Timing Guide for Stimulus Display in Pro Lab
Version 1.1
Timing Guide for Stimulus Display in Pro Lab

March 2018
Tobii AB

Pro Lab is a research platform for the entire research process that enables, among other things, the recording of eye tracking data while displaying visual stimuli on a screen. In many research areas, it is important to obtain accurate timing information of when a stimulus is displayed on the screen. This document aims to provide a general understanding of the different components and procedures involved during the process of displaying a stimulus, present the results of the stimulus-onset timing tests with different setup configurations, and describe in detail how Pro Lab achieves an accurate estimation of stimulus-onset times.
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Introduction

Precise timing in relation to the presentation of visual stimuli is a requirement in many types of research methodologies. Some examples are experiments measuring saccade latencies, participants' manual reaction times, or electrophysiological responses with high timing resolution such as EEG. In these types of experiments, it can be critical to set or determine the stimulus-onset time (i.e., the point in time when a stimulus first becomes visible on the screen) as well as the stimulus duration to an accuracy down to the millisecond.

To ensure a stimulus presentation with millisecond accuracy, it is essential to understand the different system components, as well as hardware and software factors involved in the display of stimulus on a monitor, and how they affect the timing of the stimulus-onset and display duration. There are characteristics of the presentation system that the computer has access to (e.g., monitor refresh rate) but there are other factors that a computer cannot determine or control (e.g., pixel response time of an LCD monitor). Depending on the stimulus control process, these factors will affect to varying degrees the timing accuracy of the stimulus onset on the screen and its estimation by the stimulus presentation software.

Pro Lab controls the stimulus display process by synchronizing the display of a stimulus with the monitor vertical scan. This practice prevents image tear on the display\(^1\), enables an accurate estimate of stimulus onset, and an accurate synchronization of the stimulus presentation with any data stream recorded in Pro Lab. External data streams recorded outside Pro Lab will also benefit from accurate stimulus control when sending TTL stimulus-onset markers to register onset events in any external data. However, it is also important to understand that there are factors that Pro Lab cannot automatically control. These factors are usually related to constant monitor latencies and can be easily corrected for. In an experiment with high timing accuracy needs, the overall system latency should be measured to ensure that the setup does not have any significant jitter or variable latency that can affect the results.

In this document, the reader will learn about the following topics in detail:

**Part 1: General concepts about stimulus presentation timing:**
- Properties of the stimulus display process and associated latencies (Chapter 1).

**Part 2: Stimulus presentation timing in Pro Lab:**
- How Pro Lab controls the stimulus presentation, estimates stimulus-onset times with image and video stimuli, and sends stimulus-onset markers to external devices (Chapter 2).
- What stimulus-onset timing accuracy can be expected in Pro Lab with different computer system configurations: low-end, mid-range and high-end system configurations (Chapter 3 and 4).
- Setup recommendations to maximize the timing performance of your setup (Appendix A).
- A method to test the system latency of your setup with a TX300 or Spectrum eye tracker (Appendix B).

The scope of this timing guide document is limited to the timing of Tobii Pro Lab stimulus display process: stimulus onset time, stimulus duration and stimulus-onset marker timing

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\(^1\) Image tear is a visual artefact where information from two or more frames are presented at the same time, creating a defective image.
accuracy. This document does not discuss the latencies generated by the eye tracker (total system latency) or any other timing concept related with the eye tracker performance. These concepts are of importance mainly in gaze-contingent experiments where gaze information needs to be available in real time to update the stimulus image. You can learn about these concepts on our Learning center (https://www.tobiipro.com/learn-and-support/learn/) and check your eye tracker’s timing properties in the specific product description.
Part 1: General concepts about stimulus presentation timing
1 Understanding the stimulus display process

The display of a visual stimulus involves several components in the display computer and the monitor (Figure 1). At the display computer, the graphics card receives information from the CPU about the stimulus that needs to be displayed and renders the corresponding image according to the monitor characteristics. The graphics card can either send the stimulus image to the monitor display right away or hold the completed image in a buffer until it is time to display it. Once the image arrives at the display, the stimulus is first stored and buffered by the screen controller card. Finally, the stimulus is displayed at the next refresh cycle.

Without any timing stimulus control, there will be a latency from the time that the CPU sends the image information to the graphics card until the image is finally displayed. Both computer and monitor factors influence this latency. In the computer, the time that it takes the graphics card to render the visual stimulus adds to the latency, and operating systems can also introduce delays. More specifically, the time that it takes the stimulus to be ready to send to the display will depend mainly on the computer’s processor usage and speed, the RAM memory allocated to this task, and the graphics card’s speed and available memory. In modern computers, these factors will not necessarily have a big impact in the stimulus display latency, especially when using a graphics card with a dedicated processor.

There are several monitor factors that influence stimulus display latency that depend on the monitor characteristics. For this reason, we need to first introduce the working principles of the main types of monitors.

1.1. How do CRT and LCD monitors work?

Cathode ray tube (CRT) and liquid crystal display (LCD) are the two most commonly used monitors for research purposes nowadays. Although CRT monitors are based in an old technology and are bulkier than other modern monitor technologies, researchers that need high accuracy stimulus onsets still use them due to their reliable and precise display process.

The main procedure for updating the display with a new image is common to both LCD and CRT for compatibility reasons, i.e., LCD monitors were designed to work as CRT monitors. The main concepts that are involved in the stimulus display process can be explained using a CRT display as an example:
A computer screen is divided into a discrete number of horizontal and vertical pixels, known as the monitor’s **resolution**. In a CRT display, the electron beam inside the cathode ray tube is continuously scanning and updating the state of each of the display’s pixels. They are not updated all at once, but sequentially, following a specific pattern. The update usually starts from the leftmost pixel of the first horizontal line, scanning line by line from left to right (horizontal scan), going to the next line when it reaches the end of the current one (vertical scan). When the electron beam arrives at the rightmost pixel of the last line, it returns to the starting position and starts a new scan cycle or **refresh cycle** (Figure 2). The number of times in a second that a display draws the image on the display is known as the **refresh rate** (e.g., 100Hz in a standard CRT monitor). Also, the time that it takes for the electron beam to get from the last horizontal line to the first horizontal line to start a new display update is called the **vertical blanking interval**. Ideally, the monitor will receive the next stimulus during the vertical blanking interval because then it will display it entirely during the next refresh cycle, thus avoiding any tearing effect.

![Illustration of a CRT display refresh cycle scan. The dashed lines represent the direction of the electron beam.](image)

1.1.1 Differences between CRT and LCD monitors

LCD monitors have a similar scan procedure to update information on the display as the described for CRT. However, they use very different technologies to display information. Below are the main differences that affect the stimulus display process:

1. LCD technology uses the light-modulating properties of liquid crystals to passively illuminate the pixels with a steady backlight. When an LCD display draws new content, there is a luminance transition of each pixel that needs to be updated. The duration of an LCD luminance transition is called **pixel response time** and it will delay the appearance of the information on the screen.

2. LCD monitors display information well at only the resolution they are designed for, which is known as the **native resolution**. If the resolution changes, the display will need to scale the image with the potential decrease in image quality and added latency to the display. CRT monitors do not have this limitation.

3. CRT displays will constantly redraw the same image every refresh cycle until a new image arrives to the display to be updated. An LCD display will only draw the image once and keep it displayed until a new image arrives.

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Most **TFT**, **LED** and all types of **OLED** displays have the same stimulus display process described for LCD monitors. The main difference is the technology used to build and illuminate pixels, which modify pixel response times, refresh rates and color, among other properties.
1.2. Stimulus display latencies introduced by the monitor

Now that we have a better idea about how the main types of monitors work, we can talk about the factors that will influence the total latency until a stimulus is finally visible on the screen. They all are related to the nature of displays and some cannot be controlled by the computer.

**Refresh rate**: The monitor will usually display the stimulus at the next refresh cycle to avoid the tearing effect. In a 60Hz monitor, this means that the latency added is up to 1/60Hz = 16.67ms. If, for example, the monitor is ready to draw the stimulus right at the start of a vertical scan, this latency will be 0ms. If, however, the stimulus is sent when the vertical scan just started, the latency will be equal to one refresh cycle (16.67ms).

**Time to vertical refresh**: The monitor draws the stimulus from the top of the screen to the bottom and line by line. All the pixels will be updated during the refresh period time (e.g. 16.67ms at 60Hz) but pixels located on the first top line will be updated before pixels that are located on the bottom lines. Stimulus-onset times usually refer to the start of the vertical scan, i.e. first top line. This latency only needs to be taken into consideration in experiments where stimulus display timing is crucial and the stimuli are drawn in a specific vertical location of the screen. In these cases, the onset time can be corrected by adding the time to vertical refresh for that specific location.

**Pixel response time**: The pixel response time will vary for different monitor models and potentially even within the same monitor for different luminance transitions. Pixel The most common approaches to measure pixel response time are gray-to-gray (GTG) and black-to-white (BTW). They both measure the time that it takes for a pixel to go from one color state to another (e.g., black to white transition time in the case of BTW). A transition from black to white, for example, will probably take a slightly different length of time to a transition from 50% grey to black. Pixel response times reported by the monitor manufacturer are usually used as the average pixel response time of the monitor and consider it as a constant latency.

**Input lag**: Many LCD displays do post-processing before displaying a new stimulus on the screen. This can include rescaling the image when not using a native resolution, image quality improvement or pixel response time improvement. These features will add a latency that, in many cases, can be unpredictable.

If your experiment needs very short or very specific stimulus durations, we recommend using a monitor with high refresh rate. For example, a 240Hz monitor will reduce by four the total latency due to the refresh cycle (4.17ms).

We recommend that you switch off all post-processing functions of an LCD display whenever possible and always work at the native resolution to keep the input lag latency to a minimum.
1.3. Expected, estimated and true stimulus onset time

The stimulus display process will introduce latencies and, subsequently, timing differences between when a computer expects that the monitor will display the next stimulus and when it is actually visible on the screen. We need to introduce the following three concepts as a consequence:

- **Expected onset time**: The onset time when the monitor should display the stimulus on the screen based on the stimulus timing properties defined by the user or on event (keyboard or mouse) during the experiment design. In the example shown in Figure 3 this time is $t_0$.
- **True onset time**: The final time when the monitor displays the stimulus on the screen. The time difference between the true onset time and the expected onset time is the latency created by the stimulus display process. In the example shown in Figure 3 this time is $t_0 + 11$ ms (6 ms until the next monitor refresh time + 5 ms due to monitor latency such as pixel response time).
- **Estimated onset time**: The onset time that is predicted by Pro Lab. Most of the times, Pro Lab estimates the onset time as the start of the next refresh cycle after the expected onset time. Depending on how many factors Pro Lab can take into account when computing the estimated onset time, the prediction will be more or less close to the true onset time (e.g., information about vertical blanking, or average pixel response time). In the example shown in Figure 3 this time is $t_0 + 6$ ms.

*Read Chapter 2 to know in detail about the stimulus display process in Pro Lab.*

To minimize the differences between the expected onset time and the true onset time, the monitor latencies described above should be as small as possible (e.g., by using a monitor with higher refresh rate, or with lower pixel response time).

*Figure 3. Example of expected, estimated and true onset time. In the example, the time difference between the expected onset time and the true onset time is created by the computer and monitor factors introduced during the stimulus display process.*
Part 2: Stimulus presentation timing in Pro Lab
2 Stimulus display in Tobii Pro Lab

2.1. Stimulus-onset control in Tobii Pro Lab

Tobii Pro Lab takes into consideration all the factors that can introduce latency during the stimulus display process and that can be controlled from the computer. This ensures an accurate estimation of every stimulus-onset time, achieved by two key methods. **First**, Pro Lab calculates when the display will start the next refresh cycle (start of vertical scan). **Second**, Tobii Pro Lab commands the graphics card hardware to synchronize the appearance of stimuli with the start of the vertical scan. This practice has the advantages of having control of the stimulus-onset time and a tear-free presentation of the stimuli. Combining these two pieces of information when a stimulus is displayed allows Pro Lab to know with high timing accuracy when the next stimulus will be displayed. These simple concepts are actually the result of Pro Lab’s accurate control of the low-level graphics card hardware responsible for sending the image information to the display.

2.1.1 Low-level stimulus onset control function

Below is a detailed description of how Pro Lab estimates the next vertical synchronization with every type of monitor:

1. **Querying the current scan line:** Pro Lab queries the graphics card for the display’s scan line position. The graphics card informs Pro Lab of the vertical line number that is being drawn by the monitor at that moment. Note that the scan line is usually estimated by the monitor driver in non-CRT monitors, which means that the stimulus onset control function mainly depends on the estimation accuracy of the monitor driver.

2. **Calculating the next refresh cycle start:** By knowing the screen resolution and the scan line at the moment of the query, Pro Lab can accurately estimate the start of the next refresh cycle or vertical scan.

3. **Every refresh cycle:** Pro Lab repeats this operation every refresh cycle to refine the time when Pro Lab queries the scan line and to compensate for any time drift.

![Figure 4. Illustration of the scan line position query done by Pro Lab every refresh cycle (yellow line) and the line position of every refresh cycle start (orange line).](image)

2.1.2 Stimulus display process

During the stimulus presentation, when a new stimulus needs to be displayed on the screen, Pro Lab follows these steps to ensure that the new stimulus will be displayed at the start of the next refresh cycle:

1. **Sends next stimulus to graphics card:** Right after querying the display’s scan line position, Pro Lab uses Direct3D graphics windows API to render and send the next stimulus image to the graphics card’s hardware acceleration.
2. **Back buffer rendering**: The image is drawn into the graphics card’s back buffer, which is a portion of the card memory that is not being displayed, but rather used to store the image that will be presented at the next refresh cycle. What is currently displayed on the screen is known as the front buffer.

3. **Buffer swap**: The graphics card hardware is synchronized with the display scanning status. At the vertical synchronization (VSYNC) signal during the vertical blanking interval, the back buffer and front buffer swap content. This action happens within microseconds during the vertical blanking interval (i.e., nothing is being drawn on the screen) and before the next refresh cycle starts.

4. **Image display**: When the next refresh cycle starts, the display draws what is in the front buffer. This process ensures a tear-free image for the user.

5. **Onset timing events**: Pro Lab stores the last calculated start of refresh cycle as the onset timing event of the new stimulus, which gives a very accurate estimate of the real onset time of the beginning of the image drawing. Since the onset time of the new stimulus corresponds with the offset time of the previous stimulus, Pro Lab also creates an offset timing event for the previous stimulus with the same estimated time.

![Figure 5. Illustration of the stimulus display control in Pro Lab during the presentation of three-image stimuli. The first row corresponds to what the screen displays in each moment. The second row corresponds to what the front buffer stores in each moment. The third row corresponds to what the back buffer stores in each moment. The first row corresponding to the screen is the only visible part for the user.](image)

2.2. **Stimulus duration control in Tobii Pro Lab**

A direct consequence of displaying stimuli at the start of a vertical scan is that the stimulus duration will always be a multiple of the refresh time. Depending on the refresh rate of your monitor, the stimuli duration will be more or less influenced by this. For example, with a 60Hz monitor, stimuli durations will be multiples of the refresh time: 16.67ms.

For the majority of experiments, the **duration difference** created by the refresh time of the monitor is negligible. However, for some types of research where stimuli duration is critical to the research question, this matter needs to be considered when designing the stimuli duration of your experiment.
Pro Lab controls the stimulus duration every time a new stimulus is displayed as follows:

If the stimulus duration was designed to advance at a designated time, Pro Lab starts a high-level stopwatch; otherwise Pro Lab waits for the type of event defined (key press or mouse). When either the stopwatch reaches the duration time as defined by the user or an advanced event is registered, Pro Lab sends a notification to its low-level stimulus-onset control function to inform that the next stimulus should be displayed at the next possible refresh cycle. At that moment, the mechanisms described in the previous section for controlling and displaying the next stimulus onset are activated. The stimulus duration that is defined by the user during the stimulus design is called “expected duration”. The stimulus duration that Pro Lab estimates is based on the onset time estimation of each stimulus, which gives an accurate measure of the actual duration of the stimulus on the screen. This is called “estimated duration”.

Take the following example to understand the differences between expected and estimated duration. Looking at Figure 6, the expected duration of stimulus “A” was 70ms. Since 70ms is not a multiple of the monitor refresh rate (60Hz): 70ms / 16.67ms = 4.2 frames, it is highly probable that Pro Lab will show the new stimulus at the next refresh cycle after 70ms has passed, which means that the estimated duration of the stimulus will be 5 frames = 83.33ms. See Setup Recommendations, Chapter 0 on page 10 to learn more about how to design the duration of your stimulus in Pro Lab to maximize the possibilities of obtaining a specific stimulus duration.

Note that Pro Lab minimum stimulus duration time is 50ms. This means that in a 60Hz refresh rate monitor, the minimum duration of a stimulus is equal to three refresh cycles.

![Figure 6. Example of expected duration vs. estimated duration with a 60Hz monitor.](image)

**2.3. Video stimulus control in Pro Lab**

A video is a particular type of stimulus that consists of image frames and audio displayed at a specific rate, known as frame rate. Pro Lab follows the same principles explained for stimulus-onset control with videos. However, the difference is that it does so not only for the video onset but also for every frame that is displayed. Pro Lab stores all the displayed frame onset times together with the frame number. This allows Pro Lab to control any video drift or dropped frames that could potentially occur during the presentation of the video (Figure 7). Although drifts and dropped frames are rare with modern computers, this procedure ensures that the data streams can be fully aligned with the video replay as displayed to the participant.
2.4. Stimulus-onset markers to other devices

When recording other biometric data streams outside Pro Lab (e.g. EEG, GSR, or HR) it is possible to send out TTL shared events at the onset of every stimulus, known in Pro Lab as Stimulus-onset markers (S-OMs). The events are sent from the parallel port of the computer and can be configured to send up to 8-bit data, i.e., 255 different events. This makes it possible to timestamp the onset of each stimulus in the external data stream together with, if needed, information about the stimulus condition. It is important, and especially critical in data streams such as EEG, that the stimulus-onset markers are sent as precisely in time as possible. In Pro Lab, this means sending the stimulus-onset marker to the external device as closely in time as possible as the estimated onset time.

2.4.1 Stimulus-onset marker control in Pro Lab

If the setting Send Stimulus onset markers (TTL) was enabled during the design phase, Pro Lab will follow these steps when a new stimulus with a “TTL marker value” other than 0 needs to be displayed:

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**Figure 7.** Example of a video stimulus displayed in Pro Lab during an experiment recording. The video is displayed at 30fps and the monitor refresh interval is 60Hz. A - the video was displayed at the correct frame rate, B - a frame was dropped during the display, and C - the video suffered drift. Pro Lab stores all frame onset times of the video together with the frame number and uses it during replay to synchronize correctly each gaze sample with the corresponding video frame.
1. **Notification to TTL module**: The low-level stimulus-onset control function informs ProLab’s TTL module that the parallel port value needs to be changed at the next stimulus onset. The TTL module receives, together with the request, the new TTL value and the estimated start time of the next refresh cycle.

2. **Change parallel port to stimulus value**: ProLab TTL’s module calculates the time when the parallel port needs to be updated with the onset marker value so that the stimulus-onset marker is as close as possible to the estimated onset time of the new stimulus. When the time comes, ProLab sends a request to the parallel port driver with the new pin values. The time at which this request is sent is stored as an event in ProLab as “TTL out”.

3. **Change parallel port to default value**: After 34ms, ProLab’s TTL module sends another request to the parallel port driver with the default pin values, i.e., all pins low; 0 value.

In most cases, the estimated S-OM and the estimated stimulus-onset time will be the same or very close in time. Especially with modern computers and up-to-date parallel port drivers, the TTL functionality should not suffer from any substantial delay, i.e., order of less than a millisecond. However, the TTL functionality can suffer from unwanted random delays depending on the principal amount of RAM and CPU load.

There are two types of accuracy errors associated with S-OM. The first one is the accuracy in sending S-OMs close to the estimated stimulus onset time, i.e., how closely in time to the estimated stimulus onset ProLab sends the S-OM. The second is the accuracy in estimating S-OMs close to the true S-OM time, i.e., how accurately ProLab timestamps the S-OM with respect to the actual time that the TTL marker is sent. The ability to estimate S-OM close in time to the true S-OM time (Figure 8. Example 2 and 3) is the most important accuracy error because it usually can’t be known and therefore can’t be compensated. The accuracy error in sending S-OM close to the estimated stimulus onset time when there is a high accuracy in estimating the S-OM (Figure 8. Example 2) can be corrected offline by the user if this is needed. This could be done in the external device data stream by shifting the markers with the time difference between the estimated S-OM and the estimated stimulus onset.

*You can check the ProLab S-OM timing accuracy test results in section 4.2.*

![Figure 8. Illustration of the two accuracy errors associated with S-OM: accuracy error in sending the S-OM close in time to the estimated stimulus-onset time and accuracy error in estimating the S-OM timestamp close in time to the true S-OM.](image)
2.5. Sources of onset delays

Pro Lab controls and minimizes the error as much as possible between estimated onset time and true onset time. Despite this, there are some factors that Pro Lab cannot automatically control, such as the pixel response time in LCD monitors or the input lag. The potential delay created by these factors will produce an onset time delay and therefore a time difference between the true onset time and the estimated onset time in Pro Lab.

2.5.1 Constant latency vs. jitter

We can divide delays into two main types: constant latency and jitter. Constant latency means that there will be a stable delay at every stimulus onset. One of the most common is the constant delay created by LCD monitors due to the pixel response time. Jitter means that the delay is unpredictable and different at every stimulus onset (e.g., irregular delays due to high CPU workload).

![Figure 9. Example of the difference in the estimated onset time by Pro Lab and the true onset time of a stimulus with a constant latency and no jitter. The true onset time will be delayed as will the offset time. In this case, the estimated duration will be equal to the final duration. This error can be corrected just by shifting the estimated onset events an amount of time that is equal to the constant latency.](image)

Constant latency is readily compensated. Pro Lab can correct any constant latency by shifting every estimated stimulus onset event the amount of time defined by the user (Figure 10). Jitter must be avoided as much as possible as it is usually not possible to correct jitter and it can even affect the final results when using time-sensitive measures such as saccades latencies.

![Figure 10. You can add the total constant latency of your setup under the Target Screen setting (Record module). Pro Lab will add that constant time to all the estimated onset events. In this example, Screen 1 has been defined to have a constant latency of 5ms and Screen 2 of 12ms. Note that this latency can include any constant delay introduced by your setup, not only the monitor latency.](image)
3 Timing verification tests. Setup

3.1. Stimulus-onset timing tests

The stimulus-onset timing tests focused on measuring the discrepancies in time reported between the estimated onset time by Pro Lab, the expected onset time by the user, and the true onset time when the stimulus was shown on the screen. We measured stimulus-onset time and duration latencies with this setup.

3.1.1 Introduction to the test setup

Figure 11 shows the setup used for the stimulus-onset timing tests. Pro Lab was run on each of the computer configurations presented in Table 3. Pro Lab recorded eye-tracking data from a Tobii Pro Spectrum eye tracker and showed the stimulus presentation on its monitor (see monitor characteristics in Table 4). A light sensor attached to the monitor measured the true onset time. The light sensor was sensitive to black-to-white and white-to-black changes on the screen with high timing accuracy (see light sensor device characteristics in Table 5). The Pro Lab computer registered the light sensor signal via the parallel port and timestamped using the same clock as Pro Lab. Section 4.1 show the test results of each of the tested computer configurations.

![Diagram of the test setup used for the stimulus timing test.](image)

3.1.2 Stimuli test design

Two stimuli sequences were tested, one with images and one with videos:

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Stimulus type</th>
<th>Number</th>
<th>Duration</th>
<th>Sequence</th>
<th>Stimulus format</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Image</td>
<td>1000</td>
<td>0.5 seconds</td>
<td>Black – White images alternated</td>
<td>jpeg</td>
<td>1920x1080</td>
</tr>
<tr>
<td></td>
<td>Videos (V) &amp; Images (I)</td>
<td>20 (V)</td>
<td>10 seconds (V)</td>
<td>Video - Image alternated</td>
<td>H.264 (V) jpeg (I)</td>
<td>1920x1080 (V)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19 (I)</td>
<td>100 ms (I)</td>
<td></td>
<td>jpeg (I)</td>
<td>1920x1080 (I)</td>
</tr>
</tbody>
</table>

Table 1. Stimuli sequences used for the stimulus timing tests.
3.1.3 Measurements

Stimulus-onset timestamp accuracy
This measurement gives information about Pro Lab’s timing accuracy in estimating onset time as closely in time as the moment the stimuli are displayed on the monitor.

The accuracy of the stimulus-onset timestamp in Pro Lab was measured as the interval of time between the moment Tobii Pro Lab timestamps the start of the stimulus (estimated stimulus-onset time) to the actual instant the stimulus is displayed on a screen (measured stimulus-onset time). The pixel response time of the monitor and light sensor response time were subtracted to the calculated interval of time (see Table 4 and Table 5 for the monitor and the light sensor response time characteristics) as constant delays. The stimulus sequence was Sequence 1 (Table 1) only on the black-to-white transitions (500 images).

Stimulus duration accuracy
This measurement gives information about Pro Lab’s timing accuracy in presenting stimuli for the duration expected.

The accuracy of the stimulus duration in Pro Lab was measured as the difference in number of refresh cycles (1 refresh cycle = 16.66ms with a 60Hz monitor) between the actual duration of the stimulus on the screen (measured stimulus duration) and the duration designed by the user based on the stimulus properties (expected duration). The stimulus sequence was Sequence 1 (Table 1) only on the white stimuli (500 images).

Video frame duration accuracy:
This measurement gives information about Pro Lab’s time drift when presenting video stimuli.

The video frame duration accuracy in Pro Lab was measured as the difference in number of refresh cycles between the actual duration of each frame on the screen (measured frame duration) and the duration of each frame timestamped in Pro Lab (estimated frame duration). The stimulus sequence was Sequence 2 (Table 1; 20 videos x 10 seconds x 30 frame/second = 6,000 frames).

3.2. Stimulus-onset markers timing tests

3.2.1 Introduction to the test setup
Figure 12 shows the setup used for the stimulus onset makers timing test. Pro Lab was run on the high-end system configuration, setup 5 (see Table 3). Pro Lab recorded eye tracking data from a Tobii Pro Spectrum eye tracker and showed the stimulus presentation on its monitor. Tobii Pro Spectrum eye tracker received and registered the stimulus-onset markers with high timing accuracy (timing offset of less than 100µs; true stimulus-onset marker time).

Figure 12. Diagram of the test setup used for the stimulus-onset markers timing test.
3.2.2 Stimuli test design

One stimulus sequence was used to test the accuracy of stimulus-onset markers:

<table>
<thead>
<tr>
<th>Stimulus type</th>
<th>Number</th>
<th>Duration</th>
<th>Sequence</th>
<th>Stimulus format</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image</td>
<td>1000</td>
<td>500ms</td>
<td>Black–White images alternated</td>
<td>jpeg</td>
<td>1920x1080</td>
</tr>
</tbody>
</table>

*Table 2. Stimuli sequences used for the stimulus-onset marker timing tests.*

3.2.3 Measurements

**Stimulus-onset marker accuracy in sending markers**

This measurement gives information about Pro Lab’s timing accuracy in timestamping stimulus-onset markers in Pro Lab. Specifically, how closely in time to the estimated stimulus-onset time Pro Lab timestamps the stimulus-onset marker.

The accuracy of the stimulus-onset marker in Pro Lab was measured as the difference in time between the moment Pro Lab timestamps the onset of the stimulus (estimated stimulus-onset time) and the moment Pro Lab timestamps the stimulus-onset marker (estimated onset marker time). The stimulus sequence was Sequence 1 (Table 1; 1000 images).

**Stimulus-onset marker accuracy in timestamping markers**

This measurement gives information about Pro Lab’s timing accuracy in timestamping stimulus-onset markers in Pro Lab. Specifically, how closely in time to the same event received in the eye tracker Pro Lab timestamps the stimulus-onset marker.

The timestamp accuracy of the stimulus-onset marker in Pro Lab was measured as the difference in time between the moment Pro Lab timestamps the stimulus-onset marker (estimated onset marker time) and the timestamp of the shared event received in the eye tracking data (measured onset marker time). The stimulus sequence was Sequence 1 (1000 images).

Note that the total maximum error of the stimulus onset markers will be the sum of the individual errors produced by the stimulus-onset marker in sending markers and the stimulus-onset marker in timestamping markers. See section 2.4.1 for more information.

3.3. Test configurations — Hardware

3.3.1 Computers

Table 3 shows the computers used for Pro Lab timing tests. The computer configurations have been chosen to provide the user with an overview of the timing performance in Pro Lab with different computer characteristics. It can also serve as a guide to choose the computer category that best suits your type of experiments. The first category, low-end system configuration, is recommended for users with no need of high accuracy in stimulus onset and duration. The second category, mid-range system configuration, is intended for the vast majority of users who need to have an accurate stimulus presentation but the timing is not critical for their paradigm. The third category, high-end system configuration, is recommended for any user with high accuracy timing requirements because accurate stimulus onset and duration is a key part to obtain valid results.

---

2 This measure depends on the synchronization accuracy between the eye tracker clock and the computer clock running Pro Lab. This process is automatically done by Tobii Pro SDK.
### Table 3. Computer configurations used for the different timing tests.

#### 3.3.2 Monitor

All the tests were performed using the Tobii Pro Spectrum native LCD monitor. The table below contains the detailed monitor specifications:

<table>
<thead>
<tr>
<th>Monitor</th>
<th>Panel Type</th>
<th>Backlight</th>
<th>Native Resolution</th>
<th>Refresh Rate</th>
<th>Response time (Gray to gray)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIZO FlexScan EV2450</td>
<td>IPS</td>
<td>LED</td>
<td>1920 x 1080</td>
<td>60Hz</td>
<td>5ms</td>
</tr>
</tbody>
</table>

*Table 4. Monitor characteristics used for all the timing tests presented in this document. The pixel response time is the average reported by the manufacturer.*

#### 3.4. Light sensor

The stimulus-onset timing tests were performed using a Stim Tracker® light sensor device. It received the light sensor signal and transferred to the computer via the parallel port. We subtracted the response time delay from all the time measurements as we considered it a constant delay. The signal transfer time via the parallel port has a negligible delay and therefore did not add any considerable constant or jitter delay.

<table>
<thead>
<tr>
<th>Light sensor</th>
<th>Response time white to black</th>
<th>Response time black to white</th>
</tr>
</thead>
<tbody>
<tr>
<td>StimTracker®</td>
<td>4ms</td>
<td>0.05ms</td>
</tr>
</tbody>
</table>

*Table 5. StimTracker® light sensor characteristics reported by the manufacturer. All the timing tests measured the transitions from black to white to avoid the low response time of white to black.*
4 Timing verification tests. Results

4.1. Stimulus timing tests

4.1.1 Summary of results

Pro Lab obtained the best performance in estimating the stimulus-onset time with the high-end setup ID 5 (M = 0.278ms; SD = 0.261ms). Pro Lab obtained the worst performance in timestamping stimulus onsets with the mid-range setup ID 3 (M = 1.350ms; SD = 3.489ms), followed by the low-end setup ID 1 (M = 1.034ms; SD = 2.133ms).

Pro Lab obtained similar results in stimulus duration with high-end setup IDs 5 and 6, and mid-range setup IDs 2 and 4. Roughly 95% of the stimuli were on the screen the right number of frames. Pro Lab displayed roughly 85% of the stimuli the right number of frames with the low-end setup ID 1 and mid-range setup ID 3.

In terms of the video frame duration accuracy, the best performance setup was also the high-end setup ID 5. In this setup, Pro Lab did not miss any video frame, showing 100% of the frames at the corresponding time. The worst performance setup was the low-end setup ID 1. Pro Lab showed 88.97% of the frame at the expected time, but approximately 1.5% of the frames were showed more than one frame before or after the expected time.

Overall, we obtained acceptable results in all stimulus timing tests for all the setups tested. The low-end setup ID 1 had, as expected, the worst performance in most of the tests. The high-end setup ID 5 outperformed in all stimulus timing tests. Mid-range setup ID 3 was almost on par with the low-end setup ID 1. Setup ID 3 had two main differences with the other two mid-range setups: the graphics card and the Windows version (8.1). From the current results, it is not possible to know how much each of the two factors affected the stimulus display performance.

If you want to guarantee good timing performance of your setup you should test your particular system configuration as any individual system component or software configuration may affect the timing performance to an unknow extent.

4.1.2 Stimulus-onset timestamp accuracy

This measurement gives information about Pro Lab’s timing accuracy in estimating onset time as closely in time as the moment the stimuli are displayed on the monitor.

<table>
<thead>
<tr>
<th>Computer category</th>
<th>Setup ID</th>
<th>Mean (ms)</th>
<th>Median (ms)</th>
<th>Standard deviation (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-end system configuration</td>
<td>1</td>
<td>1.034</td>
<td>0.515</td>
<td>2.133</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.508</td>
<td>0.489</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.350</td>
<td>0.579</td>
<td>3.489</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.483</td>
<td>0.470</td>
<td>0.108</td>
</tr>
<tr>
<td>Mid-range system configuration</td>
<td>5</td>
<td>0.278</td>
<td>0.086</td>
<td>0.261</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>-0.519</td>
<td>-0.529</td>
<td>0.103</td>
</tr>
</tbody>
</table>

Table 6. Mean, median and standard deviation of the timestamp accuracy of the estimated stimulus-onset time in Pro Lab for each test setup. All values are in millisecond.
Detailed test results:

Figure 13. Stimulus-onset timestamp accuracy test results of Setup 1 – Low-end system configuration (Windows 7). The histogram shows the time distribution and number of stimuli (occurrences) per time interval.

Figure 14. Stimulus-onset timestamp accuracy histogram of Setup 4 – Mid-range system configuration (Windows 10). The histogram shows the time distribution and number of stimuli (occurrences) per time interval.

Figure 15. Stimulus-onset timestamp accuracy test results of Setup 5 – High-end system configuration (Windows 10). The histogram shows the time distribution and number of stimuli (occurrences) per time interval.
4.1.3 Stimulus duration accuracy

This measurement gives information about Pro Lab’s timing accuracy in presenting stimuli for the duration expected.

<table>
<thead>
<tr>
<th>Computer category</th>
<th>Setup ID</th>
<th>&lt; -2</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>&gt; 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-end system configuration</td>
<td>1</td>
<td>0%</td>
<td>0%</td>
<td>1.2%</td>
<td>84.2%</td>
<td>14.6%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>94.2%</td>
<td>5.8%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0%</td>
<td>0%</td>
<td>4.4%</td>
<td>84.2%</td>
<td>10.8%</td>
<td>0.6%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0%</td>
<td>0%</td>
<td>0.6%</td>
<td>94.8%</td>
<td>4.6%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0%</td>
<td>0%</td>
<td>0.6%</td>
<td>94.8%</td>
<td>4.6%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0%</td>
<td>0%</td>
<td>0.6%</td>
<td>93.4%</td>
<td>6%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 7. Number of monitor refresh cycle difference from expected duration for each test setup. The results show the percentage of total number of stimuli.

4.1.4 Video frame duration accuracy

This measurement gives information about Pro Lab’s time drift when presenting video stimuli.

<table>
<thead>
<tr>
<th>Computer category</th>
<th>Setup ID</th>
<th>&lt; -2</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>&gt; 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-end system configuration</td>
<td>1</td>
<td>0.17%</td>
<td>0.44%</td>
<td>4.98%</td>
<td>88.97%</td>
<td>4.69%</td>
<td>0.60%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Mid-range system configuration</td>
<td>3</td>
<td>0%</td>
<td>0%</td>
<td>0.8%</td>
<td>98.48%</td>
<td>0.72%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>High-end system configuration</td>
<td>5</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.02%</td>
<td>0.48%</td>
<td>2.07%</td>
<td>94.8%</td>
<td>2.05%</td>
<td>0.35%</td>
<td>0.23%</td>
</tr>
</tbody>
</table>

Table 8. Number of monitor refresh cycles difference from estimated frame duration for each test setup. The results show the percentage of total number of frames.

4.2. Stimulus-onset marker timing tests

4.2.1 Summary of results

The results show that Pro Lab timestamped the stimulus-onset markers with high accuracy. Specifically, Pro Lab timestamped the stimulus-onset markers closely in time to the estimated stimulus onset timestamp (M = 0.0125ms; SD = 0.0687ms) and also closely in time to the measured TTL event Pro Lab timestamped the stimulus-onset markers (M = 0.0484ms; SD = 0.0480ms).

4.2.2 Stimulus-onset marker accuracy in sending markers

This measurement gives information about Pro Lab’s timing accuracy in timestamping stimulus-onset markers in Pro Lab. Specifically, how closely in time to the estimated stimulus-onset time Pro Lab timestamps the stimulus-onset marker.

<table>
<thead>
<tr>
<th>Computer category</th>
<th>Setup ID</th>
<th>Mean (ms)</th>
<th>Median (ms)</th>
<th>Standard deviation (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-end system configuration</td>
<td>5</td>
<td>0.0125</td>
<td>0.0050</td>
<td>0.0687</td>
</tr>
</tbody>
</table>

Table 9. Mean, median and standard deviation of the accuracy of the stimulus-onset marker time in Pro Lab in relation with the estimated stimulus-onset time for each test setup. All values are in millisecond.
Detailed test results:

4.2.3 Stimulus-onset marker accuracy in timestamping markers

This measurement gives information about Pro Lab’s timing accuracy in timestamping stimulus-onset markers in Pro Lab. Specifically, how closely in time to the same event received in the eye tracker Pro Lab timestamps the stimulus-onset marker.

<table>
<thead>
<tr>
<th>Computer category</th>
<th>Setup ID</th>
<th>Mean (ms)</th>
<th>Median (ms)</th>
<th>Standard deviation (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-end system configuration</td>
<td>5</td>
<td>0.0484</td>
<td>0.0480</td>
<td>0.0086</td>
</tr>
</tbody>
</table>

*Table 10. Mean, median and standard deviation of the timestamp accuracy of the estimated stimulus-onset marker in Pro Lab in relation with the shared event timestamp for each test setup. All values are in milliseconds.*

Detailed test results:

*Figure 16. Stimulus-onset marker accuracy 1 test results of Setup 5 – High-end system configuration (Windows 10). The histogram shows the time distribution and number of stimulus-onset markers (occurrences) per time interval.

*Figure 17. Stimulus-onset marker accuracy 2 test results of Setup 5 – High-end system configuration (Windows 10). The histogram shows the time distribution and number of stimulus-onset markers (occurrences) per time interval.*
Appendix A. Setup recommendations

Setup checklist to maximize the timing performance of your setup

The following list with setup recommendations ensures that Pro Lab will achieve the best timing performance possible in your setup. The recommendations are divided into the sections: computer setup, monitor setup, stimulus design, and eye tracker and Pro Lab. Read it thoroughly and follow the recommendations if your eye tracking experiment needs high timing accuracy in the stimulus display process.

Computer setup

- **Use recommended components**
  Choose appropriate hardware components according to your timing requirements. Specially, we recommend using a graphics card with a dedicated processor. For an overview of the different system configurations used to test Pro Lab stimulus-onset timing read section 3.3.1 and Table 3. For a more detailed list of recommended components read Tobii System Recommendations for Tobii Pro Lab that you will find online at www.tobiipro.com.

- **Keep computer processes to a minimum**
  The computer running Tobii Pro Lab should have the least number of processes running in the background. This means that you should disable or uninstall any unnecessary programs that might be running in the background (Anti-virus software, Firewall software, Anti-Spyware software, Skype or other chat/communication programs). It may also help to disable or disconnect Bluetooth, WLAN/Wifi and network connectors and to unload CD or DVD disk drives. Ideally, use the computer only to run Tobii Pro Lab tests and analysis.

- **Keep drivers up to date**
  Make sure that your computer drivers are up to date, especially the graphics card driver and the parallel port driver. You can do so by visiting the manufacturer’s website and checking for the latest update. Please note: It is not a good practice to rely only on Windows Update service to get updates on your drivers.

- **Check your graphics card settings**
  If available, set the vertical sync of your graphics card to be controlled by applications. Check if this option is available in your graphics card settings under any name such as vertical sync, vertical retrace, synchronize buffer swaps, etc.

Monitor setup

- **Use native screen resolution**
  We recommend that you use the native screen resolution and that you create your stimuli in that size. Running your study at other resolution other than native increases the time needed for clearing the buffer, drawing your stimulus and for post-processing operations.

- **Multi-screen setups**
  We recommend using multi-screen setups only in extended mode and with the “primary monitor” set to the stimulus presentation monitor. Otherwise, there is a risk that the timing functioning and estimation will be inaccurate. Dual or duplicated-monitor setups are not recommended if you need accurate stimulus display timing.
Find out the pixel response time of your monitor
To increase the accuracy of the stimulus-onset events in Tobii Pro Lab, you can include the pixel response time of your monitor in the Pro Lab recording settings (see section 2.5.1). This characteristic can be usually found in the monitor specification sheet.

Use DVI, HDMI or Display Port connectors
Whenever possible, use digital connectors between your computer and your monitor with no connector converters. This will reduce the probabilities of bad communication between the graphics card and the monitor, i.e., correct synchronization with the VSYNC signal of the monitor. Unless necessary, avoid using VGA connectors, especially if you have precise timing requirements. Also, our timing tests suggest that Display Port connector gives more precise timing than DVI connectors.

If precise stimulus onset and duration is important, use a monitor with a higher refresh rate
In time-sensitive experiments you can benefit from having a monitor with a higher refresh rate. If you replace a 60 Hz monitor with a 240 Hz monitor, the stimulus duration resolution (frame duration) will be 4.17 ms (1/240Hz), instead of 16.67ms (1/60Hz). For most eye tracking applications that involve global measuring of visual attention and area of interest (AOI) visit duration related metrics, a 60Hz refresh rate monitor is sufficient. A high refresh-rate monitor is of great importance in specialized experiments which involve for example, the measurement of saccade latencies, and especially in gaze-contingent paradigms with saccade dependent stimulus image manipulation.

Stimulus design

Use the recommended image and video format as stimuli
The recommended image stimulus format in Pro Lab is jpeg. The recommended video stimulus format in Pro Lab is H.264. We recommend that the resolution for both types of stimuli be same as the monitor resolution.

Stimulus duration preceding a video stimulus
When the next stimulus in a presentation sequence is a video, Pro Lab will spend some time (order of milliseconds) preparing the video before the video onset. This will not affect the video stimulus-onset estimation but it will likely affect the duration of the preceding stimulus, making it longer than the expected duration. Therefore, we recommend not showing time-sensitive stimulus before a video. A good practice is to show an extra black image stimulus for a short time before the video stimulus.

If precise picture stimulus duration is important, think in frames
If you really need to have precise duration of your picture stimuli, you will have better control by designing the duration of your stimuli using the following duration calculation: Use the refresh rate of your monitor to calculate the real duration of your picture (e.g., with a 60Hz monitor, possible times are multiple of 16.67ms). Take this value, subtract about 2/3 of a refresh cycle and introduce the result as the stimulus duration in Pro Lab. If this procedure is followed, it is highly likely that your stimulus will be displayed the correct number of frames that was designed for.
Eye tracking components

- **If precise stimulus onset is needed, avoid using x2-30 and X3-120 without EPU**
  If you need to have precise stimulus onset timing, the X2-30 eye tracker or the X3-120 eye tracker without EPU are not recommended. This is because these eye trackers' computational work takes place in Pro Lab's computer and that could affect the performance of the computer. These eye trackers can be used if millisecond accuracy stimuli onset and duration are not needed, e.g., recording of gaze position in larger timescales, such as AOI visit duration.

- **If you use a gaze-contingent paradigm, bear in mind the total system latency**
  You can use a Tobii Pro eye tracker together with the Tobii Pro SDK to create your custom gaze-contingent paradigms in several stimulus presentation software applications such as Psychtoolbox or Psychopy. In some gaze-contingent paradigms, it is important to take into account not only the latency introduced by the stimulus display process, but also the eye tracker latency. This is the time interval between the moment the eye tracker takes the picture of the eye (eye tracker timestamp) until the gaze information is available at the computer and you can use it to update the stimulus information. This is known as total latency and is mainly influenced by the eye tracker sampling rate and eye tracker gaze computing time. Total latency is of significant importance in gaze-contingent paradigms such as the moving-window, where the stimulus needs to be updated during saccades. To get information about the specific latency of your Tobii Pro eye tracker, go to the corresponding product description. For example, the Tobii Pro Spectrum eye tracker has a latency of less than 5ms at 600Hz.

- **If precise stimulus onset is needed, don’t use the moderator tool for live viewing in Pro Lab**
  The live view option of the moderator tool in Pro Lab allows the experimenter to view the live gaze of the participant overlaid on the stimulus on a second screen. While this is an important feature for some eye tracking research, e.g., local live viewing for real-time insight and preparing post interviews, it is not essential in most experiments and can affect Pro Lab stimulus display performance. By default, the live view of the moderator tool is disabled. We recommend that you do not enable the live view option in time-sensitive experiments.

**Last but not least… Test your timing!**

- **If you are performing experiments that require high timing accuracy, we strongly recommend testing the system latency with the stimuli you will be presenting**
  It is important to use the same computer, monitor and monitor connector when measuring the system latency as for all the recordings of the experiment. You can find information about how to run a timing test with a TX300 or Spectrum eye tracker Appendix B.
Appendix B. How to measure your stimulus display delay with a TX300 or Spectrum and a light sensor

The aim of this appendix is to provide a brief description of a setup that can be used to test onset timing offsets in Pro Lab related to stimulus display. This setup will allow you to measure the time interval from the time Pro Lab timestamps the stimulus onset (expected stimulus onset), to the time that the stimulus is actually displayed on the monitor (true stimulus onset). The constant delay measured with this setup can be input into Pro Lab’s monitor delay settings to automatically correct stimulus onset events (e.g. ImageStimulusStart, ImageStimulusEnd) as well as stimulus-onset marker events to other devices.

Note that this timing test can only be run with a Tobii Pro TX300 or Spectrum eye tracker. These eye trackers have a TTL input port, which is a requirement for the setup presented. If you wish to test your system delay using a different eye tracker, please refer to Appendix I of the Timing guide for Tobii Eye trackers and eye tracking software, published in 2010, which can be found at www.tobiipro.com.

A.1. Equipment needed

- Tobii Pro Spectrum or Tobii Pro TX300.
- Pro Lab experiment setup under test, including computer and monitor.
- Light sensor measurement device. The recommended measurement device is StimTracker by Cedrus®, but any light sensor measurement device with similar time performance characteristics to StimTracker and an appropriate connection to the Tobii Pro Spectrum or TX300 eye tracker can be used.
- Microsoft Excel or similar numeric software package.

Figure 18. Summary of the setup needed to conduct the timing test.
A.2. Procedure

1. **Stimuli:** Create the stimuli that will be tested and design the experiment sequence in Pro Lab. The stimuli sequence must contain images (or videos) that alternate black and white color squares (see Figure 19). We recommend that the alternating sequence is presented a minimum 20 times to detect if the setup creates any jitter (i.e., not constant delay).

   For a generic timing test performance, it is sufficient to use a black and white image sequence alternating every 1000ms. If you need to obtain a precise time offset for a specific experiment, we recommend using the same stimuli as will be used during the experiment and overlap a white or black square on the most important vertical position of the stimuli (e.g., center of the image).

2. **Light sensor:** Position the light sensor on top of the monitor facing the location where the black and white square will appear (or any preferred position if the stimuli sequence contains black and white images). Connect the light sensor TTL output to the eye tracker TTL input port. Perform any sensitivity adjustments needed if required by the light sensor manufacturer.

3. **Recording:** Start the recording in Pro Lab. We recommend that the test is carried out as a regular eye tracking experiment, i.e., a person is seated in front of the eye tracker, calibrated and the eye movements are recorded during the stimuli presentation.

4. **Data export:** Export the full eye tracking recording from Pro Lab in the Data Export module. Select the corresponding recording in the Recordings setting and Recording gaze data (Entire Recording) in the Time of Interest setting. Select only the following columns to be exported: Recording Timestamp, Event, and Event value.

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*Figure 19. Examples of stimuli sequence to test timing in Pro Lab. First row shows the simplest setup to test generic timing performance of your setup. Second row shows an example of a specific timing test using the experiment stimuli and overlapping a white or black square on the location of interest.*
5. **Latency analysis:**

   a. Open the data export file in a numerical computing software (e.g., Excel) and find the corresponding timestamps of both the stimulus-onset events (ImageStimulusStart) and the TTL events (Eye tracker TTL in) under the column `Event`.

   b. Use only the stimuli corresponding to the white square of background to calculate the latency so that the light sensor sensitivity does not influence the results. The image on the right shows an example of how the data export looks like in Excel after selecting the right type of events.

   c. To calculate the latency of each stimulus: subtract the timestamp—under the column `Recording timestamp`—of each TTL event to the timestamp of the corresponding (preceding) stimulus-onset event—under the same column—. Find a suggestion below of how to format the data in Excel to calculate the latency of each stimulus. This data structure format is quite easily accomplished using the *Filter* options in Excel.

   d. Calculate the mean latency and standard deviation and make sure that your setup mainly consists of constant latency.
6. **Insert your setup's constant latency in Pro Lab's setting**: Go to the *Record* module in Pro Lab and include in the *Target Screen* setting the total constant latency obtained in your test in milliseconds. All the stimulus-onset events estimated by Pro Lab will add the constant latency introduced.