The Effects of LCD Backlight Strobing on Static and Moving Target Detection

by

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Abstract

Relative to CRT displays and other display technologies, moving objects appear to be blurred on LCDs because motion is represented as a series of rapidly updated images. The eye moves over these static images when tracking simulated moving objects, which results in perceived motion blur. Backlight strobing (the rapid and imperceptible flashing of an LCD's backlight) mitigates the effects of motion blur. This improvement in image quality was framed in the context of visual perception theory. The current experiment examined the effects of backlight strobing on target detection in a visual search task that was either easy or hard, for moving (blurred) and static (non-blurred) search grids. Backlight strobing improved target detection for moving search grids, particularly for hard search tasks. However, backlight strobing impaired target detection for static search grids.

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Table of Contents

List of Tables

List of Figures

Introduction

Liquid Crystal Displays (LCDs) have become a ubiquitous display technology, supplanting the long-standing Cathode Ray Tube (CRT) and the more recent, but less popular, plasma display. Although LCDs are commonly used in situations that require high visual resolution including gaming and simulator applications, they tend to produce considerable motion blur when moving objects are displayed. LCDs are more susceptible than CRT displays or plasma displays to apparent smearing or blurring when rendering images of fast moving objects (Pan, Feng, & Daly, 2005; Zhang, Song, & Teunissen, 2008). This blurring effect is due to the "hold-type" nature of LCDs, meaning that once a frame is rendered, it is constantly displayed or 'held' onscreen until the next frame is displayed. In contrast, CRT and plasma displays are "impulse-type", meaning their luminance varies over the course of displaying a frame.

Motion blur is a detriment to any situation that requires the detection and/or identification of moving objects, particularly when they are moving quickly. This is especially relevant for simulation and gaming applications. Example simulation situations include identifying targets and waypoints using the side cockpit displays of an aircraft simulator and performing maneuvers with high rotational velocity in a helicopter simulator. Example gaming situations include displaying imagery on a head-mounted display in response to a user's rapid side-to-side head movements, or playing a game with rapid camera movements. These cases all involve displaying fast moving, high-definition images that tend to appear blurred when shown on an LCD. Given the proliferation of LCD display technology, it has become increasingly important to develop technical solutions to mitigate this undesired motion blur effect. One recent solution to the

motion blur problem is backlight strobing, which limits the amount of time each frame is visible by cyclically activating and deactivating the LCD's backlight. Although backlight strobing subjectively reduces apparent motion blur, it is unknown whether this reduction in motion blur leads to significant improvements in tasks that require visual tracking or the detection/identification of moving targets. This thesis addressed this knowledge gap using a visual search task to provide objective evidence corroborating the subjective reports that backlight strobing reduces motion blur and subsequently improves target tracking and detection.

Display Technologies

LCDs, organic light-emitting diode (OLED) displays, CRT displays, and plasma displays use different methods to display images. Each display technology presents video frames at a constant rate (for example at 60 frames per second), but have different light-to-dark ratios during the course of displaying a frame (Zhang, Song, & Teunissen, 2008; Ito, Ogawa, & Sunaga, 2013). Ratios range from always lit to only lit for a fraction of the frame time. The amount of perceived motion blur is directly associated with the proportion of light-to-dark time.

Images are displayed on an LCD via a backlight and a liquid crystal panel that blocks or transmits light. From back to front, the display is composed of the backlight, a filter that polarizes light, the liquid crystal panel, and a second polarizing filter. The liquid crystal panel twists the light to allow or block its passage. When the crystals are aligned at 0° light passes freely between the polarizing filters and when they are aligned at 90° light is blocked. Images are displayed by manipulating the orientation of the liquid crystals for each pixel (divided into red, green, and blue subpixels), which lets through a specific quantity of light from the backlight. When the image is refreshed, all pixels are updated at roughly the same time. The backlight of an LCD is typically composed of a series of LEDs on modern displays, or fluorescent lighting on

older displays. The backlight is typically always on to supply a constant amount of light over the period of the frame.

In contrast to the hold-type nature of LCDs, CRT displays are impulse type, meaning that once a frame is displayed, it quickly drops in luminance until the next frame is displayed. In a CRT, an electron gun sweeps over the inner side of the screen which is coated with a phosphorescent material. In colour displays the screen is coated in red, green, and blue phosphors. Each frame is typically rendered by one sweep of the electron gun. Although there is some amount of phosphor persistence between each frame rendering, once the phosphor is no longer excited, its luminance quickly fades. Thus, standard CRT displays are mostly dark between frame updates.

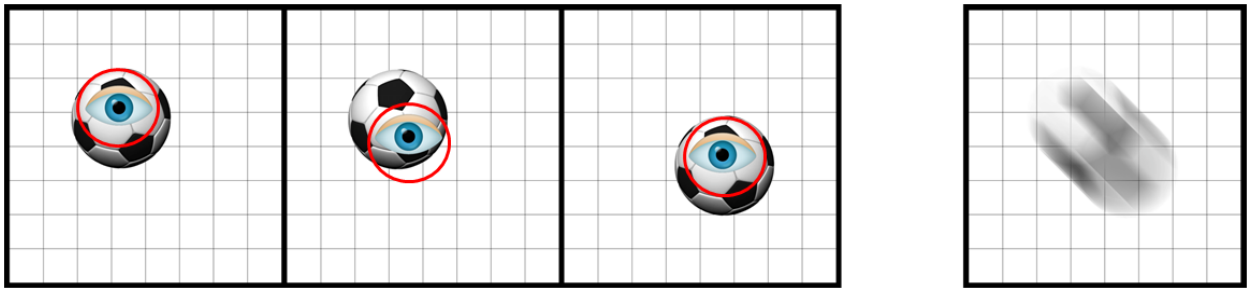
Plasma displays are also impulse type, but instead of activating the light source once per frame as in CRT displays, luminance over the duration of a frame can vary considerably. Each pixel is represented by small fluorescent cells divided into red, green, and blue subcomponents. In most displays the fluorescent cells can only be fully lit or not lit at all, so luminance for each subpixel is dictated by the amount of time per frame the subpixel is lit. For example to represent red at 50% of maximum brightness, the red subpixels are activated for 50% of the frame time. The length of time that each frame is lit changes based on its brightness and colour content.

OLED displays have only recently become available on the consumer market. They are also hold type as in LCDs, though depending on the display they may not be constantly lit. OLED displays consist of electroluminescent cells arranged in red, green, and blue subpixels that can be lit at various light intensities. The proportion of time that each frame is lit is constant and is set by the manufacturer.

Perceived Motion Blur

LCDs typically operate at 60 frames per second, which means that each frame is displayed for 1/60th of a second or 16.7 ms. The display's entire pixel array is simultaneously updated, the frame is held, and 16.7 ms later the display is again updated for the next frame. When a moving object is displayed, the object's trajectory can only be updated every 16.7 ms which results in gaps in rendering its motion. For example, an object moving at 1000 pixels per second will have trajectory gaps of about 17 pixels in length between each rendered frame. This is because LCDs do not interpolate the trajectory of an object's movement between frames. Instead, images are held onscreen between each frame update, which results in a series of static images being displayed and updated 60 times per second. When an observer tracks a moving object across an LCD, their eyes move in a continuous arc across the series of static images – effectively interpolating the between-frame images that are never displayed (see Figure 1). Motion blur is produced by the interaction of smooth pursuit tracking (by the eye) with non-continuous images being presented onscreen.

Figure 1. A Demonstration of Perceived Motion Blur



Frame 1 Frame 1 Frame 2 Result

The eye smoothly tracks over a series of static images that are updated at the display's refresh rate, resulting in displacement of the image on the retina.

It is important to note that the motion blur being discussed here is not simply due to the slow pixel transition times that can be a property of some LCDs. Modern LCDs have pixel transition times that are typically less than 2 ms, which reduces “ghosting” and blurring of moving objects. Even if pixel transition times were reduced to sub-millisecond lengths, motion blur would still be perceived due to the sample and hold effect. The motion blur effect addressed here is primarily caused by the interaction of smooth-pursuit visual tracking and an LCD’s limited refresh rate.

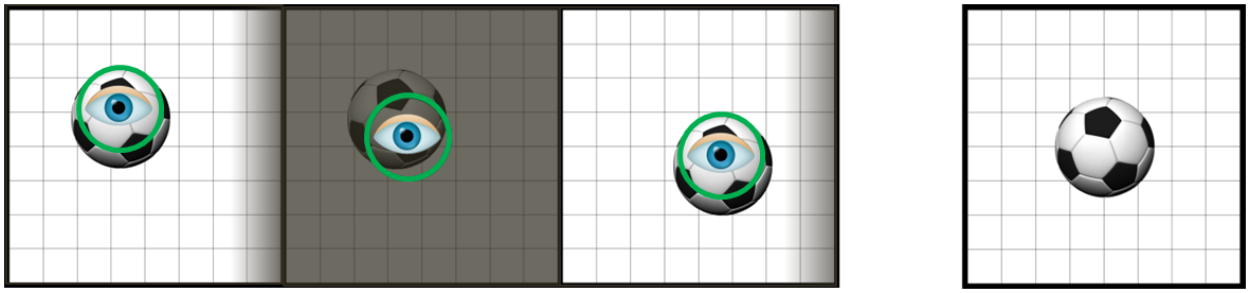
Unlike LCDs, CRT displays do not usually produce perceived motion blur. When a frame is displayed on a CRT, the image is briefly flashed onto the retina before the phosphor excitement quickly decays into darkness. Although the image is no longer present onscreen, the persistence of vision – most likely an active representation of the image in iconic/sensory memory – allows for sustained perception of the image between frame updates, even though the display is dark. This means that during pursuit tracking on a CRT display, frames are held within the human visual system – and not onscreen as with LCDs – while the eye moves with the object. Thus, there is very little blurring caused by the temporal integration of multiple stationary images across frames.

Plasma displays and OLED displays, which hold an image for less than the total length of each frame, tend to produce less perceived motion blur than LCDs (Zhang, Song, & Teunissen, 2008; Ito, Ogawa, & Sunaga, 2013). However they produce more perceived motion blur than CRT displays which only hold an image for a small fraction of the length of each frame.

Backlight Strobing

Backlight strobing is a relatively new method of reducing motion blur and is being used in a number of high performance gaming LCDs. Backlight strobing operates by only lighting each frame for a fraction of its entire duration, thereby reducing the amount of time that each static image is visible. In the same way as CRT displays, this approach exploits persistence of vision by allowing visual sensory memory to hold the lit portion of the frame as the eye "tracks" the anticipated trajectory of the now invisible moving object (see Figure 2). This reduces the amount of time that the eye can move across the still frame, which reduces the blurring of this frame on the retina. In theory, backlight strobing is functionally equivalent to increasing the display's refresh rate in that it reduces the amount of time that each frame is displayed. The key advantage of backlight strobing over increasing the refresh rate is that backlight strobing can functionally mimic the amount of blur from a refresh rate of 300 or even 500 frames per second, which is usually technically infeasible due to computational and hardware limitations. To avoid flicker effects that may arise from the rapid onset and offset of the backlight illumination (Jaén et al., 2011), backlight strobing is only used in conjunction with high refresh rates above the flicker fusion threshold (greater than 100 frames per second). This ensures that the image will be perceived as continuously lit instead of rapidly blinking on and off.

Figure 2. A Demonstration of Reduced Perceived Motion Blur



Frame 1 Frame 1 Frame 2 Result

Each frame is lit (and thus visible) for only a brief period of its duration, which reduces the effect of image displacement on the retina.

Although each frame is dark for a substantial proportion of its duration when backlight strobing is used, the brightness of the display does not appear to change compared to when the frame is visible for its entire duration (i.e., when backlight strobing is not used). This is accomplished by increasing the brightness of the backlight to compensate for the shorter duty cycle. LCDs can use pulse width modulation, which changes the brightness of the display by adjusting the ratio of the backlight's dark-to-light time. However, in order minimize motion blur, the backlight is typically lit at the highest available intensity for the shortest possible period of time such that adequate display brightness can be maintained while concurrently minimizing the duration that each frame is lit.

Organic light-emitting diode displays (OLED displays), are also susceptible to the same motion blur effects observed in LCDs given that OLED displays also rely on sample-and-hold display technology. However, unlike LCDs which use backlight strobing to reduce motion blur, OLEDs vary the electric current during each frame so that each frame is only lit for a fraction of

its display time. This achieves the same effect as in backlight strobing where the display is brightly lit for a small portion of each frame and dark for the remainder.

Present Research

The objective of the present research was to determine whether LCD backlight strobing reduces motion blur to the extent that it has a measurable impact on performance. To date, evidence for the effectiveness of backlight strobing has come from subjective reports in which observers claim that backlight strobing makes moving objects appear clearer. In order to provide objective evidence for the benefits of backlight strobing, participants in the present study performed a visual search task in which a single target letter appeared in a 6 x 6 grid with 17 distractor letters. The grid and the target/distractor letters moved on half of the trials and were static on the other half. If backlight strobing meaningfully reduces the motion blur associated with moving objects on an LCD, then backlight strobing should increase participants' target detection performance (lowered response time) in the moving condition, but not in the static condition. Backlight strobing should not affect static trials given that there was no motion blur.

According to Treisman's Feature Integration Theory (Treisman & Gelade, 1980), letters that share many of the same features are harder to distinguish from each other than letters that do not share the same features. For example, searching for an H amongst distractor O's is easy as there is no overlap between the features of an H and an O. By comparison, searching for an E amongst distractor F's is difficult as there is a high degree of feature overlap. In many easy searches, a single distinguishing feature is sufficient to identify the target, affording a search strategy that is highly parallel and causes the target to "pop out". In contrast, letters with features

that have substantial feature overlap require a more serial search. In the case of hard searches, many more features must be compared to find the target, which promotes a serial search strategy over each letter in the search grid. In the present research, both easy and hard searches were used to assess the impact of perceived motion blur on different search strategies.

The issue of whether motion blurring has the same impact as a contrast reduction on visual processing was also examined. Given that the nature of motion blurring is a stimulus quality reduction, it was expected that motion blurring would have the same negative impact on response time as in previous studies that manipulated stimulus quality. Reducing the quality of the visual search task through contrast reduction decreases the discriminability of the target and distractors, which increases response times to finding the target (Johnsen & Briggs, 1973; Pashler & Badgio, 1985; Treisman & Gormican, 1988). Additionally, it was expected that hard searches would be more affected by perceived motion blur than easy searches, as hard searches require accumulating more information on the identity of each letter. Previous research by Dawson and Thibodeau (1997) demonstrated that serial searches are more impacted by a luminance reduction than parallel searches.

Although it was not expected, there was the possibility that backlight strobing may impair visual searches, leading to increased search times. The strobing frequency of the display is above the flicker fusion threshold and so appears continuously lit. However the length of time that each frame is displayed is dramatically reduced. Any effects arising from this mode of operation should be nullified due to persistence of vision. The experimental design included a baseline response time measurement for both strobed and non-strobed conditions to validate this assumption.

Method

Participants

Twenty-six student participants recruited through the Carleton SONA system were compensated with 1% course credit. All participants had normal or corrected-to-normal visual acuity.

Materials

The visual search task consisted of a 6 x 6 grid with 17 distractor letters and one target letter. The letters were randomly distributed within the grid on each trial. The target letter was either easy or hard to find, depending on the degree of featural overlap with the distractors. The target/distractor pairs for the easy searches were H/O, Q/Y, and T/C. The target/distractor pairs for the hard searches were F/E, I/L, and P/B. The target and distractor letters were never exchanged. That is, the targets were always H, Q, T, F, I, or P and the distractors were always O, Y, C, E, L, or P. According to previous studies in search asymmetry (e.g., Treisman & Gormican, 1988; Wolfe, 2001), searching for a target among distractors based on the absence of a feature is more difficult than searching based on the presence of a feature. The target/distractor pairs in the hard search condition were therefore chosen to exploit this added difficulty (e.g., the target 'F' is missing a feature compared to the distractor 'E'). All letters were displayed in 40 point Calibri font and almost completely filled the grid cells. An example of an easy and hard search is shown in Figure 3.

Figure 3. Examples of an Easy and Hard Visual Search Task

	O				
O	H	O	O		
	O	O	O	O	
O				O	
				O	O
O	O		O	O	O

Easy Search

		E			
		E	E	E	
		E	E		E
E					F
	E	E		E	E
E	E	E	E		E

Hard Search

The search task stimuli were presented on an ASUS VG278H 120 Hz LCD monitor (see Appendix C for monitor specifications). Participants were seated approximately 70 cm from the monitor, with the LCD display subtending a visual angle of approximately 49° horizontally and 28° vertically. The search grid subtended a visual angle of approximately 6.5° horizontally and vertically. The monitor operated at 120 Hz and the backlight strobing feature was activated and deactivated through software that controlled the monitor's settings. When the backlight was not strobed, each frame was visible for 8.3 ms (1/120th of a second). Backlight strobing reduced the frame exposure duration to 2.4 ms.

The stimuli were generated and the responses recorded using a custom script written in C++ that minimized timing inaccuracies. Participants' RT responses were collected on a standard USB keyboard that was continuously polled every 1 ms by a dedicated thread. The response timer was started immediately after the software call to display the visual search stimuli, and the input delay for the monitor is reported to be less than 3 ms (Kraft, 2012). Total system latency (i.e., the time between a key press until a response appeared on the screen) was 30-40 ms, the majority of which was internal to the standard keyboard used. This latency value was constant across all experimental conditions.

Design

A 2 (Search Difficulty: easy vs. hard) x 2 (Backlight Strobing: on vs. off) x 2 (Target Type: static vs. moving) repeated measures design was used. Search difficulty and target type were mixed factors and backlight strobing was blocked and counterbalanced with half the participants receiving the strobing on condition before the off condition and the other half receiving the reverse order. Targets in the easy search condition shared few features with the distractors whereas there was significant featural overlap between the targets and distractors in the hard search condition. The backlight strobing on condition was identical to the off condition with the exception that the frame exposure duration was decreased from 8.3 ms to 2.4 ms.

In both target type conditions, an empty grid was displayed at the centre of the screen for 1500 ms prior to being populated with target and distractor letters. In the static target condition, the visual stimuli (i.e., grid and target/distractor letters) remained centered on the screen. In the moving target condition, visual stimuli moved in a diagonal trajectory at a speed of 720 pixels/second until an edge of the grid reached either a vertical or horizontal display boundary at which point it would reverse direction along that same axis. This gave the impression that the visual stimuli bounced off the display boundaries and afforded predictable motion in accordance with Newtonian physics. The purpose of selecting only diagonal trajectories was to ensure that both the horizontal and vertical features of the letters were equally blurred. In the moving target condition, the empty grid started moving 1300 ms after appearing to give participants enough time to initiate pursuit tracking before it was populated with the target and distractor letters (de Xivry & Lefèvre, 2007). The grid was in motion for the final 200 ms prior to being populated, and remained in motion over the course of the trial until the participant made a response.

Participants completed 360 trials in total, which were split into one block of 180 strobing on trials and another block of 180 strobing off trials. Within each block, the easy/hard searches and moving/static trials were randomized and presented an equal number of times.

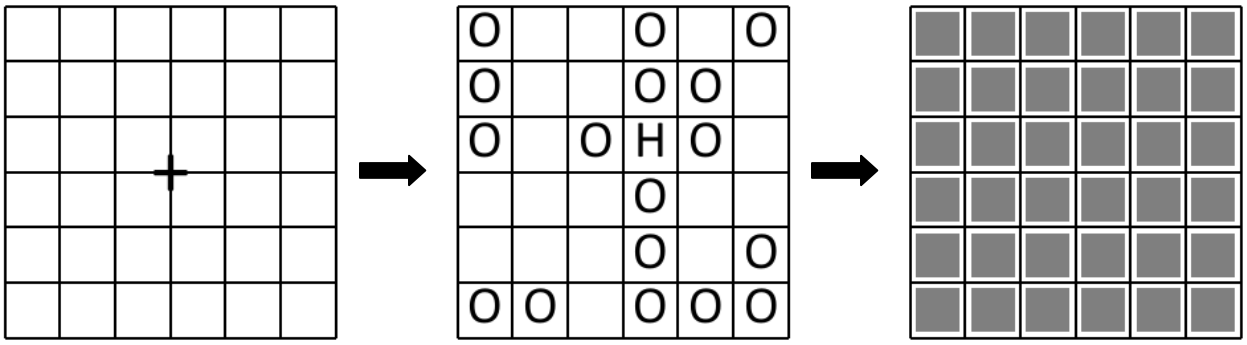
Procedure

At the beginning of the experiment, participants were given an informed consent form (see Appendix A) that explained the task and the nature of the experiment. Once consent was obtained, participants completed 12 practice trials with backlight strobing off regardless of counterbalance. There were an equal number of easy/hard and moving/static trials in the practice block. Once the practice trials were completed and any outstanding questions were answered, the first experimental block of either the strobing on condition or strobing off condition (depending on the experimental counterbalance) was presented. The second block of experimental trials followed the first block. There were three self-paced breaks, one at the midpoint of each experimental block and one between blocks, during which participants were encouraged to take a short pause. After the conclusion of the second block participants were debriefed (see Appendix B) and awarded course credit.

Participants were instructed to press the space bar on the keyboard as soon as they saw the target letter, at which point the visual stimuli stopped moving (in the moving target type condition) and the letters were replaced by opaque gray squares (see Figure 4). Participants then used the mouse to click on the square in the cell that previously contained the target letter. Response time was measured as the difference in time between the onset of the target/distractor letters and the participant's space bar response. Accuracy was a binary measure in which the participant either clicked on the target cell (correct) or did not (incorrect). Participants were provided with feedback in the form of a message ("Correct" or "Incorrect") that was displayed

onscreen for 1000 ms following each mouse click response. The next trial started following the offset of the feedback message.

Figure 4. Trial Sequence



0 – 1500 ms (any movement began at 1300 ms)

1500 ms – participant speed response (space bar)

Participant accuracy response (mouse)

Results

Data from trials on which participants incorrectly identified the location of the target were excluded from the response time analysis. This resulted in an elimination of 4.2% of the data. The remaining data were submitted to a recursive outlier analysis procedure in which scores falling three or more standard deviations above or below the mean score for that condition and that participant were eliminated from further response time analyses (Van Selst & Jolicoeur, 1994). This resulted in a further elimination of 2.66% of data. The remaining data were submitted to a 2 (Search Difficulty: easy vs. difficult) x 2 (Backlight Strobing: on vs. off) x 2 (Target Type: static vs. moving) repeated-measures Analysis of Variance (ANOVA). Post-hoc analyses were conducted and 95% confidence intervals were calculated as specified by Jarmasz and Hollands (2009). Means that differ by more than half of the confidence interval multiplied by the square root of two are significantly different. This corresponds to an overlap of less than 25% in confidence intervals represented visually.

As shown in Table 1, there was a significant main effect of target type, with moving targets (890 ms) taking significantly longer to detect than static targets (728 ms). The main effect of search difficulty was also significant, with difficult targets (977 ms) taking longer to detect than easy targets (641 ms). Although the main effect of Backlight Strobing was not significant, the impact of this factor on response time appears to be mediated by target type (i.e., whether or not the target is moving). The pattern of this Backlight Strobing x Target Type interaction will be discussed in further detail below.

Table 1. Tests of Main Effects

Variable	F(1, 25)	*p*	$\eta^2_{partial}$
Moving Target	47.01	< .001	.653
Search Difficulty	98.03	< .001	.797
Backlight Condition	0.34	= .565	.013

As shown in Table 2, there was a significant Target Type x Search Difficulty interaction, a significant Target Type x Backlight Strobing interaction, and a significant 3-way Target Type x Search Difficulty x Backlight Strobing interaction. The Search Difficulty x Backlight Strobing interaction was not significant.

Table 2. Interactions

Variable	F(1, 25)	*p*	$\eta^2_{partial}$
Moving Target | Search Difficulty	95.49	< .001	.793
Moving Target | Backlight Condition	23.59	< .001	.486
Search Difficulty | Backlight Condition	0.88	= .357	.034
Moving Target | Search Difficulty | Backlight Condition	18.82	< .001	.430

For Figures 5-7, 95% confidence intervals are shown as computed in Jarmasz and Hollands (2009). The Target Type x Search Difficulty interaction (see Figure 5) indicates that the effect of search difficulty was magnified when the target was moving as opposed to when it was static. That is, the effect of search difficulty on response times was almost twice a large in the moving target condition (436 ms) than in the static target condition (234 ms). The long

response times to hard searches in moving targets (1108 ms) likely reflects the compounded difficulty of saccading over the letter grid while tracking a moving target and attempting to identify a degraded target caused by perceived motion blur.

Figure 5. Mean Response Time (ms) as a Function of Search Difficulty and Target Type

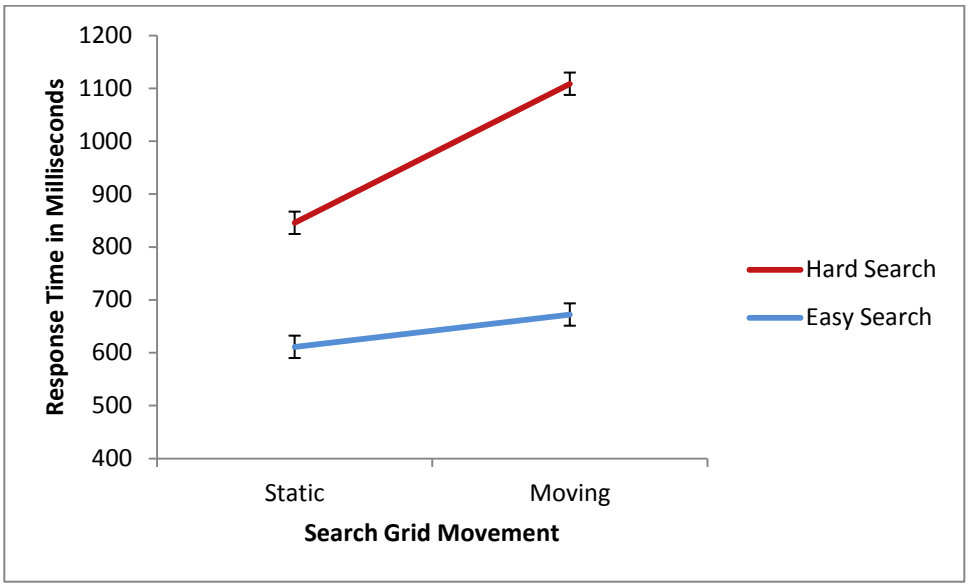
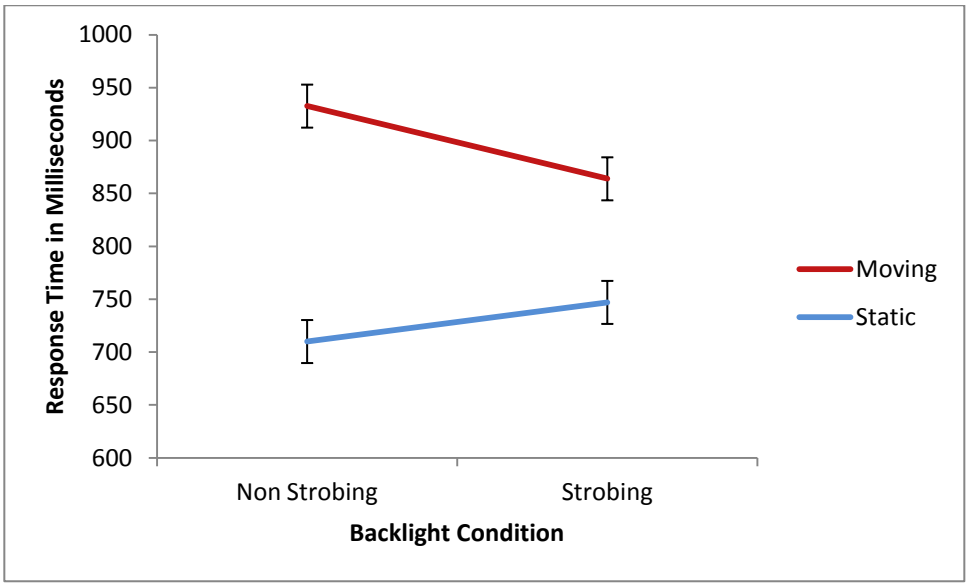
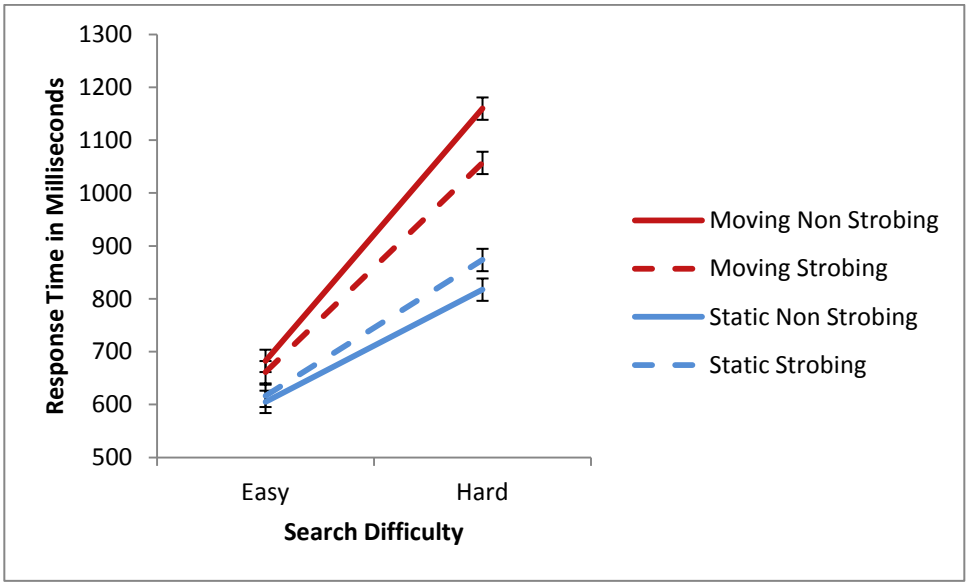


Figure 6. Mean Response Time (ms) as a Function of Target Type and Backlight Strobing



As seen in Figure 6, the response times for moving targets were longer than response times for static targets for both the strobing backlight and non-strobing backlight conditions, reflecting the higher difficulty for moving search grids. Broken down by search difficulty in Figure 7, response times between backlight conditions were significantly different for hard searches, but not for easy searches. When the search grid was moving, the strobing backlight condition had the expected positive impact on search speed, with a mean difference of 21.4 ms for easy searches and a mean difference of 102.7 ms for hard searches (only the hard search difference is significant). Interestingly, when the search grid was static, the strobing backlight condition had a negative impact on search speed. For easy static searches the mean difference in backlight condition is 11.4 ms, and for hard static searches the mean difference in backlight condition is 56.1 ms (again, only the hard search difference is significant).

Figure 7. Mean Response Time (ms) as a Function of Search Difficulty, Backlight Strobing, and Target Type



Discussion

The present research examined the effect of perceived motion blur on finding a target in a visual search task, and measured the ability of LCD backlight strobing to reduce perceived motion blur. A visual search task with two levels of difficulty was displayed with LCD backlight strobing on or off, and the search task was either moving across the screen or was static. Participants searched for a target letter among a field of distractor letters. As predicted, easy targets were faster to detect than hard targets, and moving targets were slower to detect than static targets. Backlight strobing had a differential effect for the static and moving conditions.

In the moving condition, backlight strobing had the expected positive effect of reducing response times to finding the target, particularly when the target was difficult to find. This shows that perceived motion blur can be effectively reduced via LCD backlight strobing. However in the static condition, backlight strobing had a negative effect on response times, again mainly for hard targets. This detriment could not have been from any effects of perceived motion blur as there was no movement in the static condition. Backlight strobing appears to have had an unexpected negative side effect when finding targets that were not moving.

In sum, the present research shows that perceived motion blur has the same detrimental impact on visual search times as other stimulus quality manipulations such as reduced contrast and noise overlays. Blurring increases the time required to identify a target, particularly for targets that are harder to find. Backlight strobing can reduce the effect of blurring for moving targets.

If one of the consequences of blurring the targets and distractors is that each of their features must be un-blurred (or “cleaned up”) prior to being forwarded for further processing,

then this process will add processing time commensurate with the number of features to be compared. As such, the effects of motion blur will be more pronounced for hard searches than for easy searches. This is exactly the pattern that was observed in the Target Type x Search Difficulty interaction.

The present data also show that backlight strobing reduces the time required to detect moving targets, especially for targets that require more intensive serial search. This is due to backlight strobing having the desired outcome of reducing motion blur, which is consistent with subjective reports that moving objects appear clearer when backlight strobing is used. The benefits of backlight strobing in reducing motion blur on an LCD were observable even at a high refresh rate of 120 frames per second, which itself reduces perceived motion blur compared to the standard 60 frames per second.

In contrast to the benefits of backlight strobing on the detection of moving targets, backlight strobing appears to interfere with the detection of static targets. This finding is inconsistent with the hypothesis that backlight strobing would have no effect on static targets. This unexpected finding may be due to one (or a combination) of the two following side-effects of a strobing backlight: reduced contrast and interference with saccadic masking.

An unintended side-effect of backlight strobing was an overall reduction in display contrast. As it is difficult to accurately measure the luminance of a periodic light source as perceived by the human visual system, an attempt was made in the present study to subjectively equate the luminance of the two backlight strobing conditions (on vs. off). However with the chosen monitor, backlight strobing slightly decreased the brightness of the display by increasing the overall black level, resulting in a net loss of contrast between the black search grid and the

white background. This overall reduction in stimulus quality may have had an inadvertent negative impact on visual search times. As in Dawson and Thibodeau (1997), the data reported here show that hard searches requiring serial processing are more affected by stimulus quality reductions than easy searches that rely on parallel search. Given that this contrast reduction was also present in the moving target condition, it is likely that the benefits of backlight strobing on the detection of moving targets were under represented. That is, if display contrast were held constant across the two backlight strobing conditions, then the decrease in response times for moving targets when backlight strobing was used might have been more dramatic.

Another explanation for the negative effect of backlight strobing on response times for static targets is that backlight strobing may interfere with saccadic suppression. Saccadic suppression is the tendency for the human visual system to disregard visual input when the eyes are moving during a saccade. This causes any visual input to be imperceptible under most circumstances. Previous research has shown that, relative to constant light sources, intermittent light sources can result in increased ocular displacement error when saccading to a target (Wilkins, 1986), an increase in the number of saccades (Kennedy & Murray, 1991), and increased target detection response times in a visual search task (Jaén, Columbo, & Kirschbaum, 2011). These effects have been observed even at frequencies above the flicker fusion threshold when the intermittent light source is visually indistinguishable from a constant light source. Previous research has also shown that serial search tasks require a greater number of saccades than parallel search tasks (Williams, Reingold, Moscovitch, & Behrmann, 1997), which accounts for the greater impact of backlight strobing in the hard (serial search) condition than the easy (parallel search) condition. Intermittent light sources can also produce a series of “ghost images” when a thin line is displayed on a high contrast background. As the eye saccades across the line,

multiple clear images of that line are perceived, and are not masked by the visual system. Saccadic suppression is clearly disrupted in this circumstance as images can be perceived during the saccade.

In summary, the present research shows that LCD backlight strobing objectively improves the detection of moving targets because it reduces perceived motion blur. Backlight strobing is a more computationally feasible alternative to increasing frame rates and works within the limits of current display technologies. The obvious applications for backlight strobing are those where fast-moving images are displayed on LCDs (or OLEDs) and require accurate target detection and identification. These applications include, but are not limited to, aircraft simulators, head mounted displays, and high performance gaming platforms.

Appendices

Appendix A: Informed Consent Form

Informed Consent Form

Study: **Visual Search and Pursuit Tracking on Sample and Hold Displays**
Faculty Sponsor: Dr. Chris Herdman, Department of Psychology, Carleton University, tel. 520-2600 x.8122

The purpose of this informed consent form is to ensure that you understand both the purpose of the study and the nature of your participation. The informed consent must provide you with enough information so that you have the opportunity to determine whether you wish to participate in the study. This study has received clearance by the Carleton University Psychology Research Ethics Board (Ethics Approval: 14-011). Please ask the researcher to clarify any concerns that you may have after reading this form.

Research Personnel: In addition to the Faculty Sponsor named above, the following people are involved in this research and may be contacted at any time should you require further information about this study.

Name	Title	Department	Email	Phone
Chris Herdman	Professor	Psychology	chris_herdman@carleton.ca	520-2600 x.8122
James Howell	Masters Student	Institute of Cognitive Science	james.howell@carleton.ca	520-2600 x.2487

Other Contacts: Should you have any ethical concerns regarding this study, please contact Dr. Shelley Brown. For any other concerns about this study, please contact Dr. Jo-Anne LeFevre.

Name	Position	Phone
Dr. Shelley Brown	Chair, Psychology Research Ethics Board	520-2600 x.1505
Dr. Jo-Anne LeFevre	Director, Institute of Cognitive Science	520-2600 x.2693

Purpose: Many new TV and computer screens (e.g., LCDs) produce an unwanted motion blurring effect when tracking moving objects due to our perception of how visual information is updated on the screen. The purpose of this study is twofold. First, we aim to obtain a better understanding of the cognitive/perceptual mechanisms that produce this motion blurring effect. Second, we wish to evaluate the efficacy of the strobing backlight method of reducing apparent motion blur.

Tasks: Your task is to search for a (unique) target letter in a 6x6 grid containing 17 distractor letters (e.g., a target “E” amongst distractor “Fs”. Sometimes it will be easy to find the target and sometimes it will be hard due to differences in similarity between the target and the distractors. On some of the trials, the grid of letters will be moving and on some trials it will not move. The strobing backlight feature of the computer monitor will be activated for some of the trials to determine whether or not it helps you find the target letter. When you find the target, press the spacebar. Once the spacebar is pressed, all the letters will be removed from the screen and only the (empty) grid will be displayed. Your task is to click on the cell (using a mouse) that contained the target letter.

Duration, Locale, and Compensation: Testing will take place in the VSIM Building, room 2201, and will last approximately 1 hour. You will receive 1.0% credit for your participation.

Potential Risks/Discomfort: You may experience mild/temporary eye discomfort (tiredness) due to the nature of the tracking task used in this experiment. If you begin to feel your eyes getting tired, please discontinue the task and bring it to the attention of the experimenter. There are no potential psychological risks associated with participation in this experiment. Please note that your performance on the task in this experiment does not provide an indication of your suitability for university studies. However, if you feel anxious and/or uncomfortable about your performance in this experiment, please bring your concerns to the researcher's attention immediately.

Anonymity/Confidentiality: All data collected in this experiment will be kept strictly confidential through the assignment of a coded number and securely stored on a local computer for a maximum of ten years. Similarly, this Informed Consent form will be kept for a maximum of ten years before being destroyed. The information provided will be used for research purposes only. You will not be identified by name in any reports produced from this study. Further, the information is made available only to the researchers associated with this experiment.

Right to Withdraw/Omit: You have the right to withdraw from this experiment at any time without any penalty. Your participation in this experiment is completely voluntary.

I have read the above description of the study on visual search on sample and hold displays. By signing below, this indicates that I agree to participate in the study, and this in no way constitutes a waiver of my rights. Research Ethics Board Approval: 14-011.

Name:_____ Date:_____

Signature:_____ Witness:_____

Appendix B: Debriefing Form

Debriefing

Visual Search and Pursuit Tracking on Sample and Hold Displays

Thank you for your participation. The purpose of this study is to measure the effect of apparent motion blur on sample and hold (e.g., LCD) displays and to measure the efficacy of one commonly used method for reducing motion blur (backlight strobing).

LCDs can appear to have significant motion blur that cannot be accounted for by the time required for pixels to transition from one colour to another when viewing a moving object. This is due to the discrete update nature of sample and hold displays. When you track an object onscreen, your eyes move over static images that are updated at a limited frequency – typically 60 Hz. Since your eyes receive information at an essentially unbounded rate, video frames are smeared across your retina before they update to the next position, which causes moving images to appear blurred.

Two techniques are generally used to reduce motion blur – both of which reduce the amount of time that each frame is visible: Higher frame rates (e.g., 120 Hz) and/or a strobing backlight. This experiment employed a 120 Hz monitor with a backlight that was either strobing or constantly lit. For further information on these techniques, please see the following:

> Kurita, T. (2001). Moving picture quality improvement for hold-type AM-LCDs. *SID Symposium Digest of Technical Papers, 32*, 986-989.
>
> Souk, J.H. & Lee, Jongseo (2007). Recent picture quality enhancement technology based on human visual perception in LCD TVs. *Journal of Display Technology, 3,* 371-376.

The effectiveness of the blur reduction techniques was measured using a visual search task that was either easy (e.g., finding an E among Os) or hard (e.g., finding an E among Fs). Manipulating the difficulty of the search task will indicate where the effects of motion blur occur in the visual processing stream (early vs. late). For more information on visual search, please see the following:

> Treisman, A. M. & Gelade, G. (1980). A Feature-Integration Theory of Attention. *Cognitive Psychology, 12,* 97-136.

The results from this study will help further our understanding of the cognitive mechanisms responsible for perceived motion blur, which will allow for the refinement of existing techniques used to limit the effects of motion blur on sample and hold displays.

This study has received clearance by the Carleton University Psychology Research Ethics Board (Ethics Approval: 14-011). Should you have any ethical concerns regarding this study, please contact Dr. Shelley Brown (Chair, Psychology Research Ethics Board, 613-520-2600 ext. 1505).

Should you have any other concerns about this study, please contact Dr. Jo-Anne LeFevre, (Director, Institute of Cognitive Science, 613-520-2600 ext. 2693) or any of the following individuals:

Name	Title	Department	Study Role	Contact Info.
James Howell	Masters Student	Cognitive Science	Principal Researcher	520-2600 x.2487
Dr. Chris Herdman	Professor	Psychology	Faculty Advisor	520-2600 x.8122

Appendix C: Asus VG278H LCD Monitor Characteristics

Asus VG278H Technical Specifications:

Screen size: 27 inches

Aspect ratio: 16:9

Screen resolution: 1920 x 1080 pixels

Pixel response time: 2 ms (grey to grey)

Backlight: PWM controlled LED

Maximum brightness: 300 cd/m²

User Controllable Settings Used for This Study

Backlight strobing off:

Splendid Mode: sRGB

Brightness: 90

Contrast: 80

Saturation: 50

Color temp: User Mode

Skin Tone: Natural

Smart View: Off

Sharpness: 50

Trace Free: 60

Nvidia Lightboost: Disabled

Backlight strobing on:

Splendid Mode: sRGB

Brightness: 100

Contrast: 92

Saturation: 50

Color Temp: User Mode

Skin Tone: Natural

Smart View: Off

Sharpness: 50

Trace Free: 60

Nvidia Lightboost: Max

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