# Visual Cognition and Simulation Training for Pilots

**Nina Rothstein**
**Drexel University**
**Philadelphia, PA**
**Njr56@drexel.edu**

**Marlon Gieser**
**Montclair, NJ**
**drlongieser@yahoo.com**

**ABSTRACT**

This paper evaluates visual processing for pilot-based tasks and simulation training. Object identification and visual perception will be evaluated in terms of piloting tasks. Understanding visual cognition in terms of simulation training can be beneficial for both cognitive research as well as training optimization. The ability to manipulate how we perceive an object is a benefit of technology that allows us to acquire a deeper understanding of specialized cognitive processes. When this information is tested in order to optimize these cognitive processes via a customized training scenario, this cognitive knowledge is applied. By testing the effect of visual fidelity for simulation training, this knowledge can be applied to optimize the performance and time of pilots.

**ABOUT THE AUTHORS**

**Nina Rothstein** is a doctoral student at Drexel University in the department of Applied Cognitive and Behavioral Science. She has a MS from the University of Central Florida in Modeling and Simulation and a BS from the University of North Florida in Psychology.

**Marlon Gieser** is a clinical psychologist. He is one of the country's experts on the Thematic Apperception Test (T.A.T.). He holds a Ph.D. in Psychology from the Wright Institute at Berkeley, California.

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## INTRODUCTION

Piloting is an intensely visual task that puts demands on perception that are not experienced elsewhere. Pilots are subjected to forces and movements that the human body was not designed to handle (Gibb, Gray, & Schraff, 2010). Pilots experience limitations on their ability to gather visual information. This can lead to many miscalculations and misjudgments. For example, pilots make errors judging correct distance and speed in glide path landings (Gibb, Gray, & Schraff, 2010). Pilots that received oculomotor training to promote efficient use of peripheral vision increased scores by 30% higher scores during simulation training exercises (Diaz and Bil, 2017). Differences in pilot training objectives requires that training modalities be geared towards specific visual stimuli. Unmanned aerial vehicle (UAV) pilots must make decisions based on imagery and footage fed to them while they are grounded.

In order to recognize objects from an aircraft, a pilot must differentiate between the natural background and a detail or disruption in the environment. The reviewed literature will focus on visual search strategies. Theories and various modalities of simulated visual experiences will be examined. The use of virtual reality, desktop trainers, and the role of varying visual fidelity for stimuli will be evaluated. This paper aims to better identify the perceptual theory and physiological factors involved in piloting in order to help with training capabilities of flight simulators.

## BACKGROUND

There are many theories attempting to explain how we recognize and categorize objects we see (Peterson, and Rhodes 2003). UAVs have been used in search and rescue missions as well as reconnaissance and surveillance (Fincannon, Keebler, Jentsch, & Curtis, 2011). All of these are important for consideration of the influence of our visual processes on identification of an object from an unmanned aerial vehicle. It is crucial to understand these processes in order to improve piloting of UAVs. Simulation training must include the most necessary visual components to best train pilots. To best prepare for these missions we must be aware of the underlying dynamics for visual processing in target search and target identification or recognition.

Identifying an item amongst a group of distractors is called visual search (Verghese, 2001). The number of distractors can separate efficient from inefficient search. When the increase of distractors leads to an increase in search times, this is considered inefficient search (De Vries et al., 2013). Visual search can be measured by assessing accuracy and reaction time. Visual search argues for parallel processing of the basic features of color, orientation, curvature, size, spatial frequency, scale, motion, and shape (Wolfe, 1998). Item presentation is an important consideration for training and performance for aerial targets, since they are evaluating stimuli from a completely novel viewpoint.

Models of visual attention pinpoint three aspects of visual search: (1) Guidance, (2) Selection, and (3) Enhancement (Itti & Borji 2013). Guidance refers to where and what an observer attends to. Selection is the determination of an aspect of the scene deemed visually important– a more specific area of focus, and enhancement is the point in which differential processing of the attended to stimuli is determined versus other parts of the scene which will be ignored (Itti & Borji 2013)

**Preattentive/Preparation**

Anatomical studies have showcased three main sites of action along the ventral pathway. The sites increase in complexity the higher up the path they are located. The cells in the V1 area are in the primary visual area. Neurons in the V1 area are differentiated by their preference for certain visual features such as orientation and location in reference to the retina (Bar, 2003). There is evidence of activity in the V1 area before visual search has even begun (Elmer, 2014). We mentally represent a goal before taking steps to accomplish it. This is called mental representation (Elmer, 2014). This finding supports the use of flight simulators that impede mental representation via orientation and location for training and assessment of crisis scenarios.

**Guidance**

Neurons in the V4 and middle temporal (MT) cortex have been implicated in the parallel processing that gathers information about task-relevant features to guide attention to possible targets (Elmer, 2014). During this stage the visual cognitive system attends to relevant cues and ignores irrelevant cues. For example, target prevalence (the number of targets in a scene) increases processing during visual search tasks. The amount of time participants spends looking also increases. This occurs because participants would revisit objects after the initial search (Godwin et al., 2014). The preparation and the guidance stage of visual search have been found to be temporally distinct. The prefrontal cortex shows activity due to the attentional processes required during the guidance stage, while activation of guidance signals from V4 neurons occurs during the preparation stage (Elmer, 2014).

As discussed earlier, UAV pilots differ from aerial pilots in that they are not receiving environmental cues as a result of their piloting. One of these cues is motion. Our attentional system is designed to detect motion while we are in motion (such as walking, running or driving) as well as when we are still. Motion is a basic feature of visual perception (Wolfe, 1998). According to the two-stage theory of visual perception, motion processing begins during the preattentive stage (Wolfe, 1998). In the attentive/search stage motion processing is highly reliant upon the stimuli, environment, or distractors around it. The judgment of motion is highly relative (i.e. dependent upon many factors in both motion processing and visual perception) (Wolfe, 1998).

**Selection**

Viewpoint impacts the accuracy of object identification. Familiar objects are recognized most efficiently when viewed from a familiar viewpoint and familiar objects activate different cognitive processes than unfamiliar objects. This means that recognition based on viewpoint is trainable (Bulthoff & Newell 2006).

*Position Dependence*

Feature-based attention occurs before spatial attention, during visual search when the location of a target is unknown (Elmer, 2014). Object location during visual search influences selection mechanisms (Shih & Sperling, 1996). The importance of object location in the selection process is supported for two reasons. Object representation in the visual cortex is position dependent. The transition from guidance to the selection process uses representations of items on cortical maps. These cortical maps are what guide visual search strategy (Elmer, 2014). It is during this second process that the use of top-down processing helps to guide search for specific visual properties (Elmer, 2014). It is during this process that serial or parallel processing is most relevant (Elmer, 2014). Real world visual search is susceptible to stimulus overload, which compromises the attentional processes that influences the top-down analysis of a visual scene (Guznov, Mattews, Warm, & Pfahler, 2017). The prefrontal cortex has been cited as a factor in attention allocation (Elmer, 2014). Interestingly, objects in the PFC are position invariant (Elmer, 2014).

*Spatial Context*

The importance of spatial context and influence of object location has been shown in visual search studies for UAVs. Context can improve the accuracy in recognition of an item compared to recognizing an object without context (Barenholtz et al., 2014). Contextual information for UAVs through terrain data and transparent avatar (more visual information) helps operators understand the spatial relationships between UAV and earth (Drury, Richer, Rackliffe, & Goodrich, 2006).

**Identification**

Object recognition is a complex task that is not localized to any one area of the brain. Identification has shown to have capacity limitations, linking this stage with memory (specifically, working memory) (Elmer, 2014). In a visual search task, a target must be identified amongst other distracting features (Wolfe, 1998).

Target training is the most effective technique for visual search training in a complex task environment (Guznov, Mattews, Warm, & Pfahler, 2017). Target training shows participants images of the intended target from multiple angles. Target is an exercise in the Selection stage of visual search. Cue training is the use of an outside sensory cue to notify a trainee in the presence of a stimulus. Cue training and visual scanning training have been compared. Cueing was successful in that it may inform scene gist understanding (Guznov, Mattews, Warm, & Pfahler, 2017).

This may be because visual scanning training is an attempt to rewire visual search strategy as whole (which is difficult), while target training and cue training are enhancing aspects of naturalistic visual search (both in the Selection stages). These results mirror the work of previous research that found the impact of target familiarity during visual search (Fincannon, Keebler, Jentsch, & Curtis, 2011). The results of Guznov et al.'s work (2017) show that target and cue training were the most effective and that cue training enhances performance without any explicit target training

## VISUAL SEARCH

Visual search difficulty can come from crowding, masking, lateral interaction, and surround suppression. These difficulties can occur in different stages of visual perception and it is believed that they have designated neural mechanisms (Whitney & Levi, 2011).

### Visual Crowding

Our high-definition visual comprehension of a scene is based on our ability to rapidly focus on various aspects of an environment. We basically "piece a scene together" by looking around (Whitney & Levi, 2011). However, the truth is, acute visual perception is limited due to our poor peripheral vision. The reason that a complex scene (a room or a stage) can have many details is due to our ability to move our eyes around quickly (Whitney & Levi, 2011). When there are lots of objects in the periphery, this is known as crowding. When crowding occurs, an object in the periphery that was once easy to identify now becomes indistinct (Whitney & Levi, 2011). Crowding impairs object identification not detection (Whitney & Levi, 2011).

Lower visual performance at the periphery is due to a lack of spatial resolution. At the center of a visual scene there are more receptive visual fields and the observer can therefore process more visual distractors. This implicates spatial resolution as something that may be impactful during visual search tasks (Pomplum, Garaas, & Carrasco, 2013). Physiological studies have attempted (unsuccessfully) to pinpoint the precise neural mechanisms (or levels of visual cognition) where crowding occurs. Crowding is affected by context, stimulus familiarity, and attention (Whitney & Levi, 2011).

### Target Detection

Simulation training technology has been coupled with physiological sensors (such as eye tracking) in order to evaluate the efficacy of a prescribed visual search strategy. Visual search is the goal-oriented process of differentiating a target item or finding an item of interest in a scene (usually amongst other distractor items) (Pomplum, Garaas, & Carrasco, 2013). The enabling mechanism for visual search, visual attention has been measured in reaction time and error rates. Additionally, visual search has been evaluated through visual scan patterns. Visual scan is a type of visual search that systematically scans an entire scene. The amount of scene visible to an observer is sometimes referred to as field of view (FOV).

Situational Awareness is a larger construct tied to visual search and is a training objective for much of aerial simulation. Situational Awareness is the comprehension of the current elements of a situation, comprehension of a situation, and the projection of future status (Endsley, 1995). At the baseline, visual comprehension is an integral part of understanding the elements of a situation. Drury, Richer, Rackliffe, and Goodrich (2006) used the construct of Situational Awareness (SA) to measure two unmanned aerial vehicle (UAV) interfaces. They used implicit performance measures (task performance) as a way to measure SA. These measures mixed with subjective measures comprised the outcomes of the search and rescue task. Researchers obtained three sources of data. The first source was the timing and accuracy of locating a lost hunter on an augmented video feed and a non-augmented video feed.

The augmented video feed offered participants a greater view of a geolocated map location. The more accurate the participants were at pinpointing the lost hunters on either map, the better the implied SA. The results of the experiment indicate that offering a greater amount of perceptual information (terrain) amounted to greater situational awareness. This could be related to the role that environment plays in the Selection process of visual search.

Ragan, Bowman, Kopper, Stinson, Scerbo, and McMahan, (2015) conducted a field of view (FOV) experiment along with analyzing visual complexity for training for a visual scanning task. In the context of this experiment, to create a visually complex scene means to clutter the environment. Field of view was the amount of space a participant can see on the screen (outside of the designated simulation area), and should be impactful during the Selection stage of visual search. The justification was that a smaller field of view will most likely result in better performance due to the fact that participants will not have to evaluate irrelevant space. A simulated environment with low visual complexity is best for new trainees in that it allows them to establish a baseline of task behavior, whereas high visual complexity is best for preparing trainees for real-world scenarios.

The results of the study found that higher FOV led to better target detection during a scanning task. This confirms the importance of the role of geographical context in item location. Training for a prescribed visual search strategy did not ensure that participants would use the strategy during the high-fidelity evaluative scenario (Ragan, Bowman, Kopper, Sintson, Scerbo, & McMahan, 2014), indicating the importance to train aspects of naturalistic visual search rather than train for visual search as a whole.

In terms of simulation training, the more visual complexity in a scene, the worse participants were at detecting targets. The performance in the training environment was not predictive of performance in a high-fidelity scenario (Ragan, Bowman, Kopper, Sintson, Scerbo, & McMahan, 2014). Different search strategies or mechanisms may be at play when visual realism increases.

One can use different search strategies based on the nature or number of stimuli. In an experiment conducted by Laxton and Crundall (2018), visual search was tested in lifeguards using video clips of swimmers. The lifeguards had to detect drowning targets. This study is important in that it evaluates search tasks based on experience, presents stimuli in a way that is comparable to a UAV operator, and considers the effect of motion on visual/attentional reactions.

The study compared the performance of lifeguards and non-lifeguards as they attempted to identify drowning targets in a pool full of swimmers. The tasks varied based on the number of swimmers and the types of drowning victims. Victims could be active targets (motion) or passive targets. A significant difference was found in performance based on lifeguarding experience. The amount of distracting swimmers also impacted performance. "Set size effects revealed a dip in reaction speeds at an intermediate set-size level, suggesting a possible change in visual search strategies as the array increases in size (Laxton and Crundall, 2018)." In terms of the effect of the differences in targets, active targets were more likely to be responded to, but the response time was slower that passive targets.

Could it be that the nature of distractors (compared to the target) impacts the visual search strategy used? The authors theorized that a change in the number of targets resulted in a chunking strategy. With fewer swimmers in the pool, there was more space between the swimmers. When the scene becomes more cluttered, participants must group the swimmers into chunks in order to monitor them (Laxton and Crundall, 2018).Target prevalence has also been shown to create a change in visual search strategy as well as change the time and the accuracy of target identification during visual search. The probability of target detection and false alarms has been found to increase as prevalence increases. High prevalence also led to longer searching in target absent trails (Godwin et al., 2015).

By analyzing eye movements in a virtual reality environment, it was determined that during easy visual search tasks, the center of the scene was attended to and then the eye moved toward the outside of the scene. This movement towards the outside was influenced by stimulus color. In more difficult tasks, observers started by looking to the upper left-hand corner of the display and then systematically evaluating horizontally, and then vertically. Neural evidence of activity of cells for visual processing have shown activity in V1, V2, V3, and V4 areas for basic feature processing (such as depth perception), as well as the parietal cortex making it difficult to determine the exact mechanisms behind basic feature processing (Hubel and Wiesel 1968). The effect of depth, which was induced by binocular disparity in the virtual environment, was seen only in the easy task through the first eye saccades evaluating items that were the closest to the participant.

This study is important for two reasons. The first is that is illustrates visual search strategies based on simulated depth and number of distractors. The second is that it illustrates performance in a simulated environment. Does this performance compare to performance in the real world? For the purpose of this review, is this important? For pilots in tradition flight settings, the answer is yes. For UAV pilots, the answer is no; these results and results of similar studies are sufficient enough to generalize to UAV performance. This is because UAV operators are receiving simulated or live-streamed feedback.

Target prevalence has been shown to increase false alarms and search times (Godwin et al., 2010). This finding aligns with previous work in that the most pronounced difference occurs between medium prevalence and high prevalence (Godwin et al., 2010). This could be the result of a change in search strategy as prevalence increases. This is an important consideration when designing or training for search strategies when using aerial vehicles. The number of distractors on the ground may affect pilot task performance.

### Evaluating Training Transfer

Some studies have looked at the efficacy of a training tool about its ability to impact real life performance. When testing pilots' visual scan patterns in flight operations, pilots were shown to integrate both top-down and bottom-up processes based on their experience and salience of information (Yu et al., 2014).

Wallet et al., (2011) sought to examine the effect of varying visual fidelity and its impact on the transfer of spatial knowledge during a navigation task. The more accurate the virtual environment, the more the quality of the transfer of training is improved. A virtual environment that is lacking in visual fidelity impairs performance in both wayfinding and the use of spatial representations (Wallet et al., 2011). Both the mental (spatial representation) and the motor (wayfinding) aspects of spatial navigation were impacted by visual fidelity.

### Individual Differences

Fincannon, Keebler, Jentsch, and Curtis (2011), worked to differentiate visual skills and tasks in for unmanned ground vehicles in a simulation training context. The constructs they explored that were associated with variability within the observer were target familiarity and spatial ability. The constructs related to visual stimulus variability were camouflage and obstruction (Fincannon, Keebler, Jentsch, & Curtis, 2011). The factors of target obstruction and camouflage were found to account for a large percentage of variance with object identification. Familiarity and spatial ability were found to benefit target identification. Familiarity and spatial ability are context specific, these two constructs alone are not predictors of operator performance. The researchers concluded that "familiarity alone is insuffiicent to overcome perceptual difficulties that are likely to be encountered in the field, especially if there are more than two difficulties at once (Fincannon, Keebler, Jentsch, & Curtis, 2011)." The findings suggested that high spatial ability was most useful to overcome perceptually difficult (unfamiliar or obstructed) targets (Fincannon, Keebler, Jentsch, & Curtis, 2011).

## VISUAL FIDELITY AND TRAINING

The training tasks must be carefully considered about performance context. Procedure training (rather than visual search) has been evaluated as has the effect of visual fidelity on training outcomes.

### Aspects of Visual Fidelity

Visual realism (also referred to as visual fidelity) refers to the use of polygon models in the representation of an item or a scene. When a virtual item has low polygon textures, this means that spatial information is being conveyed at a high level. When there is high resolution, the texture and color are conveyed at a high level. Usually there is an interchange between the two visual qualities in a simulation in order to be economical with regards to memory space (Lee, Gustavo, Meyer, Hollerer, & Bowman, 2013).

### Comparing a PC Trainer to a VR Trainer for Procedural Training

In a study that compared a high-fidelity flight trainer with a PC-based flight trainer in reference to its efficacy at training for pilot proficiency at a VFR traffic pattern operation explored three performance variables: maintaining correct altitude, maintaining correct airspeed, and maintaining correct magnetic heading, (Reweti, Gilby, & Jeffrey, 2017). There was no significant difference between the performances of pilots between the two simulators, implying that for this procedural training task, visual fidelity is not an important consideration.

### Considerations for Interface Design

Although visual search considers the presentation of the properties of an item and distractors in order to evaluate efficient versus inefficient search, not much work has been done to assess the effect of backgrounds (De Vries et al., 2013). De Vries et al., (2013) takes into consideration the way that a scene containing visual information is presented for UAVs using the effect of luminance to evaluate the time it took to complete a visual search task. Changing background luminance had a significant impact on response times for a search task. Luminance has a significant effect on decreasing search times, specifically when the luminance's darkness/lightness was in between that of the target and the distractors (De Vries et al., 2013). At the neural level, luminance at varying levels affects neural activity within the visual cortex (Blackemore & Campbell, 1969). Considering the results of this study, luminance may be an important consideration for UAV interface design, for visual search tasks.

## MODELS OF VISUAL SEARCH

Much research exists regarding the theoretical foundations of visual behavior. A summary of relevant theoretical work pertaining to the presentation and evaluation of pilot trainees in a simulated training environment follows.

### Top down vs. Bottom-up

Visual perception has been divided into top-down or bottom-up processing. Bottom-up processing is when the stimuli influences perception. Bottom-up processing begins with no preconception of what the observer is looking at. Because perception (and expectation) of an observation affects the visual experience, bottom-up processing builds a visual experience based on piecing together information from small observations or details. Top-down processes use knowledge to shape perception. For pilots, both top-down and bottom-up training objectives are equally as useful.

The existence of bottom-up visual processing has received much evidence-based support from cognitive studies on predictive coding. “A principle underlying the overall functioning of the visual system may be one of *predictive coding*- the construction and continual updating of an internal model of what is likely to happen in the future (Farah, 2000).”

Real world visual search is susceptible to stimulus overload, which compromises the attentional processes that influence the top-down analysis of a visual scene (Guznov, Mattews, Warm, & Pfahler, 2017). For bottom-up visual processing, the V1 area has been heavily implicated in numerous feature detection processes. The V1 area is responsible for orientation (seeing edges), direction selectivity, depth perception, color, and anything associated with feature detection (Farrah, 2000).

### Feature Integration

In feature integration theory, visual perception of an object is a two-step process. The first step is the preattentive stage by which, low-level primitive aspects of an object (such as color, luminance, and shape) are evaluated. Then, the next stage is the attentive stage, which occurs at the recognition of these features into a complex image (Treisman & Gelade, 1980). The perceptual construction of an object based on the qualities of its components is called feature integration. Feature integration is an explanation of how attentional process can influence visual search tasks (Fincannon, Keebler, Jentsch, & Curtis, 2011). Feature Integration Theory was met with some resistance when research found that parallel processing during search occurred at high efficiency (Nakayama & Silverman, 1986).

### Signal Detection

Signal Detection Theory (SDT) is based on the active role of a participant in categorizing the presence or absence of a stimulus. SDT explains the loss of time and efficiency during visual search based on an increase in set size through the concept of visual noise. Visual noise creates a condition of uncertainty, therefore increasing the probability of a distractor being mistaken for a target item (Pomplum, Garaas, & Carrasco, 2013). The effect of a distractor is dependent on the threshold level of an observer. The threshold can vary based on experience, expectations, psychological state, and the relative information contained within the environment.

### Recognition by Components

Recognition by components explains the perceptual process of recognition as the breakdown of a single object into the arrangement of basic shape components (Biederman, 1987). These components have been shown to elicit activation in V1 to V4 visual areas (Hubel and Wiesel 1968). Recognition by components is a system that identifies objects based on two dimensions. The first dimension is whether or not the object is a geon. Geons are are a set of foundational shapes that guide visual expectations. The second dimentsion is how geons appear in conjunction with observations in the real world. The perception of edges of an object are important for object recognition and identification. (Fincannon, Keebler, Jentsch, & Curtis, 2011).

### Guided Search

Guided Search proposes that in order to locate a specific item in a crowded visual field, we first look for one or more promising attributes (such as color or shape) in order to help us focus on a smaller area to evaluate in greater detail.

Information is used to guide attention in order to make visual search more efficient. Guided Search proposes that with such an information-rich visual world, it is nearly impossible for our visual system to take part in the low-level processing required by Feature Integration Theory. Attention processes are more culpable in vision than Feature Integration gives them credit for. In the Guided Search model, visual attention is directed by priority. If an item is deemed unworthy of attention, then the observer moves on to the next item (Wolfe, 1994). The Guided Search Theory supports parallel processing. Parallel processing is the brains ability to process multiple types of stimuli concurrently of various qualities (i.e. shape, color, and motion) (Wolfe, 1994).

**Viewpoint Dependent Theories**

Viewpoint dependent theories suggest that object recognition is affected by the viewpoint at which it is seen. Objects seen in novel viewpoints reduce the accuracy and speed of object identification (Tarr & Bulthoff, 1995)." This theory of recognition is based on a more holistic system rather than by parts, suggesting that objects are stored in memory with multiple viewpoints and angles. This form of recognition requires a lot of memory, as each viewpoint must be stored. Accuracy of recognition also depends on how familiar the observed viewpoint of the object is (Peterson & Rhodes, 2003). Viewpoint dependent theories are important to take into consideration when evaluating target detection and/or visual search for pilot training because the visual scene presented to pilots is novel and fits with the Selection aspect of visual search.

## DISCUSSION

Neural differentiation between varying aspects of stimuli for visual search is still a developing area of research. Differences exist between training needs of novices versus experts. Just because the trainee is performing well in the simulation, does not mean they will necessarily perform well in real life. This is why training objectives for simulation need to be different than overall learning objectives. Training requirements will differ based on the specific type of task and the specific type of trainee. Visual object representation differs significantly based on task and experience level. Further research is needed to determine what visual components of a virtually represented object are most important for simulation training.

High visual complexity seems to be an area rife with research. Although it does provide best real-world representation, is it adequate to justify its use for expert trainees, who already have a framework, or a visual example represented in their head? For instance, an experienced pilot may not need high visual fidelity for training for a mission because they can probably already imagine/have a representation of the situation in their head and the part that they need the training for may be procedural.

However, low visual complexity may sometimes be best for novices as well. Too many details may be distracting or irrelevant to their level of knowledge. Further consideration regarding the breakdown of tasks should evaluate the differentiation of efficacy of training based on type of procedure and based on level of experience. For example, it was found that training efficacy decreased due to overuse on task trainers (Reweti, Gilby, & Jeffrey, 2017).

Context and familiarity have implications for both cognitive and behavioral outcomes in simulated environments (Barenholtz et al., 2014). Training objective should be carefully evaluated with regard to the role of these constructs in desired training outcomes. It is important to note that the cognitive theories underlying visual perception should not be evaluated in isolation. It is important to simulate difficulties based on an accurate depiction of cognitive abilities, not just based on accurate depiction of our physical environments

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