Cogcues: Shifting Perception through Interactive Projected Cues in Still Life Drawing

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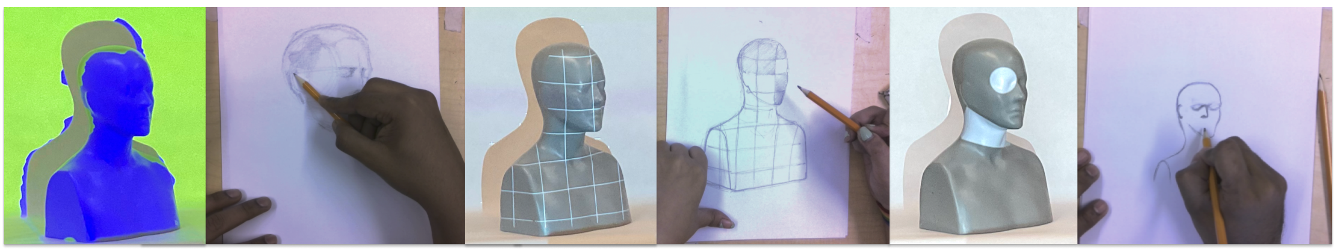

Figure 1: Cogcues. A drawer's real-world perception of objects is altered by projected light cues; each cue is procedurally generated, scene dynamic, and interactive. These cues can enhance or disrupt perceptual processes during observational drawing tasks.

ABSTRACT

The ability to visually discern shape, form, and value is fundamental to observational drawing. However, developing this skill requires a drawer to perceive a "raw" version of the scene being drawn, often referred to as regaining the innocence of the eye. This work investigates how interactive projected light cues can be used to alter the perception of drawing objects and understand how users might control their own perception. We introduce an augmented reality system capable of dynamically projecting interactive light cues onto objects within a live drawing studio. We present the design of three cues that address challenging percepts for novice drawers: gauging proportion, discerning shape, and shifting visual attention. In a formal user study with novice and intermediate drawers, we evaluate the effectiveness of these cues in supporting observational drawing. We demonstrate how cues can be designed to correct subconscious errors and visually guide users in learning to draw.

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CCS CONCEPTS

• **Applied computing** Arts and humanities; • **Human-centered computing** *Empirical studies in interaction design*; *Interactive systems and tools*.

KEYWORDS

Light Projection, Creativity Support, Skill Acquisition, Empirical Study

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1 INTRODUCTION

Observational drawing is a skilled practice that requires the cooperation of the hand, eye, and mind to accurately represent objects, figures, or landscapes. Instructors of observational drawing have emphasized the importance of accessing the "innocent eye" or returning to a moment in time when objects were strange and unfamiliar, thereby allowing an artist to see an object in its unbiased form [44]. Psychologists have linked this way of seeing as accessing an enhanced proximal mode of perception which allows artists to attend to the raw stimuli processed by the human visual system [32]. Consider, for example, drawing a table setting for a morning coffee. When considering the *distal mode of perception* (D-Mode), observers are subject to constancy effects where a familiar object like a plate, cup, or coffee is viewed as having the same shape, size, and color regardless of its position or lighting [37]. However, when engaging with the *proximal mode of perception* (P-Mode), an artist can focus on the immediate properties of the visual stimuli unrelated to its identity or its relation to the environment. For instance, although coffee may "appear" as black (D-Mode), the reflection of the light on the coffee surface produces a white stimulus (P-Mode). To accurately represent the coffee cup from their perspective, a skilled artist must strategically leverage and suppress their subjective world (D-mode) to create their depiction [32]. The innocent eye, and by extension P-Mode perception, allows artists the ability to flexibly deploy their attention and guide visual selection and enhancement. Compared to non-artists, skilled artists are better able to switch between attending to local elements (e.g., the form of the coffee cup) and global aspects of a scene (e.g., the relationships between all the objects on the table) [37].

Difficulty in shifting between D-Mode and P-Mode leads to misperceiving reference objects and scenes. This misperception is a major source of drawing errors, especially in contrast to memory and motor skills [8]. Although drawing education has developed a variety of techniques for recovering the "innocence of the eye" and counteracting constancy effects, drawing remains a cognitively demanding task that requires significant training for novice drawers. *How might interactive technologies be used to support the acquisition of these cognitive and observational drawing skills?*

This work takes a first step towards understanding how light projection and spatial augmented reality (LP-SAR) can be used to support observational drawing training. LP-SAR systems show promise in contextualizing knowledge by mapping data to relevant surfaces [26, 29] in both formal and informal learning settings [22, 34, 45, 54]; we argue that LP-SARs can be used as a cognitive training tool to "train the eye" by manipulating visual stimuli to enhance and suppress P-Mode and D-Mode perception. In this paper, we demonstrate an LP-SAR system that extracts depth information from the drawing scene and computationally generates and projects visual cues onto the drawing object. We contribute:

- Three scene-dynamic and parametric projected light cues, which we term *cogcues*, motivated from established drawing techniques and psychology literature. Each cogcue is designed to be re-configurable to adjust to the needs of drawers and counteract drawing misperceptions.
- A novel use case of a projection-based system that overcomes occlusion problems. We demonstrate a real-time SAR system capable of streaming information between multiple devices and applications to enable the iterative and experiential design of cogcues within a drawing studio.
- A formal user study with 6 novice and 6 intermediate drawers that reports the cognitive load of our SAR system in still life drawing tasks, a drawing analysis by expert raters to assess the effects of the cogcues on drawing performance, and a thematic analysis describing the experience of re-configurable cogcues.

Although focused on observational drawing, this work draws insights from this visual task to understand how interactive systems can provide feedforward cues to train the powerful sensemaking abilities of the human perceptual system and enhance creative practices.

This paper first situates our work within the space of observational drawing learning methods, interactive drawing systems, and SAR training systems. We then describe our projected light system, three cogcues, and study design. We report quantitative trends from interaction logs, drawing analyses, and qualitative themes. Lastly, we discuss how cogcues can be used to inform other forms of observational drawing and opportunities for cognitively assistive SAR systems in other skill acquisition domains.

2 RELATED WORK

Drawing is a uniquely human activity that is typically initiated in childhood and can develop into professional practices within fields such as art, design, construction, and engineering. We describe related works on technologies for supporting drawing skill development and studies for understanding the psychology of drawing. These works are contextualized in relation to the underlying principles found in drawing education.

Supporting Drawing Skill Development. Many drawing methods focus on developing visual-motor skills through repeated tasks to train kinesthetic or muscle memory (e.g., drawing with your non-dominant hand). Two important factors drive the success of these exercises – the ability to interpret outcomes as a form of feedback and the motivation and drive to sustain practice. Leveraging lessons from Betty Edwards's *Drawing on the Right Side of the Brain* [14], Lee et al. [30] developed an interactive guided drawing system that assisted users in maintaining accurate proportion and perspective in drawing tasks by providing stroke-level corrective feedback. In Sketchitivity, automated accuracy grading and gamification elements were used to guide perspective drawing tasks in a classroom setting; Williford et al. [51] encountered that drawing feedback was insightful to learners and served as a strong warm-up exercise, but lacked the nuanced feedback learners desired to refine their drawing abilities. Others have found that nuanced feedback could be acquired from sharing drawings and drawing process with communities [22] and through retrospective reflections of manual pressure, drawing process, and emotion through data visualizations and data sculptures [15]. Representing feedback in alternative modalities such as audio [9] and haptic [24] has also been effective in making drawing feedback more accessible. In contrast to the tools that use motor input-based models, guides, or corrective feedback, our work focuses on the underlying perceptual mechanisms that contribute to these errors.

Cognition and Perception in Drawing. Several drawing exercises are used to mitigate perceptual effects. Edwards's inversion technique [13], a time-honored drawing exercise, involves drawing an object upside-down to disrupt pre-existing knowledge of the object's canonical orientation [14]. The technique serves as a means for overcoming constancy biases and semantic associations. This "rewiring" of the brain to process the stimulus upside down forces the artists to focus on individual parts of the object (local aspects) and the immediate behavior of each line (P-mode) rather than the overall shape or form (global aspects) that is subject to preconceptions associated with its canonical form (D-mode). Studies of artists with different levels of expertise indicate that experienced artists are better able to integrate top-down information, i.e., their conceptual knowledge, to decide what features are essential to depict [27]. Consequently, artists also use bottom-up approaches, visually selecting and suppressing misperceptions such as size constancy. Chamberlain et al. [6] further identified that local processing biases associated with superior drawing skills result from the ability to successfully filter global information rather than a reduction in global processing, supporting the attentional theories of observational drawing. These studies affirm that leveraging visual attention and different modes of processing visual information to suit one's depictive goal is an acquired skill. We leverage these perceptual underpinnings of observational drawing to motivate the set of cogcues developed in the SAR system and understand their effects in practice.

Projection Mapping User Interfaces. Projection mapping (PM) is a technique that maps images and videos onto typically white and matte surfaces. When coupled with communicating virtual information, PM can enable spatial augmented reality (SAR) systems for creating new media worksurfaces [29], collaborative tabletops [45], informative training materials [22, 34, 54], and visually engaging urban media façades [16]. Despite the instrumentation required to calibrate and configure SAR systems, they offer an important affordance of supporting multiple viewers without the additional hardware that plagues head-mounted displays. Part of this value rests in types of data that can be mapped to physical space. Hoang et al. [22] demonstrated that annotations on projected human anatomy were effective in contextualizing physiotherapy knowledge for students. Ludwig et al. [34] showed how PM could be used to train learners to interact with equipment by externalizing the internal system status of 3D printers. In the domain of drawing, projection mapping suffers from the occlusion problem [29] – the hand over the drawing or painting surface can cast shadows, and the portability of SAR systems, in general, hampers its adoption in physical skill training. Lo et al. [31] instead purposefully introduced shadows to augment physical objects in SAR, for example, projecting raised surfaces from shadow cues. We similarly alter the perception of a physical object but instead present an SAR system situated within an observational drawing studio that makes use of projection mapping's scalable viewership and mitigates occlusion problems by projecting cues on distal still-life objects or human figures. We demonstrate the first application of LPs in an observational drawing task and showcase how this configuration overcomes traditional usability issues of LP-SAR systems while maintaining user interactivity.

Augmented Reality Training. Augmented reality technology shows promise as an engaging, tangible, and distributed medium; however, its adoption in the classroom is constrained by high overhead in implementation, the need to troubleshoot hardware and the complexity of learning tasks [12]. AR systems have been shown to support training tasks and learning mechanisms [3], generating computer-mediated scaffolds [25, 26], and spatially situating information [4], providing corrective feedback [35], prompting reflection [52], and supporting curiosity and open-ended inquiry [42]. Similar to our use of projected cues on drawing objects, BodyExplorerAR [46] projected anatomy, physiology, and clinical interventions onto full-body mannequins to promote learner experimentation and memorable experiences. We build on these works by assessing the first training system that aims for users to develop their ability to attend to proximal stimuli.

3 PROJECTION TOOL AND SYSTEM

We designed a re-configurable spatial augmented reality system for projecting light cues onto still-life drawing objects within drawing studios. We prioritized a system that minimized interactions with a desktop or mobile interface yet provided interactive control for learners to customize and tune visual cues on their drawing object. The overall system is composed of a traditional light projector (1920x1080; 1000 lumens) augmented with a depth camera (Luxonis Oak-D). In the user's drawing environment, a MIDI control board (LaunchControl) allows the user to alter the size, position, and intensity of visual cues through button presses and dial manipulations. An iMac (M1; 8-core CPU) is used to host a standalone web application that provides the projector with a visual feed via USB-C. The routine for creating drawing cues is depicted in Figure 2 and described below.

Computer Vision Routine. Each projected light cue is object-specific and enabled by a computer vision routine that extracts a contour of the drawing object of interest from the physical environment. Using OpenCV, a single-channel depth image is extracted from the depth camera; noise is reduced using morphological filters (erosion and dilation), and two thresholds are used to remove foreground and background features. We then use OpenCV's contour detection algorithm to detect the border of elements in the scene; we assume that the drawing object of interest is the largest contour in the scene. The XY coordinates of the largest contour are then streamed to a WebSocket server; overall, a drawing contour is extracted at 30 fps. The standalone web application then subscribes to the WebSocket stream and renders the resulting contour on a digital HTML5 canvas.

Projected Cue Interactions. In a standalone web application, we use the 2D vector manipulation library `paper.js` to render the drawing object contour and then procedurally generate different cues specific to the contour's geometry. During the projection mapping stage, i.e., when the digital canvas is being mapped to the physical environment, we use traditional affine transformations (rotation, translation, scaling, skew) to support direct manipulation of the cue onto the physical drawing object. Using `clipper.js`, the contour and corresponding cue can be further tuned by smoothing, expanding, or contracting the edge. Lastly, real-time interactivity is created by mapping button and knob input from the MIDI controller to parametric variations in the procedural cues.

4 LIGHT PROJECTION COGCUES

Design Process. We iteratively develop cogcues through low-fidelity prototypes created by using the contour (e.g. silhouette of a mannequin from the CV routine and placing it on a web-based vector design and collaboration tool (FIGMA). We used the contour to think through different visual cues on the drawing object. We then masked the visual elements so that they were fully contained within the contour and projected the prototype onto the physical scene. Using direct manipulation, we employed affine transformations (drag, resize, and scale) to map the contour to the mannequin.

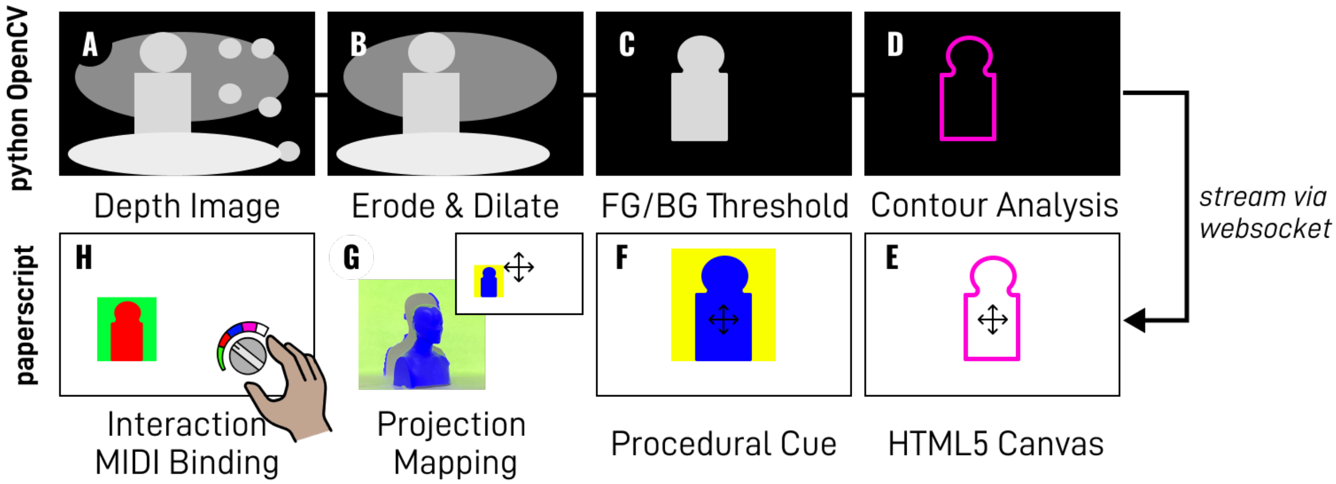

Figure 2: AR Projected Cue Routine. A) a depth image is extracted from two monocular feeds; B) morphological operations are used to remove noise; C) foreground and background elements are removed using a threshold; D) a contour is extracted and E) sent to a the paperscript routine; F) procedural instructions are used to create an object-specific cue, G) the cue is mapped to the real-world object, H) interactive cue elements are mapped to MIDI input controls

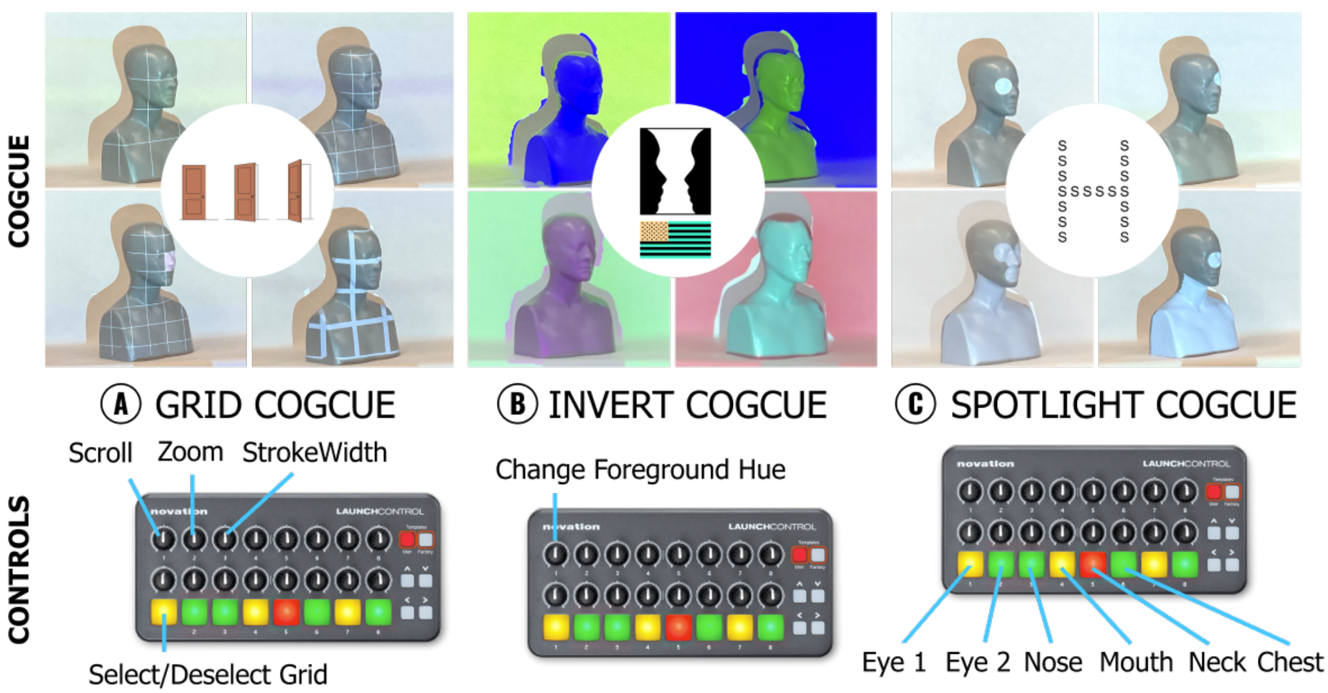

Figure 3: Projected Light Cogcues with MIDI Board Interactivity Schema. A) The grid cogcue projects a uniform grid onto the object, allowing control of grid density, grid-element tracking, and line width; the cue is designed to counteract shape-constancy effects (center); B) The invert cogcue projects background and foreground colors that can be inverted to alter figure-ground perception (center); colors are chosen to draw on opponent processes theory associated with afterimages in visual perception (center); C) the spotlight cogcue enables selective visual attention to highlight local features of the object.

This process allowed us to generate, edit, and test cues *in situ* to select which cues to implement and make interactive.

To develop interactive prototypes, we created a paperscript routine that proceduralized the FIGMA cue designs conditioned on the input contour from the CV routine. Interactive elements were then mapped to MIDI controller events. We will use the term *object contour* to refer to the outline of the drawing object extracted from the CV routine. Cogcues were designed to either suppress or enhance common phenomena in visual perception and to correct misperceptions of the visual stimulus.

4.1 Grid Cogcue

The grid cogcue (Figure 3A) was inspired by the grid drawing technique where a reference photo is divided using a grid, and the same grid is replicated on the canvas to guide the positioning of the subject. Positioning objects on one's canvas while drawing from life presents an interesting challenge, as the visual input of the stimulus changes constantly as the eyes move around.

Projecting a grid directly on the stimulus allows for a better perception of proportions to faithfully convey the form of the object. With the grid, the user is, in theory, able to break up the image into a series of sub-images that do not trigger constancy biases associated with the human form. This is especially useful in situations where symmetric objects (a forward-facing mannequin) are tilted away from the user, presenting conflicts between conceptual sizes (D-Mode) and actual sizes (P-Mode). For example, since objects further away in our field of vision appear smaller and higher, the closer eye should be drawn bigger and lower than the other eye. However, most drawers will continue to draw both eyes of the tilted mannequin as having the same size and level. A drawer would need to suppress the size constancy of the eye and instead attend to the raw visual information, seeing not an 'eye' but more simply a dark region that is smaller (more distant eye) than the other dark region (closer eye).

Stimulus. The grid cogcue consists of a network of uniformly spaced horizontal and perpendicular white lines that form a grid against a plain background. The grid is masked to only appear within the object contour.

Interactivity. A MIDI controller exposed one knob for controlling the grid density and another knob for changing the stroke width of the lines. Users could also toggle illumination on a grid square to assist with tracking visual location on the grid. A knob was used to select and scroll through the rows of the grid. Selecting/deselecting a touchpad while on a specific grid square would toggle the illumination.

4.2 Invert Cogcue

The invert cogcue uses two models to improve perception of outlines and composition (Figure 3B). The first, the figure-ground principle from the Gestalt theory of perceptual organization, is most commonly represented using the vase/face paradox. According to the principle, the object of interest is instinctively perceived as either being in the foreground (figure) or the background (ground). In the vase/face paradox, one can perceive either a vase shape or two faces in silhouette, depending on the viewer's attention and perception. Switching between the two exemplifies the figure-ground principle in action.

The second, the opponent processes theory of color perception, proposes that the visual system processes color information in opposing pairs: red-green, blue-yellow, and light-dark. The theory states that one member of the color pair suppresses the other color. For example, two types of cells in a blue-yellow receptor complex cannot be activated at the same time. The theory also explains the phenomena of afterimages: when opposing receptor cells fatigue, resulting in the perception of the opposing color.

The cogcue utilizes opposing color pairs and top-down processing from the figure-ground principle to amplify the contrast between the global aspects of the image that equally compose the scene, the figure (mannequin), and the ground (background). The cogcue uses the blue and yellow pair, as they were rendered the most accurately by the projector. While the grid cogcue allows users to segment multiple features (local aspects) of the mannequin, the invert cogcue segments the visual into only two components. This simplification of the scene allows users, in theory, to more easily process the mannequin's outline.

Stimulus. Although no color space aligns to the color opponency model, we leverage the Hue, Saturation, and Value (HSV) color space model as a practical means of controlling color opponency. First, foreground and background regions of interest are identified by subtracting the drawing object's bounding box from its contour. A fully-saturated fill color is applied to the resulting foreground and background, obeying the rule that the foreground hue is always directly opposite the background hue on the hue color wheel (+180°). This results in color dyads that roughly align to color opponency effects, including red-green and yellow-blue, which readily allow for the figure-background inversion effect.

Interactivity. The MIDI controller was configured to allow users to control both the inversion and opponent cells effects. The controller exposed one knob for selecting the color dyad (0° maps to red-green), and one touchpad to toggle the background and foreground colors.

4.3 Spotlight Cogcue

The spotlight cogcue aims to help users directly shift attention to P-Mode through directing attention to local aspects of the mannequin to elicit local versus global precedence. This approach allows the artist to capture the intricate details of a specific area first before moving on to the larger, more general shapes and forms. This selective visual attention is important in P-Mode perception because it allows an individual to focus on intricate details (e.g., the white reflection on a cup of coffee's surface) versus being overwhelemed by all the information present. The spotlight cue (Figure 3C) consists of white circles projected on a plain background to simulate the effect of spotlights. The contrast against the dim background directs the user's attention to the focal area, enabling local precedence. There are multiple "spotlights" on different features of the mannequin that users can select and deselect. The illumination provided by the spotlight produces a better visual of salient details such as the shadows, which convey depth. This facilitates P-mode processing, as users, in theory, focus on a specific area of the stimulus and work their way up to represent it integrated with its global form.

Stimulus. The cue is created by first deconstructing a drawing object into regions of interest. In the case of the mannequin, this corresponds to the eyes, nose, mouth, head, and neck-torso. Each region of interest is then converted into a vector path within `paper.js` and mapped to the contour axis geometries (e.g., the neck-torso is aligned with the bottom of the contour and extends up to the mid-point of the contour's vertical axis). Each region is then configured to take on a white fill, creating a spotlight.

Interactivity. In the MIDI controller, each spotlight is mapped to a unique button pad, allowing users to toggle the visibility of any one of the spotlights. By using the spotlight cogcue to help direct and isolate their attention on local or global forms, this interactivity supports the drawer in regulating bottom-up processing and adopting an incremental drawing strategy.

5 USER STUDY

The aim of the study is to understand how the drawing experience is affected when cogcues are introduced into the environment and whether prior drawing knowledge plays a role in how cogcues are utilized.

5.1 Participants and Recruitment

We recruited 12 students from the Engineering and Liberal Arts departments in our university. A pre-screening questionnaire was used to obtain a sample balanced on drawing practice expertise; users with sensitivity to light or changes in light stimuli were excluded from the study. The final set of participants were 21 ± 0.5 years old, 8 female, and 4 male. Through self-report, 6 participants had intermediate drawing expertise while 6 reported novice expertise. No participant reported color vision deficiencies. Participants were compensated with a $15 USD gift card. This study was approved by our Institutional Review Board (IRB).

5.2 Setup

The study was conducted in our drawing studio and configured to model a traditional observational drawing task (Figure 4). A life-size neutral-gray head-and-shoulder mannequin (45 cm x 33 cm x 27 cm) was positioned to provide a 3/4 face view 2 meters from a drawing table (2 m x 3 m). A mannequin bust was chosen as a drawing object to closely resemble a visually familiar form – the human figure – to activate top-down processing percepts and be relevant to the art community. The stimulus was placed at an angle to introduce a drawing task that challenges the drawer with a symmetric subject matter (human form) but an asymmetric stimuli (tilted mannequin).

All drawings tasks were carried out with a standard 2B pencil, polymer eraser, and sharpener on white A1 sheets of paper taped to a tilted drawing board in portrait orientation. Participants could freely sketch, erase, and make corrections. Participants were able to control the projected light cues using a MIDI board (16-knob/8-pad LaunchControl). The AR projection system (computer, projector, depth camera) was configured on the table and pointed toward the mannequin.

5.3 Study Task

We conducted a within-subjects study where participants were tasked with drawing the still-life mannequin under 4 conditions: once with each of the 3 cogcues (grid, invert, spotlight) and once in a control condition without projection. To mitigate ordering effects, a Latin square was used to vary the task order. Users were given a visual scheme of the MIDI board with all the interactivity options for each cogcue (Figure 3) and were provided a warm-up period to test out each cogcue before starting the drawing tasks to counteract novelty effects. Each user was given 15 minutes for each drawing task.

Video and Logs. A document camera recorded all drawing interactions during the study, while a log recorded all MIDI actions. A separate camera recorded the drawing object, roughly in the same perspective and eye level as the study participant.

Post-Task Questionnaire. After each drawing task, participants completed a post-task questionnaire. The questionnaire included the NASA Task Load Index [21] which was used to assess the cognitive load on six dimensions: mental demand, physical demand, temporal demand, effort, perceived performance, and frustration level. In addition, Likert statements (5-point semantically anchored) were used to gauge experiences of agency and self-efficacy with the system [1].

Retrospective Think Aloud. To minimize disruptions during the tasks, we conducted a retrospective think-aloud, during which users commented over a video recording of their drawing session. The session assessed users' attitudes toward the projection cues and how the cues supported or impaired their drawings.

Expert Ratings. After the session, two drawing instructors rated each drawing on a 5-point skill mastery scale assessing four drawing factors derived from common drawing proficiency criteria:

- COMPOSITION: The arrangement of elements within the pictorial space correctly represents the scene, e.g., the eyes are in the right place with respect to the head shape.
- PROPORTION: The drawing representation is accurate in the relationship of the size of one element when compared to another, e.g., the head is correctly proportioned to the body.
- PERSPECTIVE: The drawing representation is rendered in the correct orientation from the drawer's viewpoint, e.g., the figure is rendered in a 3/4 view.
- DEPTH: The drawing representation conveys a three-dimensional look on a two-dimensional surface through the use of shading and other techniques e.g., the drawer used cross-hatching to establish shadows and recede the neck.

To aid with the data collection, ratings were collected via a virtual card sort method. In a FIGMA file, participant drawings were stacked in the center of the canvas and the Likert statement question was presented at the top of the page. Anchor labels (e.g., 1 - Strongly Disagree) were arranged around the canvas; raters would then click and drag the drawing 'cards' to the appropriate region to signify their rating. This spatial Likert scale allowed for ratings to be weighed with respect to previous ratings, allowed raters to make changes to previous ratings, and help reduce ordering and fatigue effects. After the rating process, experts were interviewed to provide additional context for their rating choices.

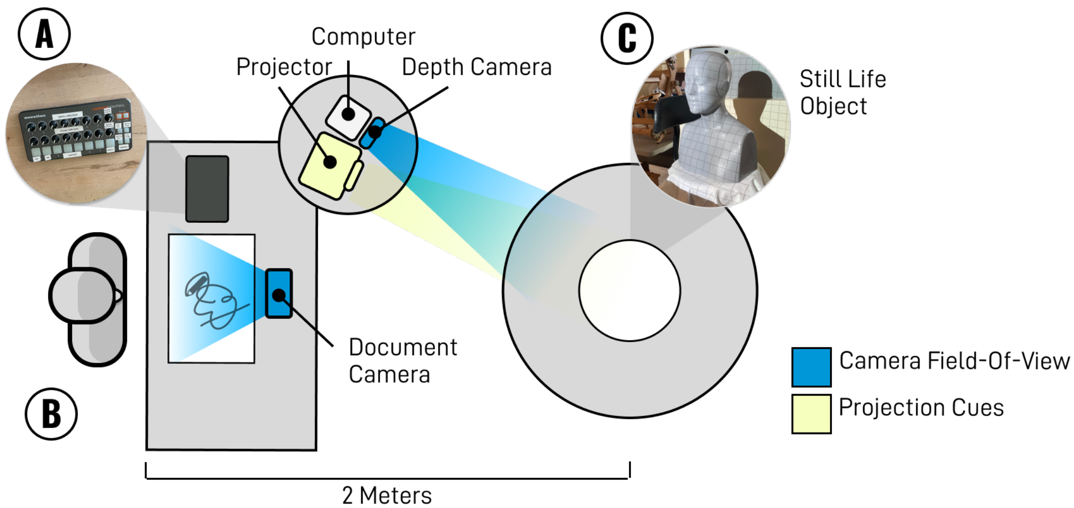

Figure 4: User Study Setup. A) The user is presented with a control board to reconfigure the cues; B) The user sits at a drawing table, on which there is drawing paper and a document camera to record their process.; C) Cues are projected on the stimulus, which is 2 meters away from the user.

5.4 Data

The study resulted in 48 drawings by 12 participants, 480 expert ratings, 12 hours of drawing videos, 34K MIDI log messages, and 12 pages of transcribed retrospective think-aloud transcripts. For clarity and contrast; drawings were vectorized before analysis; drawings are provided as supplementary materials. Figure 5 depicts a selection of participant drawings.

6 COGCUE EXPERIENCES

The data collected from the user study was used to analyze the SAR-LP's system usability, report the effects of individual cogcues on drawing performance and process, and understand design opportunities for cogcues in physical skill transfer applications. We first present a description of our analysis methods, convey results specific to each cogcue, and then communicate results that describe the collective experience of cogcue-assisted drawing experience. The use of these three analysis methods allowed for a more comprehensive evaluation of the cogcues, especially since the user experience of a system often differs considerably from the quality of artifacts produced.

6.1 Methods

Quantitative Analysis and Descriptive Statistics. Results from self-reported measures in the post-task questionnaire and expert ratings are reported relative to each participant's control condition. Scores are formatted as follows: $\mathsf{Factor}(\mathsf{Cogcue}, S) = \bar{x}_S \pm \sigma_{\bar{x}_S}$, where S signifies the pooled sample on expertise (A = all, N = novice, and I = intermediate), $\bar{x}_S$ is the sample mean, and $sigma_{\bar{x}_S}$ is the standard error. Ratings for each cogcue are presented in Figure 6. We performed a Wilcoxon signed-rank test to assess the null hypothesis that cogcue-assisted drawings/experiences showed no difference from non-cogcue drawings/experiences (control treatment). We applied a two-sided test and reported significant results with the W statistic and p-value (ρ).

Drawing Analysis. To understand how resulting drawings were affected by cogcue conditions, we conducted a visual analysis with two coders using an axial coding scheme: deductive codes were applied from our drawing factors (composition, proportion, perspective, and depth), while inductive codes were drawn from data specifically identifying features differing from the control condition drawing. Codes were applied first per participant drawing set, then on cogcue set. Similar codes were grouped together and refined into descriptive themes. Side-by-side videos of the drawing process and the stimulus were used to review and refine the themes and determine their relationship to each other.

Thematic Analysis. The objective of this thematic analysis [2, 10] was to assess collective user experiences in using the interactive projected cues and their effects on the drawing process. This method allowed us to systematically and rigorously assess the complexity and nuance in the patterns and themes seen in the qualitative data. Two paper authors with backgrounds in psychology and art practice iteratively applied and developed inductive codes to the dataset of memos from the drawing sessions and retrospective think-aloud transcripts. The codes were discussed and refined until agreement was reached, then categorized and refined into recurring themes.

6.2 The Grid Cogcue Experience

Scores and Ratings. The grid cogcue resulted in a significant decrease in drawing performance: $\mathsf{Quality}(\mathsf{Grid}, A) = -0.2, W = 14.0, \rho = 0.0892$. This effect was more pronounced with intermediate drawers: $\mathsf{Quality}(\mathsf{Grid}, I) = -4.0 \pm 0.01$. While all drawing factors showed a decline, depth and composition were the primary contributors to negative drawing performance. Participants report that

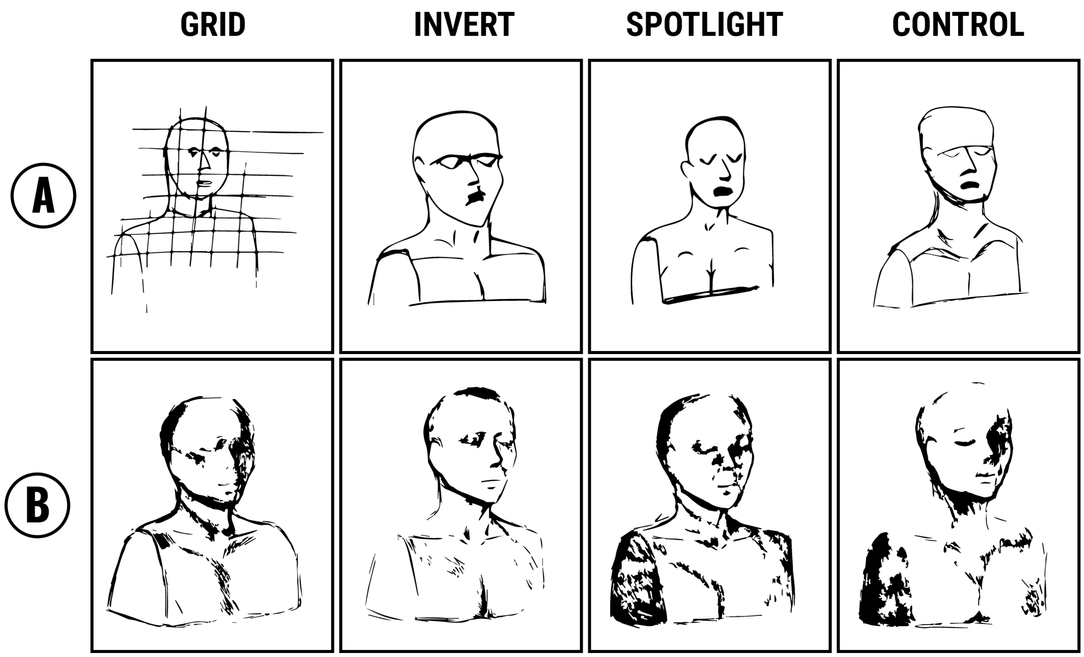

Figure 5: Participant Drawings per Condition. A) U8 - Novice Expertise; B) U9 - Intermediate Expertise; images were thresholded for clarity.

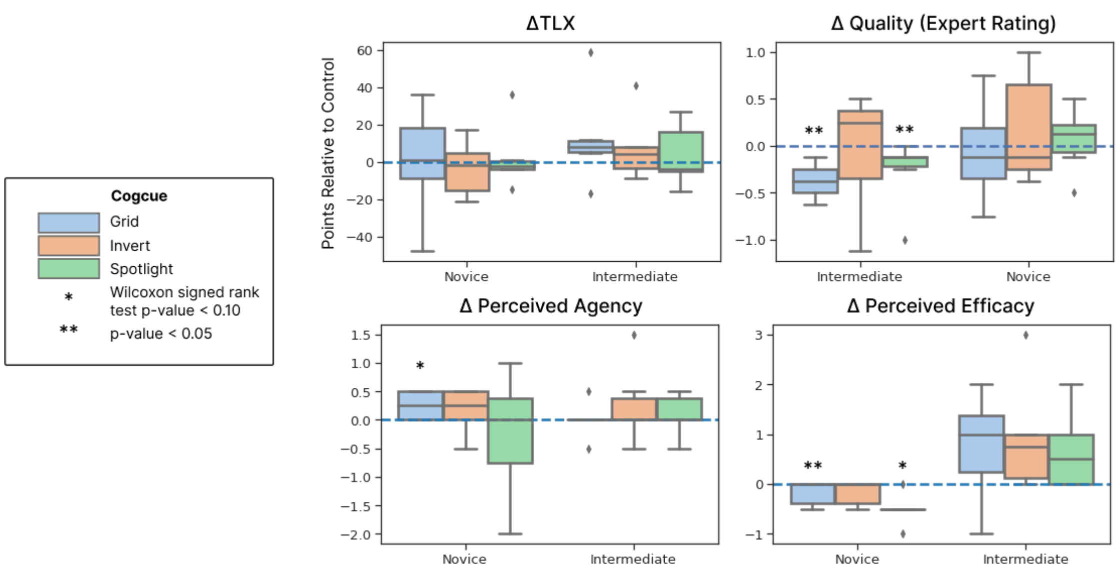

Figure 6: Scores & Drawing Ratings Scores and ratings are displayed with respect to each participant's control drawing condition. The NASA-TLX score has a 100-point range, while expert ratings and self-report values have a 5-point range. Wilcoxon signed-rank tests were performed on these relative values; significant results are annotated with asterisks (**). Results close to the dashed-blue line indicate no change from the control condition.

they were also unsatisfied with their drawing performance with this cue ($\mathsf{TLX\text{-}Performance}(\mathsf{Grid}, A) = 2.1, W = 14.5, p = 0.0980$); intermediate drawers reported an overall higher cognitive load ($\mathsf{TLX}(\mathsf{Grid}, I) = 7.7 \pm 4.5$) specifically from the mental and temporal demands of the task. Despite these negative encounters, intermediate drawers reported that the grid cogcue provided greater self-efficacy – Agency(Grid, I) = 0.8 ± 0.4 – indicating that they understood how to use the cogcue and were overall content with using them for the drawing task.

Cogcue Behaviors. Since the grid was a familiar sight to many participants, many found increased agency in using this cogcue to solve their specific perceptual problems. For (U7), the grid resonated with their usual Loomis method, i.e., a top-down technique for marking landmarks of the face. When interacting with the grid cogcue, novices preferred increase the density of the grid on the mannequin. Videos communicate this was a byproduct of users who wanted to segment the face more. Controlling grid density became a strategy for perceiving volume for intermediate drawers:

> U14 With the lines [on the grid], I know where the lines are going; in the eye, it's going inside, so I used some lines directing inside . . . , and with the head, it's round, so I used some lines that are changing direction [and curving].

Participants took time to experiment on the ideal parameters, although intermediate drawers made quicker decisions.

Drawing Trends. In the case of U14, as with other intermediate drawers, the grid was treated as a part of the visual stimulus indicating engagement with P-Mode perception. However, their ability to remain in P-Mode was complicated by the familiar percept of the grid – we see instances of the grid becoming almost rectilinear despite the curved surface of the mannequin. Compared to their other drawing conditions, there was no change in U14's drawing process, yet the grid cogcue presented the most distortion, suggesting that the drawer did not have prior issues with rendering proportion. This communicates that the grid is a particularly difficult stimulus to counteract D-Mode perception (e.g., size constancy, shape constancy), and resulted in a disoriented drawing.

One interpretation for this trend could be explained by the existing perceptual training disrupting established ways of counteracting stimuli. Although the grid technique is prevalent in fundamental drawing courses, its absence in advanced courses suggests that the grid cogcue has a scaffolding effect. As confirmed by the TLX survey, this cogcue was cognitively taxing. This inability to remain in P-Mode perception could be attributed to the visually complex and high contrast pattern projected all over the mannequin dominating the visual pathway in D-Mode perception. Although there is value in cues that assist in interpreting proportion, our results indicate that it is necessary to design cogcues with unfamiliar and low complexity marks for segmentation and visual selection, and that entering P-mode perception draws on significant attentional resources from drawers.

6.3 The Invert Cogcue Experience

Scores and Ratings. The invert cogcue showed mixed results for drawing quality for intermediate drawers, but stronger quality by novices (Quality(Invert, N) = 0.2 ± 0.2) with proportion accounting for the greatest improvement: TLX-Proportion(Invert, N) = +0.7 ± 0.3. While no significant changes in cognitive load were observed overall (TLX(Invert, A) = +1.9 ± 4.6), intermediate drawers did find the invert task required more cognitive effort (TLX(Invert, I) = 7.2 ± 6.7) largely as a result of the mental demand of the drawing task: TLX-Mental Demand(Invert, I) = 2.3 ± 0.9. Although intermediate drawers reported greater self-efficacy and agency Self-Efficacy(Invert, I) = 0.9 ± 0.4, novice drawers experienced the opposite effect.

One explanation may lie in the complexity of the cogcue – the invert cogcue was the simplest of the three and allowed experienced drawers to rely on and more actively apply their already developed skills. In contrast, there may not have been enough explicit assistance for novice drawers despite improvement in their drawing quality. Thus, effective cogcues may require designers to provide a stronger sense of perceived assistance, similar to artificial delays in progress bars, to provide a sense of scaffolding for novices.

Cogcue Behaviors. Intermediate drawers showed a preference for cooler colors in the foreground, whereas novices preferred warmer colors. This is in contrast to the theory of atmospheric perspective which recommends cooler colors for distant and receding objects to simulate depth [23]. This indicates that novices were actively making use of the figure-ground inversion effect, whereas intermediate drawers were only benefiting from the additional depth cue. As a novice drawer described:

> U10 It helped me see the boundaries of the mannequin. It was so relaxing for me. I drew the boundary with ease.

Additionally, most participants found that switching between hues gave them an increased awareness of the values and an increased ability to discern shadows.

Drawing Trends. Novices and intermediates alike depicted the shadow cast by the mannequin on the background. This is indicative of the cue's success in driving focus to the global aspects of the visual through its simplification of the scene into foreground/background. Novices who used guides such as lines and shapes to place features in other drawings opted to use them less in their drawing process for the invert cue implying a decreased focus on smaller features (local elements). Intermediates and novices alike made prominent marks in the neck and shoulder areas while using the invert cue. These marks were interpreted as construction lines to guide shading later in the drawing process. For intermediate drawers, the invert cogcue resulted in darker and denser guides for shading in all areas of the mannequin, affirming their use of the cue to understand depth information. Participants learning to create their own visual supports shows value in keeping cues simple and leaving the creative interpretation to the users.

6.4 The Spotlight Cogcue Experience

Scores and Ratings. In the spotlight cogcue, novices showed some improvement in their drawing quality, largely attributed to their ability to render proportion: Proportion(Spotlight, N) = +0.5 ± 0.2. Intermediate drawers, however, showed a decrease in the overall quality of their drawings stemming from mispositioned elements – Composition(Spotlight, I) = −0.5 ± 0.2 – most likely from the increased attention on local areas.

No significant change in cognitive load was reported and intermediate users continue to report efficacy with the system: Self Efficacy(Spotlight, I) = 0.7 ± 0.3

Cogcue Behaviors. The spotlight cue MIDI logs express that participants primarily spent their drawing time with the receding eye spotlight activated. Novices largely used facial spotlight cues and immediately worked towards transferring local visual details; however, intermediate drawers experimented more with the spotlight effects, switching between different spotlight configurations to better understand "how the light bounced off"(U9) the mannequin. The liveness of the cues lent to this form of experiential inquiry and diverted many of the drawing sessions from the drawing activity instead into exercises in hacking perception.

Drawing Trends. Spotlights were effective in commanding all users' visual attention. Areas that were initially spotlit were always drawn first. Spotlights were used as guides by some more advanced participants, incorporating the shape of the spotlight into the drawing itself (P-Mode). Although the spotlights were successful in shifting all users' visual attention, the effect was most pronounced on novices, especially since they did not have an established drawing routine. Yet, like the familiarity of the square in the grid cogcue, constancy effects continued to undermine the shift into P-mode perception. Novices and intermediates alike struggled to capture the spotlights, drawing them as simple circles or polygons rather than their distorted form. These findings affirm the power of light itself as a visual cue to command focus and attention. As with the grid, the drawing trends using the spotlights exhibit efficacy in designing cues with less familiar visuals.

6.5 Cogcue Themes

Fixations and Formulas. For many participants, their drawing approach remained formulaic. They repeated the same drawing process, attending to the same features of the mannequin regardless of the drawing condition. This fixation resulted in participants reliving the same drawing errors. For instance, although U6 changed the facial structure of the mannequin for each iteration, their attention to the neck and bust of the figure remained neglected, resulting in consistently elongated Modigliani-like renderings. This effect was less pronounced for intermediate drawers like U14; their drawing approach showed a more active response to the cogcues and resulted in more exploratory drawing experiments. These responses indicate that cogcues alone cannot overcome established drawing habits; instead, part of the training process should consider ways of persuading the drawer to resist their tried-and-slightly-successful approaches.

Counteracting D-Mode Perception with Construction Marks. During the invert and grid cogcues , drawers showed a higher proclivity to integrate construction marks onto their drawing. These marks were most commonly used to indicate the alignment of features. However, some participants employed construction marks to indicate the curvature of different surfaces. As one expert rater describes:

> Rater 1 I'm thinking that [U12 - Invert] is trying to figure out the planes of the face ... you can see the line on the cheekbone [separates the front plane and] the side plane. I'm thinking that with all those lines, they were . . . prepping to figure out where those changes in shading would happen.

Given the matte gray surface of the drawing object, perceiving changes in value was challenging. These and other construction marks demonstrate drawers actively using top-down information (e.g., parts of the bust are on similar planes) to counteract the effects of D-Mode perception (e.g., brightness constancy).

The grid and invert cogcues demonstrated two different approaches for eliciting construction marks – active sensemaking and passive sensemaking, respectively. In the grid case, users adapted the projected grid to match their area of focus, allowing the grid to provide missing details and make sense of the composition. In contrast, the invert cogcue simplified the visual stimuli into two large sections, the background, and the foreground; the drawer was left to make sense of the local details on their own. The construction marks became a problem-solving and spatial reasoning strategy to render details and better depict the 3D structure of the object. Our results indicate that cogcues can focus on passive sensemaking strategies to support greater agency and self-efficacy.

Defamiliarizing Stimuli. The spotlight cogcue and grid cogcue's ability to project light onto parts of the mannequin commanded the visual attention of drawers and had a particularly pronounced effect on defamiliarizing the object. As one participant describes:

> U11 I was only focusing on that particular area, and the other parts of the mannequin were kind of blurred.

This form of attention capture broke relationships between features and enabled a switch to processing local details isolated from the big-picture. When comparing two intermediate drawers (Figure 7), U3 and U14's drawings across conditions, the spotlighted facial areas were largely underdeveloped and presented unusually (within a spotlight) and out of context. , different from how the whole mannequin is presented. Defamiliarized stimuli is more cognitively demanding to process in D-Mode perception. For example, a tilted nose is easier to process if it belongs to a tilted figure, but here, attention is directed to a collection of values within the spotlight.

Enhancing and Counteracting Memory Effects. In observational drawing, artists often spend a significant amount with their eyes fixated on the stimulus, yet we encountered participants fixated on their drawing. Learning effects were expected and participants reported that they felt as though they "an image in my mind" (U8) that they felt allowed them to draw quicker with less of a need to observe the mannequin. This resistance to looking at the stimulus may result from cognitive biases that enable users to rely on our memory by making us more confident in our recollections [36]. However, we anticipate novelty effects encouraged users to change cogcues and observe the mannequin for more extended periods.

Participants in the spotlight cue welcomed the ability to control where focus landed on the mannequin. While one intermediate drawer did not perceive the spotlight in developing their drawing ability, they acknowledged that the spotlight would be valuable in directing attention to both small and larger "chunks" of the object. This form of cognitive chunking, characteristic of advanced short-term memory processing, suggests a subconscious reversal between local and global processing ability that contributes to their enhanced drawing ability, which follows with skilled artists' fluency in switching between local and global processing [7]. Further development of cogcues can leverage spotlights' capacity for attention manipulation to enforce this drawing ethic and encourage the tacit practice of drawing global features first and regularly switching between global and local attention.

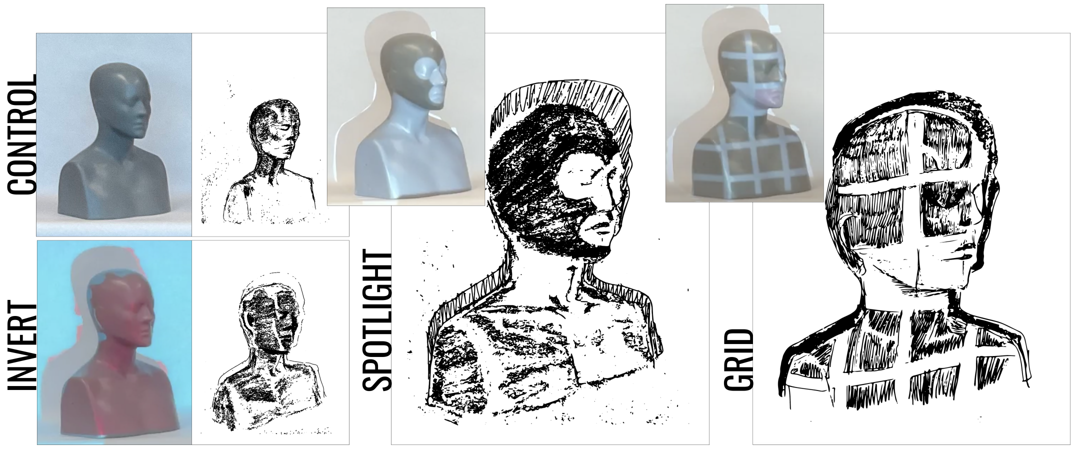

Figure 7: Participant U14's drawings for each cogcue with the corresponding stimuli.

Hacking Cogcues . Many of the participants, experienced the intended effects of the cogcues , yet the grid cogcue was the most well received:

> U10 Without the cues, I was scribbling, and with the cues, I knew exactly where the shape lay.

However, most participants adapted the cogcues to suit their different needs. For the invert cogcue, participants discovered that changing the hues heightened their ability to discern values and depth information. For others, the act of being able to move through different hues brought different features into focus, which later became a sensemaking strategy:

> U12 I had to switch colors to get more details. The focus shifted. Whatever I was missing in the previous color, I could recognize it in the next color. When I switched, I could figure out some of the details I had missed.

This trend was observed across cogcues, where participants leveraged the real-time and dynamic controls to understand the value of respective cogcues in acquiring the information they needed:

> U11 I was able to focus on the eye because I was able to select [the spotlight cue]. I wasn't able to really differentiate between what I was doing wrong before the [invert cue] came in.

> U12 The spotlight doesn't tell you about positioning. It only helps you with the shape, but the grid also helps you with positioning.

While the spotlight and grid selection were designed to track progress and focus attention, all participants leveraged the light-casting ability to dramatize shadows. The real-time nature of the cues facilitated this type of experiential investigation and steered many drawing sessions toward exploring techniques to take control of and manipulate perception.

7 DISCUSSION

7.1 Assistive Drawing Tools

Many drawing techniques and devices, from the easel, camera lucida in 1806, rotoscoping in 1915, to modern AR art projectors and wearables, have supported photorealistic and observational drawing. These approaches are successful in producing faithful representations and, in many instances, implicitly serve as cogcues by reducing the mental and physical demand of alternating gaze between the reference object and the drawing surface. However, in reducing drawing to a tracing task, they limit the growth in users to hone their perceptual system and draw regardless of the constraints each technology imparts [19]. Our study revealed that projected light cues are highly effective in directing attention yet ineffective at disrupting established and 'safer' user drawing workflows. As in other creative domains, an aversion to errors limits exploratory behaviors necessary for growth [47] – cognition-assisting creativity support tools must consider how practitioners can move beyond their safe strategies. Many computer-assisted teaching and intelligent systems for perceptual skill training are focused on providing users with corrective feedback [11, 38], step-by-step tutorials [50], or gamification [39]. Although effective, these behavioral approaches ingrain a mentality of doing things correctly or incorrectly.

These effects are especially problematic with drawing since it is often the most familiar objects that are the most difficult to draw likely due to not being consciously aware of our internal perceptual processes. This work described cogcues as ways to foreground a bottom-up approach to achieve P-Mode perception. In our approach, we suppressed one mode of processing to allow for the dominance of another. In practice, the two modes of processing work in conjunction, and it remains challenging to discern which one dominates perception at any given time. Participants in our study chose to leverage the interactivity of the cogcues to hack their perception, making salient the stimuli that best matched their drawing goal. Akin to dialing up the intensity of a desktop light, we view SAR systems as a means of further taking control of personal perception, designing personal feedback mechanisms, and encouraging exploratory behaviors to build awareness of the conflicting signals in our perception.

7.2 The Art of Drawing

Although our system focused on altering perception as means of achieving more realistic depictions, it is important to note that not all artists desire or use realism in their drawings. Drawing has also been a means of problem-solving by enabling exploration of different possibilities [41], of connecting with [18] and understanding the world around us in a deeper and meaningful way [17]. While realistic drawing is focused on capturing subject matter in a way that is true to life, expressive drawing often involves exaggerating certain features to convey the essence or feeling of the subject rather than its actual form. The experimentation and creativity that expressive drawing encourages can help artists develop their own style, as in those who create caricatures. However, researchers and practitioners have emphasized technical proficiency as foundational to developing a distinctive art style [33, 41, 48]. Learning to draw what they see in the real world is often the first lesson artists are given as a way of mastering technical skills. Our system is best suited as a supplement while learning these foundational skills. Future drawing support tools could implement features that encourage experimentation and celebrate the development of distinctive art styles.

7.3 Defamiliarization

Although our cogcues focused on counteracting bottom-up information, top-down drawing approaches suggest that knowledge-driven influences can be used to support depiction [37]. Others propose top-down information as a way of structuring and organizing the drawing process into a set of rules and principles as described in Betty Edwards's seminal book *Drawing on the Right Side of the Brain* [13]. Cogcues can be similarly structured for communicating rule-based drawing systems, such as vanishing point techniques; other cogcues could focus on reinforcing theoretical knowledge, such as human anatomy proportions for figure drawing.

An alternative strategy is to supplant the top-down information through defamiliarization. Our work saw the constancy effects of squares, circles, and eyes as culprits in pushing drawers back into D-Mode perception. While one strategy is to project unfamiliar shapes on reference objects, Yurman et al. found that introducing the material influences of watercolor could be used to introduce ambiguity from the natural bleed of watercolor lines on paper [53]. This further aligns the role of charcoal drawing in art education that forces practitioners to rely more heavily on P-mode perception.

7.4 Extending LP-SAR Systems

Our use of the light projection system to support drawing skill evaded the occlusion problem, as we projected on the drawing object and not the workspace. Depth resolution was just enough for the mannequin. Rivers et al. [43] demonstrated the use of a similar LP-SAR system for projected guidance in making a physical object to match a target 3D shape in sculpting and cake decorating. However, projecting directly onto the working material reintroduces the occlusion problem. Therefore, cogcues should be minimally obtrusive, relatively large, and not applied in works that involve extensively using the hands to manipulate materials. Cogcues offer the greatest potential in leveraging the ambient environment in creative practices, as they can be mapped to artifacts, materials, tools, and equipment in the user's periphery. Ludwig et al. [34] explore how projected visual and interactive feedback about the printer's internal functioning can be used to support users in appropriating and understanding the device. A similar system could be used to map different cogcues to various equipment in a creative workspace to guide the users through a creative practice that requires the use of multiple tools or processes. Cogcues could also be used to give users greater control over their environment. Specialized viewing chambers could integrate cogcues to highlight defects or fractures in 3-D prints or analyze circuits in a complex e-textile.

7.5 Beyond Visual Cogcues

Although our work was centered on understanding visual cogcues , the underlying theory of distal and proximal perception was initially applied to many forms of tacit knowing [40]; we envision other interactive cogcues tailored towards 'hacking' and influencing haptic, gustatory, olfactory, and sonic perception. For example, coffee grinds are regularly used as an olfactory palate cleanser in perfume sampling [49]; studies of wine sommeliers indicate that perceptual expertise is rapidly acquired [55]; and novel design opportunities exist for leveraging the memory-enhancing properties of scents in design [28]. Consequently, other 'hacks' such as sensory deprivation have been shown to support learning haptic spatiotemporal signals [5] and enhance tactile sensitivity and awareness when throwing clay pottery [20]. How might creative technologies enable users to become more aware of perceptual effects and have more self-efficacy with their perceptual abilities? Our study affirms that maximizing perceptual information is not needed for users that have already developed their visual abilities and that not all visual information is needed for an accurate depiction. This aligns with the finding that highly skilled artists are better able to identify visual information necessary for depiction than non-artists [27].

7.6 Limitations and Future Work

Balancing experimental and ecological validity in drawing studies has its limitations. Since each learner comes with a unique drawing background, the ability to counteract learning effects from cogcues and the same drawing object was difficult. Yet, the learning effects were able to tell us how cogcues interact and 'fill in' the missing information that learners are searching for. Our user study was conducted in a short time frame, and we could only assess the initial effects of cogcues; a longitudinal study is needed to assess the long-term impacts on drawing skill development. In our system design, we mirrored a natural drawing observational drawing studio environment yet maintained simple front-projected drawing scenes; integrating projection cues for other materials and scenes remains as future work. Although the legibility of projected cues is subject to ambient light, this resonated with existing drawing practices where objects of interest are placed in different lighting conditions. Lastly, we cannot discount extensive research on the relationship between visual-motor integration and drawing ability. This system only assesses the perceptual implications for drawing ability, which may account for the mistakes made by users in integrating their precepts with their fine motor skills to create their depiction. Our findings serve as a basis for further research on training the eye to select elements necessary for an accurate depiction.

8 CONCLUSION

In this work, we demonstrated that LP-SAR systems have value in observational drawing. By naturally mitigating the occlusion problem, they are able to render cues that improve novice learners' observational drawing skills with respect to proportion, placement, and shape yet negatively impact the performance of more experienced drawers. The interactivity of these cogcues was used by drawers to hack their own perception and create drawing conditions that match their drawing intention. Novice drawers used the LP-SAR system to increase the amount of cognitive assistance in mapping the form to their paper, whereas intermediate drawers used the cues to hone in and make salient regions of interest. This work maps a space for SAR systems to alter perception in observational drawing and proposes systems that support perception hacking as a means to improve perception-driven cognitive skill development.

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