish Code of Conduct for Research Integrity.

2.2 Stimuli

The Auckland Optotypes consist of 10 icons specifically designed and validated for visual acuity tests, see Figure 3.

Figure 3.

The ten Auckland Optotypes (first line). Icons that are asymmetrical were flipped (second line). This was done to ensure equal balance when presented on both the left and the right, and to facilitate overlapping.

All icons were redrawn in Glyphs 3, a high-precision vector software for icon and type design, to ensure optimal resolution and precise size control. Each item – frame and icons – maintained a consistent stroke width of 26 pixels and a 1:1 aspect ratio.

Given our focus on testing the effect of spacing between icons and between icons and a frame, we deliberately included different icon spacings and frame sizes across conditions. The objective was for the locations and size of the target icons to be consistent, regardless of the size of the frame or the spacing between the icons. To achieve this, a systematic approach was developed to maintain consistent and equalized spacing, allowing for easy implementation whether the icons overlapped or were spaced apart.

All frames were constructed within a 1000-pixel square grid, divided into units of 40 pixels. Within this grid each icon measured 214x214 pixels. Three specific spacings were determined:

Spacing S: 120 pixels from center-to-center of the icons
Spacing M: 240 pixels from center-to-center of the icons
Spacing L: 320 pixels from center-to-center of the icons.

These spacings were incorporated into two types of frames: a uniform and a proportional. The uniform frame maintained a constant size of 560x560 pixels in each condition while the proportional frame adjusted its width based on the icon spacing to ensure a consistent distance between the icon center and frame edge. Frame P spacing S measured 440 pixels wide, Frame P spacing M measured 560 pixels wide, and Frame P spacing L measured 640 pixels wide. For example, in Spacing L Frame P, the icons touched the frame, whereas in Spacing S, the icons always overlapped.

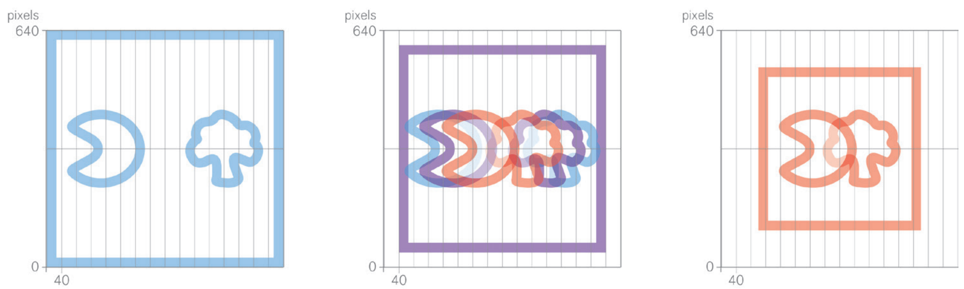


FIGURE 4.

The template was built based on units of 40 pixels.

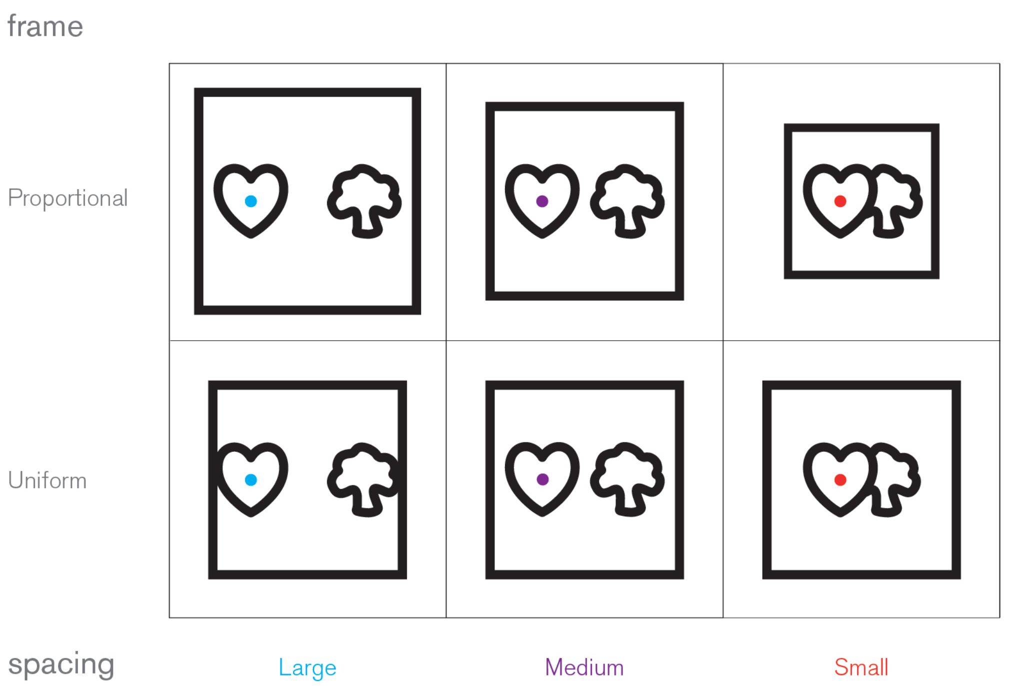


FIGURE 5.

The six different conditions. The colored dot in the target icon represents the center of the screen.

2.3 Apparatus

The experiment was conducted in a darkened room, with stimuli displayed in black (#000000) against a light background (#dadada) on a backlit 17-inch IBM/Sony CRT monitor (refresh rate = 85hz, resolution = 1024x768). The experiment was created using the software OpenSeame 3.2 (Mathôt et al., 2012).

2.4 Task and procedure

In the test procedure, participants were tasked with reporting the identity of the centrally presented target icon. This target-icon comprised part of the pictogram-stimulus, as it was flanked on the left or right by the distractor-icon, and both were surrounded by the frame (see 'Stimuli'). A trial was initiated by a black central fixation cross, size 0.63° by 0.63°—at 200 cm—presented for a variable duration of 1.300 ms with a uniformly distributed jitter of ±300 ms, followed by a 500 ms locational cue, and either the word 'LEFT' or 'RIGHT' that denoted which of the two icons was to be identified and reported. The pictogram-stimulus was then presented for 500 ms, followed by a 500 ms backward mask.

The size of the target-icon—and consequently the size of the pictogram-stimulus and backward mask—was determined separately for each participant at the start of the experimental session using an adaptive accelerated staircase procedure (Kesten, 1958; Treutwein, 1995). Specifically, the size of the pictogram-stimulus was set such that participants would correctly identify a target-icon, unflanked by a frame or distractor-icon, 75% of the time. During the staircase procedure, participants performed a similar task to the experimental test blocks, with the following differences: in each trial, participants were only presented with an isolated target-icon, unflanked by either a distractor-icon or a frame. Following a response, they received feedback in the form or a green fixation cross for a correct response and red for an incorrect response. Lastly, the size of the target-icon in the following trial was dependent on the response accuracy during the preceding trial. Please see Oderkerk & Beier, 2022 for details on the implementation of the adaptive accelerated staircase procedure.

The stimulus was immediately followed by a backward mask for 500 ms, consisting of a rectangular noise patch of variable height and width that was equal to the size of the pictogram-stimulus. Upon the offset of the backward mask, the participant was presented with the 10 possible icons included in the experiment, oriented left or right as the target icon. Participants responded using a mouse to identify the target-icon by clicking it, or by clicking elsewhere on the screen to continue to the next trial without reporting an icon. Following the participant's response, a coloured fixation cross provided feedback. Green denoted that the response was correct; red denoted that the response was incorrect or had not been given.

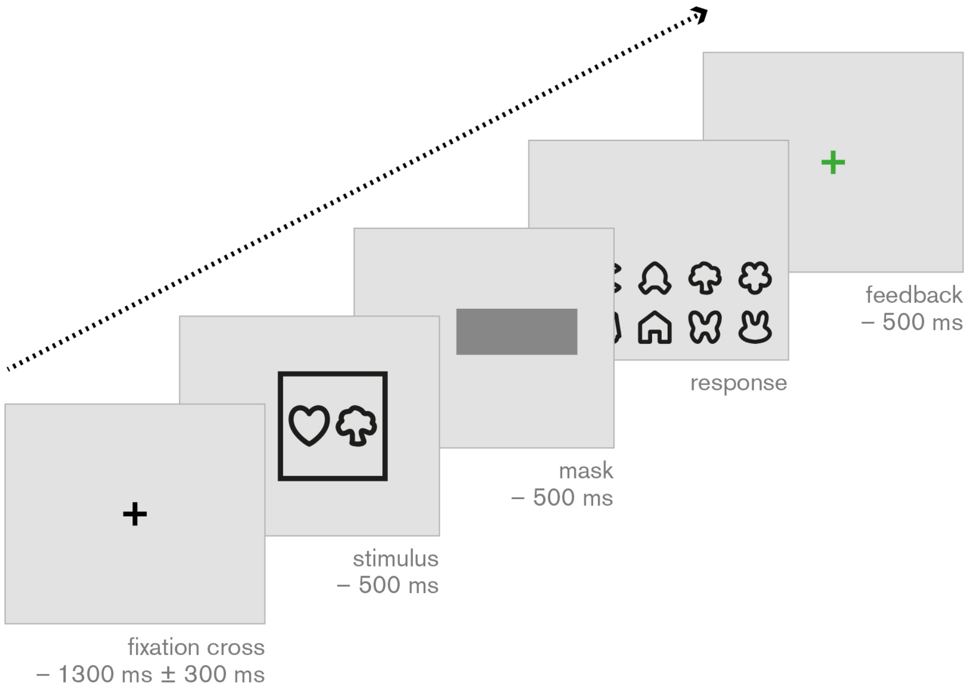


Figure 6.

Outline of the trial used in the staircase procedure and the regular experiment trials.

Each icon was presented as the target-icon in every block an equal number of times, in a randomised order. The identity of the distractor-icon was randomised and differed from the target-icon. The conditions of the frame type (i.e., Proportional or Uniform), spacing (Large, Medium, or Small), and icon target location (i.e., left or right) were varied across the test blocks. To counteract carryover effects, spacing conditions were counterbalanced using a balanced Latin-square design. Frame type was counterbalanced across participants, such that one would first see all the Proportional frame blocks, followed by all the Uniform frame blocks, or vice versa. Target location alternated after every block, with the order being counterbalanced across participants. This yielded 24 separate block orders. Participants took part in a staircase procedure for a variable number of trials, followed by a practice block of 24 trials, and 12 test blocks of 20 trials each.

3. Results

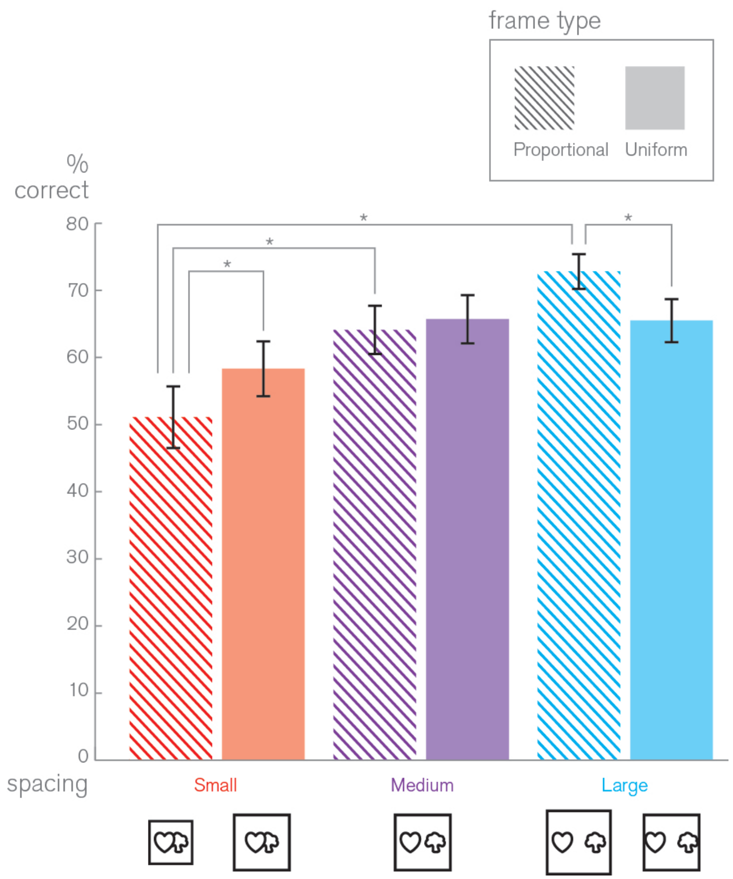
3.1 Data analysis

A 2 (Frame: Proportional vs Uniform) x 3 (Spacing: Large, Medium, Small) repeated measures ANOVA indicated a small significant Frame*Spacing interaction $F(1.60, 36.69) = 19.31$, $p < .001$, $\omega^2 = 0.029$, as well as a main effect of Spacing, $F(2, 46) = 27.43$, $p < .001$, $\omega^2 = 0.104$, but no main effect of Framing, $F(1, 23) = 0.15$, $p = .669$, $\omega^2 = 0.000$.

Planned comparisons, corrected for comparing a family of 15 using the Bonferroni method, showed that the effect Frame*Spacing interaction was the result of mean accuracy rates only decreasing monotonically with Spacing when the frame was Proportional. When the Frame was Uniform, however, the reduction in mean accuracy with Spacing was preceded by a plateau for the larger Spacings. Specifically, in the Uniform Frame condition, there was no significant difference between Large and Medium, $t(23) = 0.90$, $p = .999$, while mean recognition for Spacing Small was significantly lower than both Large, $t(23) = 3.10$, $p = .041$, and Medium, $t(23) = 3.19$, $p = .032$. In the Proportional Frame condition, mean recognition for Spacing Small was significantly lower than both Medium, $t(23) = 5.57$, $p < .001$, and Large, $t(23) = 9.34$, $p < .001$. In contrast to the Uniform Frame, however, recognition for Spacing Medium for the Proportional frame was significantly lower than Large, $t(23) = 3.77$, $p = .005$. Therefore, as a result of this interaction, recognition for Proportional-Frame Small-Spacing was significantly lower than Uniform-Frame Small-Spacing, $t(23) = 3.78$, $p = .005$, and conversely, recognition for Proportional-Frame Large-Spacing was significantly higher than Uniform-Frame Large-Spacing, $t(23) = 3.84$, $p = .004$.

FIGURE 7.

Data display of the results for the Proportional and Uniform frame. Comparisons denoted by * exhibited statistically significant differences.



4. Discussion

Our experiment focused on exploring the effect of crowding on recognition rates in three scenarios: 1) when icon–icon spacing remained constant but icon–frame spacing decreased; 2) when icon-frame remained constant but icon–icon spacing decreased; and 3) whether there would be an interaction between the effect of icon–icon spacing and the effect of icon–frame spacing. The experiment revealed that both the size of the frame and the overlap of icons significantly affects the recognition of individual icons. In the following sections we will elaborate on the different scenarios explored.

4.1 The effect of frame and icon–frame spacing

Previous research has demonstrated a significant crowding effect when a vernier is surrounded by a square compared to a vernier that is not (Herzog et al., 2015). Our study, however, did not indicate a significant main effect of framing. This does not dismiss the possibility of framing having a negative impact under different conditions. A comparison between the crowding effect of unframed icons and framed icons could potentially have revealed significant differences that were not explored in our specific experimental setup.

Although our study did not reveal a primary framing effect, significant recognition differences emerged between the Uniform and the Proportional frames for Spacing Small (red bars in Fig. 7) and Spacing Large (blue bars in Fig. 7). In the two Framing conditions of Spacing Small, the icons overlapped, while the spacing between frame and icon was increased from the Uniform frame to the Proportional frame. Similarly, from the Uniform to the Proportional frame Spacing Large, the spacing between icons was maintained, while the distance between frame and icon was increased. The significant difference between Proportional frame Spacing Small and Uniform frame Spacing Small suggests that something was influencing the recognition of Proportional frame Spacing Small more than it was influencing the recognition of Uniform frame Spacing Small, presumably crowding from the frame. In these conditions, we observed that the recognition rate increased with more spacing between the frame and icons.

4.2 The effect of icon–icon spacing

Our findings supported the hypothesis that diminished recognition occurs with tighter spacing of icons in a Proportional frame. The recognition rate for Spacing Large Frame Proportional was significantly higher than that of Spacing Medium Frame Proportional and Uniform. Although the Icon-Frame spacings were the same in these conditions, the Icon-Icon spacings differed.

Notably, the significant decrease in recognition from Spacing Medium to Small in the Proportional frame underscored the adverse effect of icon overlap on recognition. In both conditions with Spacing Small, the backmost icon was partly covered and less visible, which, as expected, impaired recognition of the target icon.

When two icons were in close proximity or overlapping, the effect of crowding increased, leading to a decline in recognition rate. This suggests the need for caution when adding elements within a pictogram as it may result in icon overlap and diminished recognition.

4.3 The interaction effect between icon spacing and icon-frame spacing

Our findings supported the hypothesis, showing reduced icon recognition with tighter spacing of icons and a smaller frame. Moreover, we found an interaction between icon-icon spacing and frame type. Specifically, recognition decreased with a Proportional frame, while a Uniform frame only reduced recognition when icon spacing decreased from Medium to Small.

When comparing the Proportional and Uniform frames for spacing Medium and Large, the findings indicated that the effect of the frame interacts with the effect of spacing. The individual features of the icons (first stage of feature detection) inside the Uniform and Proportional frame were identical in Spacing Large — the condition of wider spacing between the icons — and in Spacing Medium — the condition of equal spacing between icons and icon and frame. What changed from the Uniform to the Proportional frame Spacing L was the size of the frame and from Spacing Medium to Large was the location of the icons. Following the two-stage model of object recognition (Pelli et al., 2004), this implies that the individual icons would be equally identifiable, while feature integration would vary as spacing between features vary (the second stage of feature integration). This suggests that the significant difference identified in the recognition of these four stimuli conditions of no overlap is caused by differences in feature integration (here icon–icon or frame–icon spacing) and not by differences in feature detections (identifying icons).

Consequently, this implies that there is no notable advantage to having a larger surface area (which allows for greater distance between icons) if the icons come into contact with the frame. However, in scenarios where there are no constraints on surface area, optimal recognition is achieved through wide spacing of icons and a large frame.

Under a Uniform frame, one might expect increased crowding from Medium spacing (equal icon-icon and icon-frame spacing) to Large spacing (wider icon spacing merging with the frame). However, we found no significant differences between these two conditions (see Fig. 7). One possible explanation is that crowding primarily occurs between similar features (Herzog et al., 2015) , and when targets and

flankers differ in shape, the crowding effect is reduced (Levi et al., 1994). Although the frame and icons have the same stroke width, their difference in shape may diminish the crowding effect. However, another reason may be that the increased spacing between icons in spacing Large decreased the crowding and compensated for the increased crowding of the frame, resulting in the nonsignificant finding.

In the case of the Uniform frame, mean recognition significantly differed between Small and Medium spacing but not between Medium and Large spacing. Increasing the spacing between the frame and icons, without altering their relative spacing, resulted in improved recognition (e.g., recognition for Proportional L was superior to Uniform L). However, when transitioning from Medium to Large spacing and the icons ended up touching the Uniform frame, this adjustment had no discernible effect (no significant difference) on recognition.

5. Conclusion

This study examined how designers can improve the visibility of pictograms by strategically manipulating icon placement and spacing within a frame. Results indicated that overlapping icons are the most limiting factor to perception. Employing a proportional frame, synchronized with icon placement, progressively diminishes recognition as the space between icons narrows.

Furthermore, we observed no significant differences between conditions of a uniform frame with icons aligned with the frame (Uniform frame Spacing L) and a uniform frame with icons evenly spaced within the frame (Uniform frame Spacing M). This suggests that if the icons are not overlapping, there is room for varied spacing within the framed space. These findings offer valuable insights for designers, empowering them to mitigate the impact of crowding by strategically manipulating the spatial arrangement of icons within framed pictograms.

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