Journal of Neuroscience Methods 187 (2010) 235–242

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

Multiple serial picture presentation with millisecond resolution using a three-way LC-shutter-tachistoscope

Florian Ph.S. Fischmeister[a,b,c,*], Ulrich Leodolter[c], Christian Windischberger[a,b], Christian H. Kasess[a,b], Veronika Schöpf[a,b], Ewald Moser[a,b], Herbert Bauer[c]

[a] *MR Centre of Excellence, Medical University of Vienna, Lazarettgasse 14, A-1090 Vienna, Austria*
[b] *Centre for Biomedical Engineering and Physics, Medical University of Vienna, Währingerstr. 13, A-1090 Vienna, Austria*
[c] *Department of Clinical Psychology, Biological Psychology and Differential Psychology, Faculty of Psychology, University of Vienna, Liebiggasse 5, A- 1010 Vienna, Austria*

ARTICLE INFO

Article history:
Received 14 August 2009
Received in revised form 12 January 2010
Accepted 14 January 2010

Keywords:
Humans
Tachistoscope
Visual perception
Subliminal stimulation
Time factors
Magnetic resonance imaging
Reproducibility of results

ABSTRACT

Throughout recent years there has been an increasing interest in studying unconscious visual processes. Such conditions of unawareness are typically achieved by either a sufficient reduction of the stimulus presentation time or visual masking. However, there are growing concerns about the reliability of the presentation devices used. As all these devices show great variability in presentation parameters, the processing of visual stimuli becomes dependent on the display-device, e.g. minimal changes in the physical stimulus properties may have an enormous impact on stimulus processing by the sensory system and on the actual experience of the stimulus.

Here we present a custom-built three-way LC-shutter-tachistoscope which allows experimental setups with both, precise and reliable stimulus delivery, and millisecond resolution. This tachistoscope consists of three LCD-projectors equipped with zoom lenses to enable stimulus presentation via a built-in mirror-system onto a back projection screen from an adjacent room. Two high-speed liquid crystal shutters are mounted serially in front of each projector to control the stimulus duration. To verify the intended properties empirically, different sequences of presentation times were performed while changes in optical power were measured using a photoreceiver.

The obtained results demonstrate that interfering variabilities in stimulus parameters and stimulus rendering are markedly reduced. Together with the possibility to collect external signals and to send trigger-signals to other devices, this tachistoscope represents a highly flexible and easy to set up research tool not only for the study of unconscious processing in the brain but for vision research in general.

1. Introduction

While the study of implicit (unconscious) visual perception has a century-long and controversial history (for a review see Kouider and Dehaene, 2007), interest in neuroimaging studies of perception without awareness has started only recently. Neuronal processes associated with implicit perception are generally inferred from contrasts between conditions of unawareness and conscious perception. Central for most studies in this area is the idea that a reduction of conscious awareness, achieved either by reduced stimulus presentation time or visual masking (Enns and Di Lollo, 2000; Kim and Blake, 2005), goes along with less conscious stimulus processing. Stimulus design and stimulus presentation, therefore, represent the most crucial part of an experiment, and great care needs to be taken to ensure stimulus presentation quality, in particular stimulus duration.

In a typical experiment, stimuli are presented using either a cathode-ray tube (CRT), a liquid crystal display (LCD), or a thin-film transistor (TFT) monitor or projector. The actual processing of visual stimuli, however, critically depends on the display-device employed. CRT monitors, for example, permit excellent timing due to CRT-internal refresh rates, but stimuli are reproduced with low reliability in space, luminance, and colour (Krantz, 2000). On the other side, LCD/TFT monitors or projectors present images in steady state, thus representing a more valid method for stimulus delivery. However, neither picture onset nor duration can be controlled exactly with these devices.

In general, all standard presentation devices show great variability in stimulus latency, onset, luminance, and duration across trials. This variability is even increased when pictures are presented very briefly (Wiens et al., 2004). At first sight, such variability in stimulus parameters seem to pose no problem, since individual conditions

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[*] Corresponding author at: MR Centre of Excellence, Medical University of Vienna, Lazarettgasse 14, A-1090 Vienna, Austria. Tel.: +43 1 40400 1795; fax: +43 1 40400 7631.
E-mail address: florian.fischmeister@meduniwien.ac.at (F.Ph.S. Fischmeister).

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doi:10.1016/j.jneumeth.2010.01.016

are repeated several times and thus variability in stimulus parameters is often thought to simply "average out". Yet, research suggests that minimal changes in the physical stimulus properties may have an enormous impact on stimulus processing by the sensory system and therefore on the actual experience of the stimulus (Esteves and Öhman, 1993). Additionally, presentation parameters become dependent on each other with brief presentation times, e.g. manipulation of stimulus duration also affects overall luminance (Wiens et al., 2004). Thus, experimental results are confounded by duration as well as overall luminance changes and, therefore, conditions involving unequal stimulus durations (i.e. different levels of awareness) cannot be compared directly. Furthermore, efforts to establish and assess objective thresholds for awareness for single subjects are impaired since such approaches (e.g. signal detection methods) require multiple trials with constant and reliable presentation parameter to show that observers actually perform no better than chance (Hannula et al., 2005). Finally, unwanted variability in stimulus parameters induces "noise" in the data, leading to an increased type II error and, therefore, subtle differences across conditions may not be detected.

Clearly, these are crucial theoretical and methodical issues that have to be considered (Erdelyi, 2004; Hannula et al., 2005; Wiens and Öhman, 2007; Kouider and Dehaene, 2007) when investigating implicit (unconscious) visual perception involving very brief stimuli (e.g., below a supposed threshold of awareness). However, the afore mentioned issues not just apply to tachistoscopic presented stimuli, but to all experiments where stimulus presentation is repeated with the necessity of identical physical parameters, e.g. rapid serial visual presentation protocols (RSVP). Therefore, novel techniques are required to achieve well-defined and controlled stimulus delivery to overcome these shortcomings.

Several technical approaches have been proposed in the literature, however, exact parameters for the stimulus delivery are either not available or hard to verify. Some devices also fall short in one dimension (e.g. control of luminance), or lack flexibility in stimulus parameter ranges (e.g. with CRT monitors only in multiples of their refresh-rate, like 16 ms, 32 ms, etc.). Compatibility with the MR-environment is another critical issue, as some presentation systems are optimised for CRT monitors (MacInnes and Taylor, 2001; Tsai, 2001; Fiesta and Eagleman, 2008) which however cannot be used in functional MRI studies because they interfere with the imaging process.

Here we present an approach for visual stimulus delivery that is aimed at surmounting these shortcomings, e.g. that allows well-defined stimulus timing in the millisecond range, homogeneous stimulus brightness, and high stimulus reproducibility. The device is based on three separate LCD-projectors equipped with shutters that are combined to form a so-called tachistoscope, first described by Volkmann in 1859. This first tachistoscope consisted of a movable metal plate with an opening that corresponded to the size of an image placed on a table. This metal plate was fixated by a handle and attached to a weight hanging over the edge of the table. By releasing this handle, the plate quickly moved over the table pulled along by the weight and the previously hidden image under the plate became briefly visible to an observer standing in front of the table. Since then various solutions were proposed, e.g. so-called gravity chronometers allowing for a much tighter control of the stimulus presentation duration (for a review see Benschop, 1998). Modern devices consist of two slide projectors with mechanical shutters attached to their lenses (Esteves and Öhman, 1993). However, careful analysis of available tachistoscopes (Mollon and Polden, 1978) and recent measurements by Wiens et al. (2004) showed that most devices offered poorer presentation parameters than assumed or claimed by the manufacturer.

In order to use the tachistoscope for our current experiments it was necessary to develop a three-way LC-shutter-tachistoscope with a dedicated programming language to adequately control stimulus generation and shutter switching sequences. These experiments involve the rapid presentation of images below the subjects' individual visual threshold, e.g. below 10 ms. Such designs cannot be accomplished with only two LCD-projectors since the refresh-rate of the projector (72 Hz in our case) is too long to guaranteed steady-state image production, i.e. the presentation duration of one image is shorter than the time needed to update the image of the other, not presenting projector. However, for most other experiments in the domain of vision research two or even one projector might be sufficient. Thus, we will also show how such a tachistoscope can be set up by providing the connection scheme and driving methodology for a single projector system. Since the LC-shutter-tachistoscope follows a modular concept, this logic can be used to set up any system, based on one's own needs.

The performance of the tachistoscope with a particular focus on stimulus reproducibility was assessed using a photodiode setup according the recent recommendation by Wiens and Öhman (2005).

2. Methods and materials

2.1. Apparatus

The device described herein consists of three components: (1) the projection-unit, (2) a shutter-control-device (SCD), and (3) a control PC.

The projection-unit (developed and assembled by K. Zickler G.m.b.H., Paffstätten, Austria) consists of three EMP-7900 LCD-projectors (Epson America, Inc., Long Beach, CA, USA) mounted on top of each other in horizontal position. Each projector is equipped with a long-focus NuView 606 MCZ087 zoom lens (Navitar Presentation Products, Rochester, NY, USA) allowing for distances of several meters between the tachistoscope and the small-sized projection screen, as required for fMRI-applications when presenting from an adjacent room.

Single projector light paths are collected and joined to a single light-output via a mirror-system to enable stimulus presentation through a single waveguide when used in a fMRI environment (Fig. 1). As an additional benefit this setup avoids trapezoidal distortions which would occur with direct single projector light paths due to different projection angles. The mirror-system consists of four achromatic mirrors (Prinz Optics G.m.b.H., Stromberg, Germany) that are adjustable in angle. The bottom and top mirror are "simple" mirrors, while the two mirrors in between have semireflecting properties, splitting the light beam at a translucence/reflection ratio of 0.5 : 0.5 and 0.7 : 0.3, respectively. While the specific features of the mirrors used already ensure similar luminance from all three light paths, brightness can additionally be adjusted individually for each path via the projector-control device.

The actual presentation timing is accomplished by FOS-25x30-PSCT high-speed liquid crystal optical-shutters (LC-Tec Displays AB, Borlänge, Sweden) with an active display area of 21 mm×21 mm. LC-shutters were favoured since they combine high transmittance (according to the manufacturer $T > 86\%$ in transparent state) together with fast switching speeds without any noise. Furthermore, they provide more natural viewing conditions than mechanical shutters, e.g. transitions from light-scattering to transparent mode and vice versa occur homogeneously across the whole picture, which avoids unwanted pinhole-effects as well as opening or closing bounces. Two such shutters are serially mounted in front of each lens to ensure complete blackout when in light-scattering state (Fig. 1). Pilot test with only one shutter per lens showed residual light-transmittance of about 2% during dynamic switching, which did not lead to non-zero visibility of presented stimuli when shutters were closed.