Development of a light-emitting diode tachistoscope

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This paper describes a new method for rapid visual stimulus delivery, the light-emitting diode (LED) tachistoscope. An array of white LEDs provided a luminous intensity greater than 1 000 000 mcd. This array was placed behind a liquid crystal display (LCD) to function as a backlight; switching it on and off determined the visibility of the display. Commands to illuminate for periods from 1 ms to continuously on were relayed from a computer to the LED array. Changes in luminous intensity at the surface of a LED and the LCD were recorded via oscilloscope. The required duration of light pulses consistently matched the durations displayed, with only microsecond discrepancies due to turn-on and turn-off delays. Images were illuminated on the LCD screen for as little as 1 ms, with the amplitude of the luminance consistent across trials. The LED tachistoscope can be used with any computer to display images extremely briefly, potentially at the submillisecond level, providing superior performance to traditional and computer monitor tachistoscopes. © *2010 American Institute of Physics.* [doi:10.1063/1.3327837]

I. INTRODUCTION

Limitations of traditional and computerized tachistoscopes restrict their ability to accurately present visual stimuli, particularly when the exposure durations are brief. Traditionally, electrical and mechanical tachistoscopes were the mode of stimulus delivery used in psychological research; however, while both types of tachistoscopes may reliably present the same exposure durations over trials (precision), there can be considerable discrepancies between durations requested by the control setting and the exposure durations achieved (accuracy), particularly with exposure durations of less than 100 ms.[1] The main problem with electrical tachistoscopes is that the fluorescent lights used to illuminate stimuli have slow and variable response times.[2,3] This prevents rapid exposure durations from being achieved at full luminance, if at all. Mechanical tachistoscopes have problems associated with their physical construction. These problems include significant variance in data resulting from wear and tear over time,[4] asymmetry in rise and fall times due to the way the shutters open and close,[3,4] and the simple fact that mechanical shutters cannot open and close fast enough to reveal images for very brief durations.

Computer monitor tachistoscopes have replaced electrical and mechanical tachistoscopes. However, as with their predecessors they also are compromised, particularly for short exposures. While cathode ray tubes (CRT) consistently deliver the same exposure duration over trials, problems occur because the light source of the CRT is not constant. For images to be maintained an electron beam needs to constantly scan and update the screen starting from the top left corner and working down to the bottom right.[5–7] To display images in their entirety, stimulus exposures must be multiples of the refresh rate, placing physical limits on the durations that can be achieved. Liquid crystal displays (LCDs) are equally problematic. LCD panels use layers of liquid crystals behind a pixel grid to act as shutters for background illumination. Unlike the CRT, the light source of the LCD is constant, and once steady state is reached the image is stable until changed.[7,8] The liquid crystals, however, can be slow to react and their performance can vary from one trial to the next.[7] Thus neither validity nor reliability can be assured.

While liquid crystal technology is constantly improving, until a LCD with an almost instantaneous response time is created, some form of additional shutter is needed. The solution offered here is a LCD with a custom backlighting system composed of light-emitting diodes (LEDs). The advantages of LEDs are that they can be ultrabright,[9,10] have a long lifetime of operation,[11] and importantly, have on and off switching times in the order of nanoseconds.[12,13] In operation, stimuli are delivered to the LCD but not revealed by the LEDs until the image is in a steady state. The capabilities of the LCD therefore are irrelevant, given that it is the LED backlight that switches on and off to control stimulus duration. This forms the basis of the LED tachistoscope.

II. LED TACHISTOSCOPE

A diagrammatic representation of the tachistoscope's components is given in Fig. 1. A 20×15 cm LED array was constructed comprising 160 white phosphor converted LEDs[14] soldered onto a circuit board. The lights were ar-

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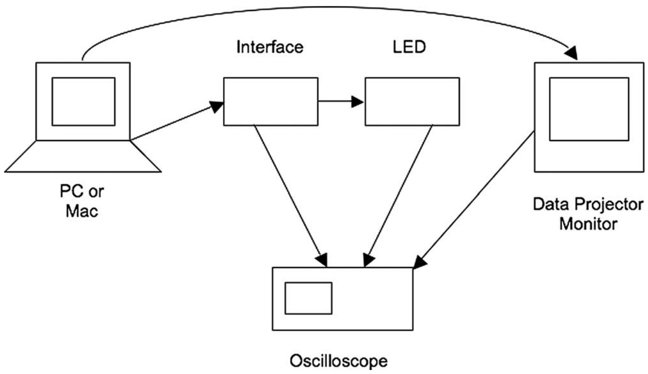

FIG. 1. LED tachistoscope experimental setup. The tachistoscope comprises a computer, interface equipment, a LED array backlight, and a LCD flat panel. Stimuli are viewed on the LCD flat panel. The computer is connected to the LCD flat panel so that stimuli present on the computer monitor are also present on the flat panel. The LED array is placed behind the flat panel so that the images, while present on the flat panel, are only visible to the participant following computer-driven instructions relayed by the interface equipment to switch the LED array on and off.

ranged in a series of parallel groups of ten and have a typical luminous intensity in excess of 7000 mcd. The array has the potential for luminous intensity in excess of 1000–000 mcd. A microprocessor-controlled IRF540 HEXFET Power metal oxide semiconductor field effect transistor[15] (MOSFET) was used to switch the LEDs. This device permits the switching and amplification of signals, has a low on-resistance (0.044 Ω), and is efficient at low voltages. The low on-resistance removes the necessity of heat sinking the MOSFET. Each LED has a dedicated current limiting resistor to eliminate current imbalances created by individual LEDs. This maintains an even illumination of all LEDs in the array. More than 3.3 V is required to drive the IRF540 HEXFET Power MOSFET. A low-power Schottky transistor-transistor logic (TTL) type logic chip was used to switch the MOSFET. This receives signals from the microprocessors and converts them into a pulse that drives the MOSFET (which in turn activates the LED lights). To accommodate the need for varying the luminance of the LED display, a variable voltage supply was implemented to drive the display. The range is from 20 to 35 V. The voltage supply has standard three-terminal regulators, with one output being adjustable via a ten-turn variable resistor.

Both Macintosh and Windows computers can be used to control the tachistoscope via its Zilog Z8 microprocessor. The computer was connected to the LCD flat panel via the monitor port, and to the interfacing equipment via the parallel port (LPT1). Connections between the computer and tachistoscope can involve either the parallel port (LPT1; 25 pin printer) or the serial port (RS232; recommended standard). Any computer and software program capable of utilizing TTL signals can control the presentation sequence of the stimuli and the rate with which the lights turn on and off. In this instance, the software program, DirectRT[16] was used. The computer transmits TTL signals via the ports to the interface equipment, which converts them into LED turn on and off instructions. The interface was programmed to convert byte values between 1 and 125 to the corresponding duration in milliseconds, and to convert values 126 and 254 to an instruction to keep the lights on for any given duration in milliseconds.

In order to display visual stimuli a 17×13 cm LCD flat panel with the LED backlight was used. The LCD flat panel used with this device has 16.7 million colors, with 640×480 resolution and has a contrast ratio of 100:1. The LED array was fixed into a metal case to prevent leakage of light, and was mounted on the back of the LCD data projector panel. Between the lights and the screen was a sheet of diffusing film used to evenly distribute the light and to make the exposure appear as one cohesive light source. The flat panel used has a 30 ms response time according to its manual. To be conservative, and, in accordance with Wiens and Ohman,[17] the tachistoscope was programmed to have a 70 ms delay to accommodate the time taken for images to be written to the screen. The interface therefore switches the LED array on 70 ms poststimulus delivery to the LCD flat panel, meaning that the image is already present on the LCD, but is only perceivable by the participant following backlight illumination of the LEDs.

III. EXPERIMENTS AND DISCUSSION

To overcome the validity and reliability problems associated with existing tachistoscopes, the LED tachistoscope must display stimuli for the duration requested, including durations as brief as 1 ms. The tachistoscope must also have a near-instantaneous response time (both onset and offset), and its performance must be consistent across trials.

To test the above, a simple perceptual experiment was designed involving very brief (1 ms) exposure durations. A black fixation cross on a white background was presented for 200 ms and then after a delay of 200 ms, a white bitmap image was presented concurrently on the LCD flat panel and the computer display. The visual duration on both displays was 200 ms; however, the LEDs were only switched on for durations of 50, 5, and 1 ms, and thus the image should only be visible for 50, 5, or 1 ms. The procedure was run with backlighting kept to a minimum. High sensitivity, low speed phototransistors were used to record light changes on an oscilloscope. Two conditions were examined. In condition A the phototransistor was placed directly on a LED. The intention was to assess the functioning of the light source, the dynamics of them switching on and off, and if they could remain on for the duration in milliseconds requested. In condition B the phototransistor was placed on the surface of the LCD flat panel. The aim was to assess the capacity of the lights to illuminate an image on the screen for the required duration at the required time. In both conditions the command from the interface to the LED array was also measured to establish if the light outputs of the LEDs corresponded with the TTL commands from the computer.

Because it is rapid exposure that is so difficult to achieve with existing instrumentation, only the results of the 1 ms duration condition are presented. A minimum of 30 trials per level of exposure duration were conducted for both conditions. Performance was consistent across trials. Plots (acquired from the digital oscilloscope, phototransistor output

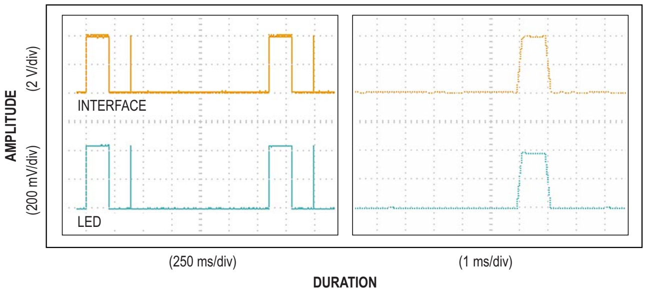

FIG. 2. (Color online) Oscilloscope outputs of a 1 ms pulse recorded from the surface of a LED. For both plots the upper trace represents the interface command signal directed by the computer and the lower trace the light output from the LED. The left plot displays two trials whereby the wider peaks represent the 200 ms cross and the narrower peaks are the 1 ms stimuli. Each horizontal division is 250 ms and each vertical division is 2 V for the interface channel (upper trace) and 200 mV for the LED channel (lower trace). The right-hand plot displays a faster sweep time display of the 1 ms stimulus. Each horizontal division is 1 ms and each vertical division is 2 V for the interface channel (upper trace) and 200 mV for the LED channel (lower trace).

level against time) showing a typical response from condition A and condition B are presented as Figs. 2 and 3, respectively.

A. Measurements taken directly from the surface of a LED

An oscilloscope output showing a typical response from the 1 ms condition is given in Fig. 2. As can be seen from both plots, comparing what was asked by the TTL command (upper trace) with what was recorded from the LEDs (lower trace), the duration of the pulses requested successfully corresponds with the durations achieved. Effectively, the LEDs switched on for the requested duration, namely, 1 ms. Also, onsets and offsets of the light pulses were virtually instantaneous. The amplitudes and duration of the signals were consistent across trials.

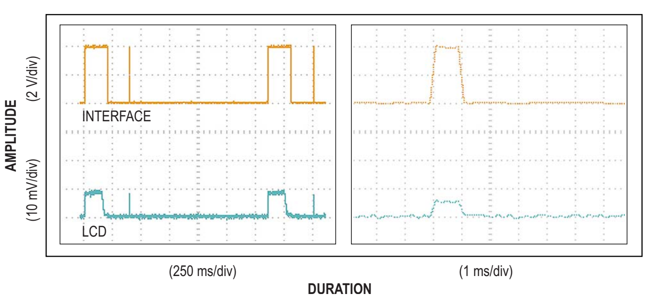

FIG. 3. (Color online) Oscilloscope outputs of a 1 ms pulse recorded from the surface of the data projector LCD. For both graphs the upper trace represents the interface command signal directed by the computer and the lower trace the light output detected through the flat panel LCD while a white image is presented. The left plot displays two trials whereby the wider peaks represent the 200 ms cross and the narrower peaks are the 1 ms white images. Each horizontal division is 250 ms and each vertical division is 2 V for the interface channel (upper trace) and 10 mV for the LCD channel (lower trace). The right-hand plot is a faster sweep time display of the 1 ms stimulus. Each horizontal division is 1 ms and each vertical division is 2 V for the interface channel (upper trace) and 10 mV for the LCD channel (lower trace).

B. Measurements taken from the surface of the data projector LCD (LED backlit)

Figure 3 shows an oscilloscope output of a typical response from the 1 ms condition. As can be seen from both plots, comparing what was asked by the TTL command (upper trace) with what was recorded from the data projector LCD (lower trace), the durations of the cross and stimulus image requested successfully corresponded with the durations achieved. That is, images were successfully illuminated on the LCD for the requested duration. The stimulus image was accurately displayed even at 1 ms. Also, onset and offsets of the light pulses were virtually instantaneous. The first plot also indicates that the amplitudes and durations of the signals were consistent across trials.

IV. CONCLUSION

The LED tachistoscope used a LED backlight as a shutter to finely control stimulus exposure duration, onset, and offset of images displayed on a separate LCD flat panel. It successfully presented visual stimuli for durations as brief as 1 ms. Response time was virtually instantaneous (as far as biological systems are concerned), with the rapid switching of the LED backlight permitting images to reach full luminance within microseconds. Performance was consistent across trials. The tachistoscope can easily be constructed, with all components commercially available. Response time, accuracy, and consistency are superior to existing electric, mechanical, and computerized tachistoscopes, making the LED tachistoscope a suitable instrument for experiments where control over stimulus exposure duration is crucial.

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