Evaluating Preattentive Processing in Game Settings with Consistent Visual Scenes

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Abstract: Preattentive processing refers to the human brain's ability to rapidly detect specific visual features before conscious awareness. This study evaluates the effectiveness of preattentive processing in identifying objects with distinct features—motion, color, and shape—within controlled 3D game-like environments. Participants were shown a series of short game runs, each containing an object designed with one of these preattentive attributes, and were tasked with identifying these objects within a 250-millisecond window, the time frame optimal for preattentive processing. To minimize confounding variables, the visual complexity of the scenes was kept consistent, ensuring a uniform look and feel across trials. Results reveal that motion and color are highly effective in guiding attention, with participants achieving near-perfect accuracy. In contrast, shape detection was notably less accurate, with greater variability in responses, suggesting that shape may be less effective as a preattentive feature in visually dense 3D environments. Additionally, participants with gaming experience demonstrated better performance in shape-based tasks, hinting at the influence of prior visual processing experience. These findings contribute to understanding how visual complexity and uniformity impact preattentive processing in digital environments, with practical implications for designing visual tasks, game environments, and interfaces that guide user attention more effectively.

1 INTRODUCTION

1.1 Background

Preattentive processing has been extensively studied in controlled 2D environments, where features such as color, motion, shape, and spatial orientation are used to guide attention effectively (Chih and Parker, 2008) (Healey and Enns, 2012) (Ware, 2012). These environments, often used in information visualization and user interface design, allow for minimal visual distractions, enabling preattentive attributes (used interchangeably with the term preattentive features throughout this paper) to stand out clearly. Previous research has demonstrated the power of these attributes in focusing attention quickly and efficiently.

As interactive 3D environments, particularly video games, have become more prevalent, questions have arisen about the efficacy of preattentive features in more visually complex and dynamic settings. Game environments often contain a wealth of dense visual information, where distractors can vary not only in number but also in form, color, and motion, potentially overwhelming players (El-Nasr and Yan, 2006). Moreover, recent work suggests that the process of feature binding and perception may proceed independently of top-down selective attention and conscious awareness, with peripheral vision introducing information loss that can affect attention shifts (Rosenholtz et al., 2012). This understanding highlights the potential for preattentive processing to function in visually rich environments without overwhelming the player.

El-Nasr and Yan (El-Nasr and Yan, 2006) emphasized the importance of understanding visual attention patterns in 3D game environments to improve game design, showing that player attention can be guided more effectively through intentional adjustments to level design, textures, and object placement. In fast-paced 3D games, where conditions change rapidly, traditional methods for studying attention may fall short, making research on preattentive processing crucial for enhancing gameplay.

Hsiao et al. (Hsiao et al., 2021) extended this discussion by introducing a method for analyzing user interactions in 3D navigational spaces using eye-

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tracking technology. Their work proposed 3D object attention heat maps that allow for a better understanding of how visual stimuli guide user attention in interactive environments. These insights can be directly applied to video games, where understanding player interactions with 3D objects can inform more efficient object placement and visual design. This approach aligns with the goal of optimizing gameplay by leveraging preattentive processing to guide attention in complex environments.

Warnhag and Wedzinga's study further explored preattentive attributes in both 2D and 3D video game scenes, examining visual variables like color, motion, and texture, with a focus on player perception and performance. They found that while red hues captured attention effectively, the application of preattentive attributes in complex environments, particularly in 3D scenes, requires careful balancing. Overusing saliency can divide attention and degrade the user experience (Warnhag and Wedzinga, 2019).

In contrast, our study pushes this research further by focusing on 3D environments that are visually denser and have more complex lighting. By isolating specific preattentive attributes like **motion**, **color**, and **shape** in uniform game-like scenes filled with potential distractors, we aim to assess the real-world applicability of these features in guiding attention. The findings of Warnhag and Wedzinga, along with the contributions of Hsiao et al. (Hsiao et al., 2021), align with our approach, reinforcing the importance of balancing visual saliency and scene complexity to maintain effective preattentive processing in highly interactive, dynamic environments.

Recent research has also highlighted the role of preattentive processing in professional settings such as aviation, where color-coded head-up displays (HUDs) are used to improve pilot performance by enabling quick visual recognition (Blundell et al., 2020). Similar to game environments, these displays help reduce cognitive load by leveraging preattentive features like color to guide attention. This study is particularly relevant to our work, as it provides further evidence that color, when used effectively, can enhance task performance in complex visual settings. By drawing parallels between these distinct environments, we further underscore the applicability of preattentive features beyond gaming, extending their relevance to professional, high-stakes domains.

1.2 Objective and Contributions

The primary objective of this study is to evaluate how well preattentive features—motion, color, and shape—are detected in controlled, consistent 3D environments. The secondary goal is to understand the role of uniformity in facilitating or hindering the detection process.

The main contributions of this paper are as follows:

- A novel experimental setup designed to isolate preattentive features in visually consistent 3D game-like environments.
- Empirical evidence demonstrating the detection accuracy of preattentive features—motion, color, and shape—within controlled 3D settings.
- Insights into how different preattentive features (motion, color, shape) perform in comparison to each other, with shape showing reduced detection accuracy.
- An analysis of the influence of prior gaming experience on the ability to detect preattentive features, particularly shape.
- Practical recommendations for game designers to leverage motion and color for guiding player attention in complex visual environments.

1.3 Paper Organization

The remainder of this paper is structured as follows: Section 2 describes the experimental setup and methods used for evaluating preattentive processing in consistent 3D environments. Section 3 presents the results of the experiments, including the accuracy of object detection based on motion, color, and shape attributes. Section 4 provides a discussion of the findings, their implications for game design, and comparisons with related work. Finally, Section 5 concludes the paper by summarizing the key takeaways and potential directions for future research.

2 METHOD

2.1 Experiment Setup

The experiment was designed to evaluate the effectiveness of preattentive attributes—specifically, motion, color, and shape—in a controlled, game-like setting. The goal was to assess how well participants could detect objects that stood out based on these attributes within a consistent visual environment. This consistency was crucial in isolating the preattentive features without introducing additional visual complexity that might confound the results.

The experiment was conducted online using a web-based platform. Participants accessed the study

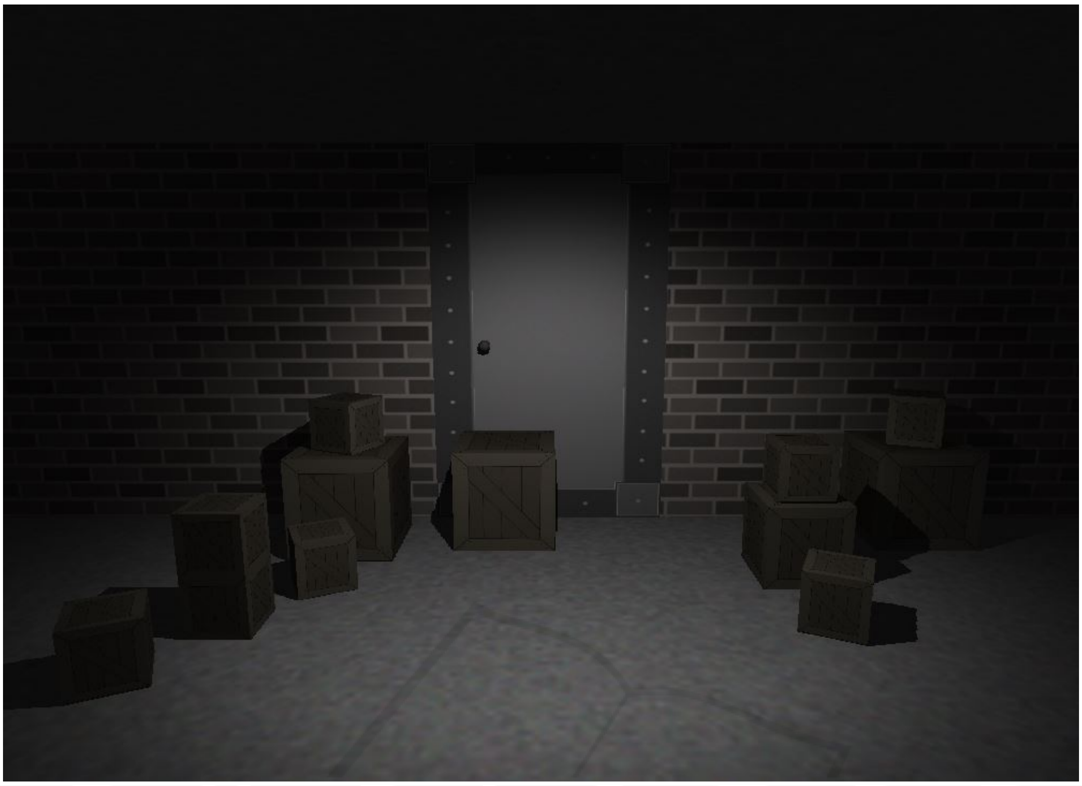

Figure 1: The visual scene used in experiments. The boxes serve as distractors.

from their own devices, where they completed the tasks in their usual environment. This allowed for flexible participation but also introduced potential variability in screen sizes and resolutions, which were controlled to the extent possible through instructions given at the beginning of the study.

The visual scenes were designed to resemble simplified 3D game environments, with a metal door at the center and uniform brick walls on either side (see Fig. 1). Scattered across the stone floor were wooden crates, which served as distractor objects. Amidst these crates, one object was designed to stand out in each scene, either by:

- **Motion.** Objects moving along the x-, y-, or z-axis (Table 1).
- **Color.** A single object with a distinct hue, in contrast to the light brown crates (Table 2).
- **Shape.** A non-square form, differing from the otherwise even wooden crates (Table 3).

Each scene was presented for a duration of 250 milliseconds, a timeframe chosen based on established research indicating that this is the optimal duration for preattentive processing to occur (Healey and Enns, 2012) (Ware, 2012). This rapid exposure ensured that participants had to rely on their preattentive capabilities to detect the standout object, rather than focused attention or deliberate search strategies.

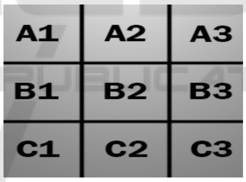

Figure 2: The grid shown in-between scenes in the experiment used to help subjects articulate target locations.

After each scene, participants were presented with a grid overlay (see Fig. 2), which helped them indicate the approximate location of the target object. This grid system allowed participants to express both the attribute that made the object stand out and its spatial location in the scene, providing a dual measure of accuracy.

The nine scenes alternated between the three preattentive groups—motion, color, and shape (see Fig. 3). This structure ensured that participants were exposed to each feature type multiple times, allowing for comparisons across different attributes. By rotating the type of preattentive feature in each scene, we minimized the likelihood that participants could anticipate the nature of the standout object, ensuring that their reactions were genuine and based on the imme-

Table 1: Motion Levels with descriptions and corresponding scene images.

Level	Description	Scene Image
Level 1	Motion along the X-axis from B3 to B2	
Level 5	Motion along the Y-axis from C1 to B1	
Level 7	Motion along the Z-axis in C3	

diate visual input.

All participants received the same instructions, emphasizing that the goal was to quickly identify the standout object based on its preattentive attribute. To avoid any influence from external variables, the experimental environment remained constant, with no audio distractions or external stimuli that might have interfered with the visual processing task.

The choice of consistent scenes was made to eliminate the effect of environmental complexity on the ability to detect preattentive attributes. The visual design of each scene, with repeated crate patterns and minimal variations, ensured that the standout object's feature was the sole distinguishing factor. This approach allowed for a focused investigation of the power of preattentive attributes in uniform settings, without the added variable of changing or distracting backgrounds.

2.2 Participants

The experiment involved 11 participants, with ages ranging from 21 to 55, recruited from a mix of backgrounds. Of the participants, 8 had prior experience playing video games, particularly fast-paced games that require rapid visual processing, such as first-person shooters. The remaining 3 participants reported minimal gaming experience, which allowed for a balanced comparison of performance between experienced and novice individuals. This mix was crucial for investigating how familiarity with visually complex environments influences the detection of preattentive attributes. All participants had normal or corrected-to-normal vision and were screened to ensure they were free of any visual impairments that might interfere with their ability to detect color, motion, or shape. No personal data other than gender and age was collected, and participants gave informed consent before the experiment began.

3 RESULTS

The primary objective of this study was to assess the effectiveness of preattentive attributes—movement, shape, and color—in a controlled 3D game-like environment. Participants were tasked with identifying standout objects based on these attributes in visually

Table 2: Color Levels with descriptions and corresponding scene images.

Level	Description	Scene Image
Level 2	Red box in B3	
Level 4	Blue box in B1	
Level 8	Box with a blue outline in B3/C3	

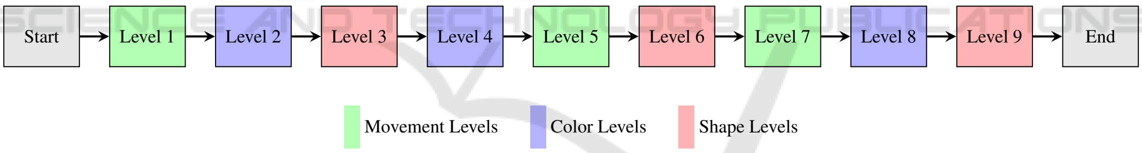

Figure 3: This diagram illustrates the experimental process in sequential order of levels. The participants proceed through each level, starting from Level 1 and ending at Level 9. Between each arrow after Level 1, a grid was shown to participants for selecting the standout object (refer to Fig. 2).

consistent scenes, designed to minimize distractions and complexity. The data was analyzed to evaluate detection accuracy across the three features.

3.1 Performance by Preattentive Feature

The analysis revealed clear differences in participant performance across the three preattentive features: movement, shape, and color (see Fig. 4). **Movement** and **color** achieved perfect detection, with participants identifying objects based on these features at an average accuracy of 100% (SD = 0.00). This suggests that both movement and color stand out effectively, even in visually consistent game-like environments.

However, **shape**-based detection was significantly less reliable, with an average accuracy of 70% (SD = 0.46) (see Fig. 5). This greater variability in performance, reflected by the higher standard deviation, suggests that shape is a less salient preattentive feature. The subtle differences between the distractor objects (e.g., crates) and the target shape likely contributed to this inconsistency, making shape-based identification more challenging for participants.

3.2 Overall Participant Performance

Overall, participants demonstrated strong performance in detecting movement and color, with total correct responses reaching 100%. However, the disparity in shape detection highlights a potential chal-

Table 3: Shape Levels with descriptions and corresponding scene images.

Level	Description	Scene Image
Level 3	Oblong box in C1	
Level 6	Sphere in B2/B3	
Level 9	Large skewed cube across B1/B2/C1/C2 (Parallelepiped)	

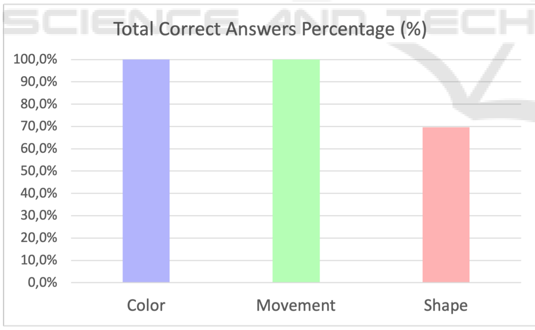

Figure 4: Participants identified the target with 100% accuracy when the standout feature was *color* or *movement*. However, *shape* showed more inconsistent results.

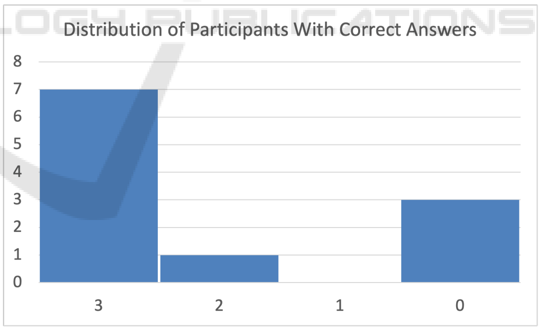

Figure 5: Distribution of participants who achieved 3, 2, 1, and 0 correct answers for the *shape* attribute.

lenge when using shape as a preattentive cue in game-like environments. The results indicate that shape-based detection is more complex, potentially due to subtle variations in object forms, lighting, or environmental factors influencing perception.

Interestingly, participants with more extensive experience in fast-paced video games showed better performance in shape-based tasks, as shown in Fig. 5. Three participants, all with little to no gaming experience, failed to identify any shape-based targets. While this finding is anecdotal, it suggests that familiarity with 3D environments may enhance preattentive processing of shape, adding a potential layer of variability in performance based on prior experience.

4 DISCUSSION

4.1 Implications for Game Design

The study's results demonstrate that motion and color are highly effective preattentive features in guiding attention within complex 3D environments. Participants consistently performed with perfect accuracy across all motion and color-related tasks, emphasizing the saliency of these attributes even when the scene's complexity is controlled. This finding supports the use of movement and color as reliable attention-guiding cues in game design. For game developers, leveraging these features could enhance the player experience by intuitively directing focus to key in-game elements, particularly in fast-paced or visually dense scenarios.

However, shape detection presented a challenge, as reflected in lower accuracy rates across shape-related tasks. Participants showed more variability in detecting objects based on shape, with the lowest average accuracy in Level 3. This suggests that shape, while an essential visual feature, may require greater differentiation in 3D environments to be effectively recognized. Subtle variations between objects were not as easily detected by participants, highlighting the need for additional emphasis on shape cues if they are to play a significant role in guiding player attention.

Moreover, an interesting pattern emerged in relation to participants' gaming experience. Those with prior exposure to fast-paced video games performed better in shape detection tasks compared to participants with minimal gaming experience. This observation suggests that familiarity with visually complex environments may enhance the ability to detect preattentive features like shape, potentially through better-developed visual processing skills. This finding could inform game design for various player skill levels, tailoring experiences to ensure that essential elements stand out clearly for both novice and experienced players.

4.2 Comparison to Related Work

Warnhag and Wedzinga's study investigated preattentive attributes in simpler 2D and 3D graphical scenes. Their work, focusing on visual variables such as color, motion, and texture, revealed that while red hues captured attention effectively, their Time to First Fixation (TTFF) means for visual elements were consistently above 250 milliseconds, a threshold typically associated with preattentive processing (Warnhag and Wedzinga, 2019). This suggests that their experimental setup may not have fully tested the classic definition of preattentive processing, particularly in their 3D scenes.

In contrast, our experiment methodology ensures that we adhere to the literature's definition of preattentive processing, with visual features designed to be detectable within the 200–250 millisecond window. By maintaining consistency in scene design and controlling the number of potential distractors, our study isolates the effectiveness of motion, color, and shape as preattentive attributes. This methodological rigor ensures that our findings align more closely with the established understanding of preattentive processing, demonstrating that these attributes remain effective even in visually dense environments, provided that visual complexity is carefully managed.

Similarly, Blundell et al. (Blundell et al., 2020) highlight the importance of color coding in improving task performance in complex visual environments, such as aviation head-up displays (HUDs). Their findings show that color can act as a preattentive feature, helping pilots to quickly detect critical information, much like in our study, where color improves detection in game-like scenes. While Blundell et al. focus on professional settings like aviation, both studies underscore the broader applicability of preattentive processing, particularly the role of color in reducing cognitive load and improving response time in dynamic environments.

4.3 Limitations

A limitation of this study is the uniformity of the visual scenes, which were designed to control for potential confounding factors. While this approach allows us to isolate the effectiveness of preattentive features, it may limit the generalizability of the findings to more visually diverse game environments. Future research should explore how these features function in more varied and dynamic settings, where visual stimuli may differ significantly in form, size, and motion.

Another limitation is the variability in participants' display conditions. Since the experiment was conducted online, participants used different devices with varying screen sizes, resolutions, and refresh rates. These factors may have influenced how effectively participants were able to detect preattentive attributes, particularly motion, which can appear differently depending on display settings. Future studies should consider conducting experiments in more controlled environments to ensure consistency across visual conditions.

Moreover, the limited sample size (11 participants) might restrict the statistical power of the findings. A larger and more diverse sample would provide more robust conclusions and allow for more generalizable insights into how preattentive processing functions in different populations. Future work could also benefit from including a more diverse participant pool in terms of age, cultural background, and prior experience with digital environments, to better reflect a broader audience.

Finally, while this study focused on motion, color, and shape, other important preattentive features such as luminance, texture, or depth cues were not tested. These features may play a critical role in guiding attention in 3D environments and should be considered in future work. Investigating how these additional features interact with each other in complex settings will provide a more comprehensive understanding of preattentive processing.

5 CONCLUSION

This study explored the effectiveness of preattentive attributes—motion, color, and shape—in guiding attention within a consistent 3D game-like environment. The findings indicate that motion and color remain highly effective preattentive features, with participants demonstrating perfect accuracy in identifying objects based on these attributes. In contrast, shape proved to be less effective, with greater variability in detection accuracy. This highlights potential limitations in using shape as a standalone cue in complex visual settings, particularly when the differences between objects are subtle.

These results have significant implications for game design, suggesting that motion and color should be prioritized as key elements for directing player attention in visually dense environments. On the other hand, additional emphasis on shape, such as using more distinct forms, may be necessary to ensure its effectiveness in guiding attention. Furthermore, the study revealed that players with more experience in visually complex games performed better in shape detection, underscoring the importance of considering player experience when designing visual tasks in games.

Overall, this research provides valuable insights into how preattentive features function in game environments and offers practical recommendations for enhancing player focus and experience through effective visual design.

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