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Tachistoscopic illumination and masking of real scenes

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Abstract

Tachistoscopic presentation of scenes has been valuable for studying the emerging properties of visual scene representations. The spatial aspects of this work have generally been focused on the conceptual locations (e.g., next to the refrigerator) and the directional locations of objects in 2D arrays and/or images. Less is known about how the perceived egocentric distance of objects develops. Here we describe a novel system for presenting brief glimpses of a real-world environment, followed by a mask. The system includes projectors with mechanical shutters for projecting the fixation and masking images, a set of LED floodlights for illuminating the environment, and computer-controlled electronics to set the timing and initiate the process. Because a real environment is used, most visual distance and depth cues may be manipulated using traditional methods. The system is inexpensive, robust, and its components are readily available in the marketplace. This paper describes the system and the timing characteristics of each component. Verification of the ability to control exposure to time scales as low as a few milliseconds is demonstrated.

Tachistoscopic presentation of stimuli is a valued tool for studying how visual representations develop at fine-grained time scales. As such, limited viewing-time paradigms are ubiquitous in the field of vision research. They are used, for example, to determine the properties of an image that support the categorization of a scene (e.g., Greene & Oliva, 2009) and to determine the image features that drive the targeting of saccadic eye movements (e.g., Vö & Henderson, 2010). Limited-viewing-time paradigms are especially useful when experimenters wish to preclude the possibility of an eye movement (e.g., Adam, Davelaar, van der Gouw, & Willems, 2008). Limited viewing durations are also considered important for controlling the way visual stimuli are encoded (Eng, Chen, & Jiang, 2005; Vogel, Woodman, & Luck, 2001). As a result, most work in the widely researched domain of visual working memory employ durations of around 100 ms. Until recently, the ability to manipulate viewing duration in visual space perception paradigms has been very limited, and, as a result very little was known about the time course underlying the development of egocentric distance perception (the distance between an object and the observer). There are many situations that restrict the effective time available to extract information about a target's distance: high workload environments, highly dynamic environments, neurological

disorders, normal aging, etc. Given the potentially dire consequences of mislocalization for aviation, driving, and even vulnerability to falls, there is a need to understand the impact of reduced viewing durations on target localization.

Owing to the limits of computer displays (luminance and duration variability and the need to use multiples of the refresh rate), there has been a surge of interest in developing techniques to precisely control stimulus presentation time (see Fischmeister et al., 2010; Sperdin, Repnow, Herzog, & Landis, 2013; Thurgood, Patterson, Simpson, & Whitfield, 2010). We have previously developed a device that is unique in that it provides precisely-controlled glimpses of a real environment (i.e., neither virtual nor photographed), followed by a visual mask (Pothier, Philbeck, Gajewski, & Chichka, 2009). A mask is generally considered crucial for the precise control of viewing because the mask image terminates visual processing (e.g., Breitmeyer, 1984; Breitmeyer & Ö men, 2000; 2006), disrupts visible and informational persistence (e.g., Irwin & Yeomans, 1986), and/or interferes with the formation of durable memory codes (e.g., Gegenfurtner & Sperling, 1993; Vogel et al., 2006). The primary components of this device are an electronic liquid crystal shutter window, used to control viewing duration, and a mechanical shutter mounted to a projector, used to expose the masking image. The mechanical shutter is triggered to open by the same pulse that causes the liquid crystal shutter to “close” (that is, return to its translucent, light-scattering state). The masking image is projected onto a screen beside the observer, which reflects into a beamsplitter and appears straight ahead from the observer’s perspective. The electronic shutter, beamsplitter, and a chinrest are mounted to a wheeled stage that allows them to be moved aside so that observers can indicate the remembered location of objects seen during the glimpse by blind walking, a type of visually-directed action (e.g., Creem-Regehr, Willemsen, Gooch, & Thompson, 2005; Loomis, Da Silva, Fujita, & Fukusima, 1992; Rieser, Ashmead, Talor, & Younquist, 1990; Thomson, 1980; Wu, Ooi, & He, 2004).

Using this device, we have begun to characterize important properties of the earliest stages of egocentric distance perception. First, we have discovered that extraction of information about egocentric distance does not proceed at the same speed for all visual cues (Gajewski, Philbeck, Pothier, & Chichka, 2010). Distance judgments for targets glimpsed for only 9–113 ms are quite sensitive to the physical target distances (response vs. physical distance slope near 1) when the target is on the ground; longer viewing durations are required to reach a similar level of performance when the target is at eye level. This suggests that the target’s angular declination below eye level is extracted particularly quickly; indeed, subsequent testing indicates that if the target can be assumed to rest on a horizontal ground surface, its angular declination can be extracted and used to support subsequent distance judgments almost immediately upon detection of the target (Gajewski, Philbeck, Wirtz, & Chichka, in press). Angular declination is uninformative for eye-level targets, so other distance cues must be used in this case, and presumably their extraction proceeds more slowly. Another observation made possible by precise control over stimulus viewing durations is that in its earliest stages, egocentric distance perception is powerfully shaped by information stored from previous glimpses of the environment. Distance judgments after 113-ms glimpses are significantly more sensitive to physical target distances if these brief glimpses come after a series of longer 5000-ms glimpses than if the observer has never seen the environment. On the basis of these and other findings, we have developed a dynamic

framework that describes the microgenesis of egocentric distance perception (Gajewski et al., in press).

Despite its utility for addressing these issues, however, our apparatus suffers from several limitations. The most significant stems from its reliance upon the liquid crystal (or LCD) shutter window to control glimpses of the stimulus environment. This device uses a Polymer-Stabilized Cholesteric Textured (PSCT) liquid crystal panel. In relaxed mode, with no voltage applied, these devices scatter light and thus appear semi-translucent, or nearly opaque. When voltage is applied, the panel clears and allows nearly all light through (claimed values are greater than 86% transmitted when clear, as opposed to less than 3% relaxed). The PCST panel also offers very fast transition (measured under 2 milliseconds) in both clearing and relaxing mode. A major issue, however, is that devices of this type are becoming difficult if not impossible to find. The market for them is limited, and for most purposes the market has moved to more common polarized panels. This renders reliance on the PCST risky, and hinders other researchers from being able to duplicate and extend the results obtained using the device.

Replacing the PCST panel with commonly available polarized panels is not sufficient for our application, however. Though polarized panels can be driven to near-total opacity, and are easy to find, they are undesirable for our application. They transmit less than 50 per cent of incident light even in “clear” mode, which produces a sunglasses-like effect for scenes viewed through such a device. They also tend to have longer relaxation times, so that “opening” the shutter takes several milliseconds. This limitation can be overcome only at the cost of yet more blockage in the open state. Alternate optical panels are readily available (e.g., consumer smart windows), but these generally do not have adequate transition speeds. Thus, there is a need for a device that can provide precise control of viewing durations, but uses hardware that is more readily accessible and does not rely upon LCD shutters.

Methods and Materials

Experimental System Overview

In this paper, we describe a solution that uses LED floodlights to meet the specification of providing brief glimpses of a real environment in a way that does not require LCD shutters. The viewing environment contains the viewing control system and associated hardware, as well as the screens and targets that comprise the experiment itself (see Figure 1, Top). The environment consists of the following components. (a) A projection screen is situated on the observer’s left, and the screen is visible straight ahead from the observer’s perspective via (b) a beamsplitter situated at an angle just in front of the observer’s eyes. Two slide projectors are aimed at the projection screen; one (c) projects a blank white image that is viewed between trials to keep the observer in a relatively constant state of light adaptation. A fixation cross may be included in this image if control over gaze direction prior to the glimpse is required.¹ The second projector (d) is used to project the masking image. If the

¹It should be noted that inclusion of a fixation point would lead the observer to fixate on a virtual location that depends on the distance from the beamsplitter to the projection screen. With or without a fixation point, the oculomotor posture of the eyes may not be informative about target distance when viewing time is limited. However, monocular and binocular parallax, the cues that elicit accommodation and convergence, remain available and potentially useful sources of information about target distance (Foley, 1978).

fixation and masking images do not change from trial to trial in an experiment, then projectors (c) and (d) could be carousel-type projectors carrying a single slide; alternatively, one or both could be an LCD projector, and if so, an additional computer would need to be added to the system to control them. Both projectors are outfitted with electromechanical shutters (e, f) that can be opened independently for variable exposure durations. These are crucial for precise control of the onset and offset of the projected target stimuli. Two LED floodlights (g) are used to illuminate the environment for durations as brief as two to three milliseconds. Any number of lights could be used depending on the size of the environment and the desired brightness of the stimulus scene.

The viewing control system (see Figure 1, Bottom) is comprised of the components that actually control what is seen by participants, and for how long. These components include the shutters and lamps (e, f, and g) as well as the controlling electronics. The controlling electronics are the light sensors (h, i) that detect whether the shutters are open, a switch unit (j) that allows power to flow to the floodlights when both shutters are closed, and a timing board (k) that sends control pulses to the shutters. The timing is controlled by a computer through a variable resistor.

Experimental Configuration

In a typical experiment, the observer begins a trial with his or her head in a chinrest, situated just in front of the beamsplitter. The electromechanical shutter mounted on the fixation projector is open, projecting the fixation image on the projection screen to the observer's left. The image is reflected by the beamsplitter to appear straight ahead from the observer's perspective. This image not only provides a stimulus for controlling fixation but also keeps the subject light adapted. The testing environment is kept completely dark at this stage, to eliminate any light that could potentially make the environment visible directly through the beamsplitter. Though some light can spill into the environment from the fixation projector, it is effectively masked by the fixation image visible in the beamsplitter. It is possible that in some configurations the light spillage could cause visual information from the stimulus environment to be available despite this. In such cases baffles will be required to eliminate this effect. When the experimenter initiates a trial, the fixation projector shutter closes, terminating the fixation image; simultaneously with the shutter closing, the LED floodlights are illuminated to provide a time-controlled glimpse of the environment, seen directly through the beamsplitter. After the desired interval, the shutter on the masking image projector opens, causing the floodlights to turn off. From the observer's perspective, the apparent sequence of events in a given trial is one in which the fixation image is rapidly replaced by a glimpse of a real scene containing a target object, rapidly followed by a masking image. If an action-based indication of the target distance is required (e.g., blindwalking; Gajewski et al., 2010; Pothier et al., 2009), the wheeled stage containing the chinrest and beamsplitter may be pushed aside for the response phase.

Design Considerations and Specifications

Beamsplitter—Our beamsplitter is 35.6 cm wide $\times$ 25.4 cm tall (Edmund Optics, model NT72-500), providing a field of view of approximately 65×60 degrees (horizontal $\times$ vertical) in our current configuration. It is mounted in a wooden frame and oriented at an

approximately 45° angle relative to the observer's line of sight. It reflects 30% and transmits 70% of the incident light; this provides a reasonably bright reflected image without unacceptably attenuating the light coming directly from the scene.

LED floodlights—LED floodlights have several beneficial properties for our application. Because they have general utility as lighting instruments, they are readily available, relatively inexpensive, and unlikely to become obsolete in the near future. They consume relatively little power (in general, one watt of power to an LED lamp should generate light equivalent to approximately nine watts to an incandescent lamp) and generate relatively little heat (a feature that is especially important in small, confined laboratories). They are available in a very wide range of power and in varying values of light “temperature” (soft white, daylight, et cetera). Furthermore, their operational life is quite long, and they are much less fragile than LCD shutter windows.

A major benefit of LED floods over traditional incandescents is their very fast transition from off to fully on, and vice versa. In general, this should be on the order of one millisecond, though the actual time will vary according to the power electronics and specifics of the LED. In our case, we use a bank of two 50 watt floodlights (Hero-LED model OU-LFL50W-24V-WW), 24 volt direct-current in warm white. Each lamp is nominally equivalent to a 450-watt incandescent lamp, and has a beam spread of 120 degrees. In our experience, using direct current is important. The LED element itself is direct current, so that floods using alternating current have power electronics onboard. These electronics introduce unpredictable delays if the AC power to them is switched. Using direct-current lamps allows the switching to be done after the AC to DC conversion, which results in smaller, and more predictable, delays.²

Figure 2 shows the response of one of the Hero-LED floods as a square wave is sent to the solid-state relay used to switch power. (The relay is a Crydom MPDCD3 direct-current relay with a published maximum switching time of 100 microseconds.) The response was measured with an Advanced Photonix PDB-C156 photodiode. A photodiode produces current when exposed to light; the current is converted to voltage using a resistor (Sharp Corporation, 1999). Photodiodes tend to be most responsive to infrared wavelengths, but the PDB-C156 is “blue-enhanced” and responds to wavelengths throughout the visible spectrum, as well. The diode response time is measured in tens of nanoseconds, and is considered negligible here. The data were recorded using a Tektronix TDS-2014 4-channel digital oscilloscope. The same oscilloscope was used to record all electronic data for this paper. As can be seen in Figure 2, we show a pure delay of approximately one millisecond. This is likely due to the power conditioning electronics on the lamp. After this delay, the lamp rises to peak in 500 microseconds, and within 5 milliseconds after triggering has settled to a steady state. At power-off, the light level begins to fall within 200 microseconds, and has dropped fifty per cent within a millisecond. At two milliseconds after power-off it is effectively extinguished.

²Another consideration is that many solid-state relays designed for alternating current wait for a “zero crossing” to actuate, resulting in an unpredictable delay of up to 8 milliseconds. This can be avoided by careful selection of components.

Mechanical Shutters—The fixation and masking shutters (Melles-Griot model 04RDI132) can rest in either fully-open or fully-closed state. From either state, the shutter is switched by sending a 5-volt pulse on the appropriate control line. The shutter's on-board electronics then actuate a solenoid that will drive the shutter to the opposite state. There is a delay of ten to 40 milliseconds between the rising edge of the pulse and initiation of the transition (according to the shutter documentation). Once motion begins, the shutter requires a few more milliseconds to complete the transition. The overall delay depends on the input voltage and the direction of transition. For constant conditions, the delay is highly stable. In repeated tests, shutter response curves lie literally atop one another on the oscilloscope, indicating that the variance in shutter delay is less than 100 microseconds between same-day tests.

Timing and Control Electronics

The timing of an experimental trial is driven by the electromechanical shutters mounted to the fixation and masking image projectors. These shutters are driven by pulses sent from the timing board (k). The floodlight is driven by logic connected to the sensors that detect the state of the shutters. In this way, the delay in the shutter response to the triggering pulse is removed as a significant factor in the design.

Timing Board—At the beginning of a trial, the fixation shutter is open and the masking shutter closed. Both projectors are on. The timing board has been set by the computer to the desired nominal delay. The trial begins with a pulse (square wave, about 4 ms) to the fixation shutter, causing it to close. The same pulse also closes a relay, causing a delay circuit to be triggered. When the delay is finished, a second pulse is sent, this time to the masking shutter, instructing it to open. Due to the delay in each shutter transition, the actual time between fixation off and masking on is not precisely the delay specified by the timing circuit. The difference is a constant time shift that is easily found in testing the completed device.

The timing circuit itself is based on a standard LM555 timer chip in monostable configuration. The delay is based on the voltage level of a capacitor being charged through a resistor; the greater the resistance or larger the capacitance, the longer the delay. In our application, we use a variable resistor (Microchip MCP41050), which is computer-controlled to set the resistance from 150 Ohms to 50 kOhms in 256 steps. By switching between a pair of capacitors, we are able to choose nominal ranges up to 500 milliseconds maximum delay, or 5 seconds maximum delay.³

The Microchip resistor is controlled via industry-standard Serial Peripheral Interface (Microchip Technology Incorporated, 2003). For convenience, we do the control using a MicroUSB u401 interface board. This board is controlled over a standard USB port,

³Standard capacitors are (depending on construction) generally only guaranteed to be within 10 or 20 per cent of their nominal capacitance. Thus a nominal 100 micro-farad capacitor may be anywhere from 80 to 120 micro-farad. The actual value must be determined through testing. However, the capacitance, once determined, is constant. The minimum nominal delay as the circuit is configured is theoretically 150 microseconds. To limit current draw by the delay circuit, an artificial lower limit of about 4 milliseconds is enforced in software.

allowing the system to be controlled from any computer so equipped. Our control software is written assuming the GNU/Linux operating system and is otherwise system-independent.

The initiation of the sequence for a given experimental trial is also done from the computer, using one of the digital I/O lines of the u401. Resetting the shutters for the next trial is likewise done from the computer. The u401 operates through opto-isolated relays (Panasonic AQV257) to separate the control from the power supply. The triggering signals that activate the shutters can also be used to initiate external devices. The signals are simple five-volt square pulses of short (about 2 to 4 ms) duration, and the shutters activate on the rising edge. As the board is designed, the pulses are generated by opening the Panasonic relays, so that connecting the control pulses to a second device (in addition to the mechanical shutters) would not interfere with the basic functioning. Various additional recording equipment (such as for measuring EEG) or other devices could therefore easily be added to the experimental configuration. It should be noted that the initial triggering signal has very low current, and should not be used to activate any additional equipment. However, the fixation shutter “close” signal is identical to this signal, to within the speed of the solid state relay.

Floodlight Control—Because the floodlights respond much more quickly than do the shutters, they are not controlled directly by the timing board. Instead, a photodiode (Advanced Photonix PDB-C156) is affixed to each shutter. When the shutter is open, the photodiode produces current, converted to voltage through a resistor. Each photodiode is connected to a comparator circuit (LM339), so that when the voltage is sufficiently high to indicate that the shutter is open, the circuit produces a logical true. These outputs are used as inputs to a NOR gate (Texas Instruments CD4001BE). A NOR gate produces a non-zero output only when neither input is true. Thus, when neither photodiode senses light (and therefore both read false), the NOR gate produces a logical true, which appears in the circuit as a positive voltage from the chip. It is this signal that controls the Crydom MPDCD3 solid-state relays, which switch power to the floodlights whenever (and only when) neither shutter is open.

It should be noted that the photodiode must be positioned towards the center of the shutter opening. Mechanical shutters tend to bounce on opening, and if the diode is near the outer edge of the aperture, this bounce will be noted by the diode. This can cause spurious results. Photodiode placement also affects the timing in that the shutter requires several milliseconds to fully open or close. Placing the diode towards the center therefore causes the circuit to trigger near the beginning of an opening transition, but to detect closing only near the end of the transition. For this reason, high-fidelity timing comparisons between experiments require precise control over the experimental setup.

Results and Discussion

To establish the viability of the approach, several tests have been run. In these tests, the responses of the shutter photodiodes, as measured by the oscilloscope, are recorded. The trigger pulse is measured directly by the scope, and the floodlight response is measured by using a third photodiode placed in the light field of the lamps. The results of one such test

are displayed in Figure 3. The potentiometer was set for a nominal delay of 23 ms. The sequence began at zero with the rising edge of the trigger pulse. The fixation shutter begins to close at about 11 ms, and at 13 ms the floodlights come on. At 32 ms the masking shutter begins to open, and just after 34 ms the floodlights dim. The actual time that the floodlights are activated is 21 ms.⁴ Figure 3 also shows the characteristics of the system's shutters. The delay before the fixation shutter begins to close is about 11 ms, and the transition time is approximately 3 ms. The masking shutter takes a bit longer to transition open. Each shutter has individual characteristics (delay and transition times), but each has shown itself to be consistent over several tests.

Given the temporal characteristics of all the system's primary events, a remaining question concerns the effective duration of the stimulus. We assume there is some stimulus masking until the fixation shutter is completely closed and as soon as the masking shutter begins to open. As can be seen in Figure 3, the floodlight onset occurs at nearly the precise time that the fixation shutter is completely closed (within 0.5 ms). However, the masking shutter begins to open about 2 ms before the floodlight begins its transition to dim. The effective stimulus duration we would report for this nominal delay would be 19 ms.

To determine the relationship between nominal delay setting and the effective stimulus duration, we measured the floodlight activation time for a range of speed settings (Figure 4). We measured each speed three times and each measure returned the same value (measured to within 1% of the observed activation time). Two outcomes should be noted. First, the strongly linear response indicates that the device is capable of providing very reliable stimulus durations. Because the floodlights are driven by the shutters, the very small measured deviation from perfect linearity indicates that all parts of the system are giving nearly identical performance from one trial to the next, even over large variations in stimulus duration. Any variation in shutter response would show up clearly in these values. Second, the regression equation indicates a minimum nominal delay of 4 ms. However, the early onset of the mask image must also be taken into account. With a nominal delay setting of 7 ms, the floodlight activation time is about 4 ms but the effective stimulus duration is about 2 ms. We consider this the practical limit of our system as it is configured.

Conclusion

A central topic of investigation in the scene perception literature concerns the localization of objects. However, localization in distance or depth has heretofore not been a focus in this work. Instead, studies have commonly investigated the directional or conceptual location of objects in 2D arrays and picture of scenes (e.g., Becker & Rasmussen, 2008; Hollingworth, 2005; Huebner & Gegenfurtner, 2010; Irwin & Zelinsky, 2002). In fact, there has been surprisingly little cross-talk between the scene perception and visual space perception literatures. Thus, little is known about the role that perceived object distances and depths play in the construction of scene representations. Similarly, little is known about how perceptual representations of object distances and depths emerge alongside with, and

⁴Because the photodiode saturates in the experimental configuration, we take the LED lamps to be fully illuminated when the photodiode output is at its saturation value. Comparing the rise and fall curves of the LED response in figures 2 and 3, it is clear that the LED has reached at least 75% of full illumination at saturation.

possibly interact with, scene representations in the early stages of a glimpse of a scene. In particular, the role of eye movements and visual attention in these joint processes is poorly understood. Integrating the visual space perception and scene perception literatures stands to significantly enhance and broaden theories in both domains.

The system described in this paper provides a powerful and versatile means of investigating the linkage between these domains. Visual cues to object distance and depth may be manipulated and controlled just as they would be in typical contexts involving non-speeded visual presentations. The use of tachistoscopic presentation and masking, meanwhile, borrows a common methodology from the scene perception domain. In fact, while we present only the basic system, it could be used in conjunction with a head-mounted eyetracking system. This would afford the monitoring of gaze direction when viewing time is limited and gaze patterns when the viewing time affords the execution of eye movements. Finally, the particular implementation described here uses robust, commonly available components with long operational lifetimes. It is also relatively inexpensive and easy to maintain.

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Figure 1. TOP: Schematic diagram of system configuration (not to scale). BOTTOM: Control schematic.

Figure 2.
LED Floodlight response to trigger pulse.

Figure 3.
System Response.

Figure 4.
LED activation time (ms) as a function of nominal delay setting (ms).