Scientific Research

Light Emitting Diodes as a Rapid Visual Display for Use in Psychological Experiments

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ABSTRACT

In this paper we show how light emitting diodes (LEDs) can be used in conjunction with existing display technologies as a means for achieving ultra-rapid visual stimulus exposure durations. We review existing rapid visual display methods, and show how our apparatus overcomes the limitations inherent with each technique. Our apparatus, the LED tachistoscope, takes advantage of the fast-switching times and high-brightness capabilities of LEDs in order to present stimuli at previously unachievable durations as rapid as 1 ms. The rapid exposure durations are achieved by external LED backlight illumination of images on a liquid crystal display (LCD) after the components of the LCD have stabilized. This ensures that stimulus onset and offset are discrete. Furthermore, the fast-switching of the LEDs enables stimuli to be revealed for very rapid durations. The paper also describes studies in which the LED tachistoscope has already been applied, and offers suggestions for other possible applications. Interestingly, in our studies we show that the human visual system is very adept at extracting information with only very minimal stimulus exposure durations. Such studies have not been possible with existing display equipment. The LED tachistoscope opens up avenues for a variety of psychological and physiological experiments and provides a means for revealing the limits of human visual perception.

Keywords: Light Emitting Diode; Tachistoscope; Liquid Crystal Display; Rapid Exposure; Visual Perception

1. Introduction

Many studies of visual perception require precise and often rapid stimulus delivery. A commonly used apparatus, the traditional tachistoscope, was created in 1859 and has since been used extensively in perception research. Traditional tachistoscopes display images either by "lighting them up" with stroboscopic lights (electric tachistoscopes) or exposing them by opening mechanical shutters (mechanical and electromechanical tachistoscopes). Computer-monitor tachistoscopes also exist, whereby the images are displayed on a computer monitor at the command of software programs. The basic function of all tachistoscopes is to precisely control visual stimulus delivery. In some instances the stimulus image is deliberately presented under degraded conditions so that the viewer does not consciously process it, and therefore is not aware of seeing it. Hence, the popularity of tachistoscopes for use in subliminal visual experimentation paradigms, including the mere exposure effect [1]. However, close inspection of the workings of tachistoscopes and a review of the literature indicates that problems exist that can significantly impact upon their operation. Although traditional and computer-monitor tachistoscopes may be

reliable across trials, the exposure durations that they generate are not necessarily valid, especially for rapid exposure durations. In the sections to follow we review existing tachistoscopes, highlighting their limitations at rapid durations. We then show how light emitting diodes can be used in conjunction with components from existing tachistoscopes to precisely display images, even at ultra-rapid durations. Finally, we describe the findings from our studies that have used the LED tachistoscope, and conclude with suggestions for future research.

1.1. Traditional Tachistoscopes

Traditional tachistoscopes can involve the subject peering into a box whereby a fluorescent lamp is flashed to reveal the test stimuli. Mirrors are used so that any of several images can be projected onto the one location, making it possible to switch between images in succession. Traditional tachistoscopes can also have mechanical shutters that control exposure duration by disrupting the passage of light. They can be of the projection variety, with the shutters placed in front of slide projectors, enabling groups of participants to be tested at a time [2,3]. In terms of performance, traditional tachistoscopes may reliably produce the same exposure durations over trials;

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however, considerable discrepancies between the durations requested by the control setting and the actual durations displayed have been found, especially for exposures of less than 100 ms [4].

The main problem with traditional tachistoscopes concerns the performance of the lamps used to rapidly illuminate stimuli. The lamps have slow and variable response times [5,6]. This limits the ability to produce rapid stimulus exposures at full luminance, if at all. Additionally, the colour and intensity of the lights change with age, making regular replacement necessary [5].

A further problem regarding luminance is that the luminance data reported in journals usually refers to "steady-state" as opposed to that resulting from brief flashes of the light. In tachistoscopic applications, the lights are flashed on and off briefly, not simply left on in steady-state. Steady-state measures of luminance are inappropriate for tachistoscopes due to variations in temperature across time. Temperature affects the perceived brightness of the lamp whereby those that have been allowed to "warm up" have a greater light output than those that have not. Given that lamp steady-state can take up to 2 minutes to achieve, in instances where the flash durations have been varied between 0 ms and 2 minutes, experimenters may have unintentionally varied the stimulus intensity [7,8].

Traditional tachistoscopes with mechanical shutters also encounter other problems. The shutters are mechanical devices that are opened by solenoids but closed by a return spring that pulls the shutters together as the solenoid relaxes [9]. Rise and fall times can be manipulated by adjusting the spring tension to make one faster: as a result there can be asymmetry in the way that a shutter opens and closes [6,9]. Also, shutters operate multiple times under the heat of the projection lamp whereby over time their performance deteriorates, adding significant variance to the data [9]. Another feature that tends to be overlooked is that the image displayed by mechanical tachistoscopes is not evenly presented. The shutters open from the inside out and close from the outside in, effectively revealing the centre of the image for a longer duration than the periphery. While this difference in timing is small, it could impact studies involving exposure presentations at the millisecond level.

1.2. Computer-Monitor Tachistoscopes

A computer monitor can also be used as a tachistoscope. Software programming enables simple stimulus preparation, sequencing and storage, data collection, and subsequent data analysis. However, again, due to difficulties associated with stimulus illumination, the validity of computerized tachistoscopes for brief exposures is also problematic. The Cathode Ray Tube (CRT) consistently delivers the same exposure duration over trials; however, problems arise because the light source is not constant. For images to be maintained, an electron beam must continuously illuminate the phosphor layer of the screen line by line starting from the upper left hand corner and working down to the bottom right hand corner [10-12]. At the end of each line a horizontal synchronization pulse triggers another scan slightly lower down on the screen until the final scan where a vertical synchronization pulse restarts the process again [10]. This process constitutes the refresh rate, and this process takes time. To display images in their entirety, stimulus exposure durations must be multiples of the refresh rate, thus limiting the durations that can be achieved. Although refresh rates are improving, images are still displayed in a series of scans rather than as one cohesive whole, with portions of the image beginning to decay before other portions are displayed.

A computer-monitor tachistoscope that does not have to contend with the problem of the raster scan is the liquid crystal display (LCD). Although LCDs tend to be replacing CRTs due to their convenience and the appeal of the flatter screen, computerized tachistoscopes involving LCDs are equally problematic. The LCD does not have a refresh rate in the sense that it does not continually scan and update the screen in the same manner as the CRT. Basically, the screen comprises thin layers of liquid crystals that act as filters for the background illumination [12]. The picture is illuminated from behind by a constant light source and remains steady on the screen until it is instructed to change. Picture onset is gradual, with images being "built up" on the screen. After this, stimuli are in a constant state, similar to how they would be perceived in the real world, and do not need constant refreshing [12,13]. However, picture onset and offset are slow and unreliable, making an LCD on its own an unreliable tachistoscope [12]. In an effort to overcome difficulties associated with the slow response times of the liquid crystals, Wiens and Ohman [13] suggest programming a mechanical shutter to open in front of an LCD monitor after a delay post-stimulus onset. Unfortunately, the use of a mechanical shutter brings with it the associated problems discussed earlier. A solution we offer is to use an LCD with a backlight shutter system composed of light emitting diodes.

2. Light Emitting Diodes as a Tachistoscope

As the foundation for a tachistoscope, light-emitting diodes (LEDs) conveniently provide both a shutter and a light component. LEDs are semiconducting devices that produce light when an electric current passes through them [14,15]. They possess a number of desirable attributes. These include true colour representation [16-18],

high brightness [15,19], robustness and long lifetime of operation [20] and, importantly, rapid on and off switching times [21,22]. Such characteristics have led to their widespread use in a range of existing lighting applications including backlighting (mobile phones, cameras, and more recently LCD TV screens), outdoor lighting (automotive indicators and traffic light signals), and even general lighting replacing that of incandescent and fluorescent sources. These characteristics also make them particularly suitable for use as a tachistoscope.

As a tachistoscope, images are presented on an LCD, but are only made visible following backlight illumination of an externally controlled array of light emitting diodes. An image of the LED backlight shutter is presented in **Figure 1**. **Figure 2** shows a diagrammatic representation of the experimental set-up. The computer software displays images on the computer monitor and the external LCD. At the same time, the computer uses transistor-transistor logic to command the interface equipment to switch on the LED array for a specified duration.
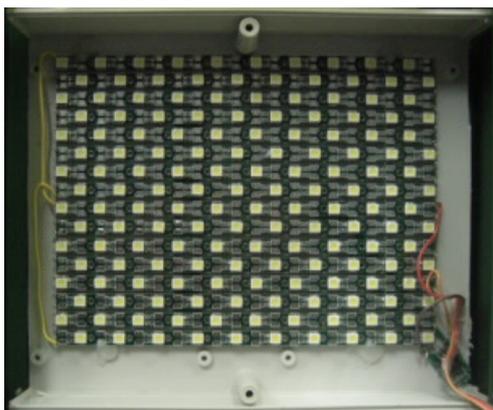
Figure 1. LED array encased in a lightproof box.
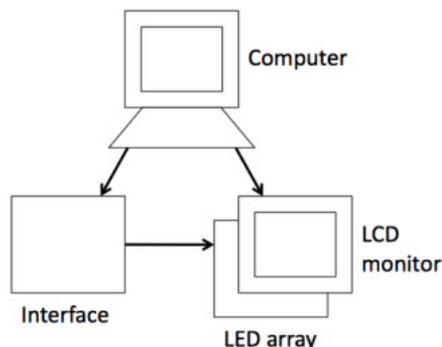
Figure 2. LED tachistoscope components. The light emitting diode tachistoscope comprises the following components: a computer with a parallel or serial port to send transistor-transistor logic (TTL) commands, an interface component to receive the TTL signals that switch the LED array via a power metal oxide semiconductor field effect transistor, and an LCD data projection monitor to display the visual stimuli.

Images are deliberately presented on the LCD for a longer duration than what the LEDs reveal, and the LEDs only flash on after a delay. Such techniques ensure that stimulus onset and offset are discrete, and that the components of the LCD are stable before images are revealed. In addition, the fast-switching capabilities of the light emitting diodes permit very rapid stimulus exposure durations. The light emitting diode tachistoscope has been developed and a provisional patent is held. The equipment has been verified as capable of accurately and reliably presenting images as rapidly as 1 ms [23]. In the following section, we describe our studies that have used the new apparatus, and conclude with suggestions for future research.

3. Applications of the LED Tachistoscope

In a visual perceptual identification task, we presented a series of pictures of animals with and without backgrounds for 10 ms and 1 ms [24]. We found that verbal recognition performance was better when animals were presented in isolation than with a background at the most rapid duration (1 ms). In both the isolated and background conditions, however, participants successfully identified animals at 1 ms at least 83% of the time. The findings were attributed to iconic memory and top-down feedback mechanisms.

In a second application using the new apparatus, we performed two mere exposure studies. Mere exposure studies are used to investigate the phenomenon that repeated exposure to a stimulus enhances affective evaluations directed towards it [1]. The effect has also been used to demonstrate that such attitudes can be formed even in the absence of conscious recognition. Hence, these studies provide a more indirect measure of the effects of visual perception than overt recognition or identification tasks. In our first study, participants viewed a series of pictures of polygons for five repetitions each at either 1 ms or 1000 ms [25]. They were then presented with the polygons again for a longer duration, together with similar but never-before-seen equivalents. They made liking and recognition ratings for both old (previously encountered in the exposure phase) and new (encountered in the test phase only) polygons. The mere exposure effect was found for the 1000 ms stimuli, with old stimuli receiving significantly higher liking ratings than new stimuli. The findings for the 1 ms failed to reach significance. Interestingly, at both 1 ms and 1000 ms, participants correctly recognised old stimuli from new. The procedure was repeated for photographs of furniture, specifically chairs [26]. This time the mere exposure effect was found for stimuli at both 1 ms and 1000 ms. Again, at both levels of exposure duration old stimuli could be differentiated from new.

4. Suggestions for Future Research and Conclusions

The new LED tachistoscope uses an externally controlled array of LEDs to illuminate images on an LCD for very precise and rapid durations. It has already been applied to three studies and the findings suggest that the human visual system is very efficient at extracting information from stimuli. Although it should be acknowledged that a stimulus of any duration could potentially be recognisable provided it is of sufficient intensity, we believe that these are the first studies to achieve such rapid exposure durations. The next step for future research would be to perform more complex judgments of stimulus recognition; for instance, requiring participants to state whether a particular stimulus is present or absent among other stimuli within a display. Again, the stimuli would be presented for previously unattainable durations as rapid as 1 ms. We would also like to develop a modified LED tachistoscope that would have faster LCD response times and thus enable us to follow test stimuli with masking stimuli. Such an apparatus would enable us to probe subliminal aspects of visual perception. A further avenue for application is to probe the speed of affective processing. For example, Lindgaard, Fernandes, Dudek and Brown [27] have demonstrated that extremely reliable affective judgements of web sites are achieved with 50 ms exposures. Limitations in technology have prohibited more rapid exposures. These limitations can now be overcome as the new apparatus is capable of exposures down to 1 ms. The current LED tachistoscope is suitable for any visual or psychological experiment that requires precise control over exposure duration, and provides a means for allowing us to get closer to a more accurate measure of the thresholds of visual and affective processing.

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