**Real-Life Continuous Flash Suppression - Rendering The Real World
Unconscious Using Augmented Reality Goggles**

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Abstract

Continuous Flash Suppression (CFS) is a popular method for suppressing visual stimuli from awareness for relatively long periods. Thus far, it has only been used for suppressing two-dimensional images presented on-screen. We present a novel variant of CFS, termed ‘real-life CFS’, with which the actual immediate surroundings of an observer – including three-dimensional, real life objects – can be rendered unconscious. Real-life CFS uses augmented reality goggles to present subjects with CFS masks to their dominant eye, leaving their non-dominant eye exposed to the real world. In three experiments we demonstrate that real objects can indeed be suppressed from awareness using real-life CFS, and that duration suppression is comparable that obtained using the classic, on-screen CFS. We further provide an example for an experimental code, which can be modified for future studies using ‘real-life CFS’. This opens the gate for new questions in the study of consciousness and its functions.

Introduction

In the last decades, the field of consciousness studies has experienced a substantial growth and development (Koch, Massimini, Boly, & Tononi, 2016; Kouider & Dehaene, 2007; Lau, 2017). Once considered to be a question outside the scope of scientific investigation, the neural correlates and possible functions of conscious awareness are now widely studied. Accordingly, a myriad of new, elegant techniques to suppress stimuli have emerged (Kim & Blake, 2005; Lin & He, 2009; for review and comparison, see the special issue by Dubois & Faivre, 2014), all leading to subjects' inability to report seeing a stimulus that was presented to them.

One of the most popular methods for rendering stimuli invisible is Continuous Flash Suppression (CFS; Tsuchiya & Koch, 2005), which is a variant of Binocular Rivalry (BR; e.g., Blake & Logothetis, 2002). In CFS, a dynamic pattern of shapes (often referred to as "Mondrians") is presented to the subject's dominant eye, usually alternating at a rate of around 10Hz. At the same time, a target stimulus is displayed to the non-dominant eye. As a result, the target stimulus is suppressed from awareness and subjects perceive only the dynamic pattern of shapes for relatively long durations, that can sometimes last for as long as tens of seconds (see again Tsuchiya & Koch, 2005).

CFS has been widely utilized to study unconscious processing of information; since it was introduced to the field, it was used in more than 250 studies, probing different types of unconscious processing (for reviews, see Yang, Brascamp, Kang, & Blake, 2014; Gayet, Van Der Stigchel, & Paffen, 2014). The mechanisms of CFS are still unclear; for example, it is not yet known whether the suppression achieved with this method is driven by low-level processes controlling the gain of visual information arriving from each eye, or by higher-level processes (Yuval-Greenberg & Heeger, 2013; Watanabe et al., 2011). Similarly, it is still debated if it differentially activates the ventral and dorsal streams (Fang & He, 2005;

Almeida, Mahon, & Caramazza, 2010; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Rothkirch & Hesselmann, 2018). Perhaps not surprisingly then, the results obtained with CFS are also somewhat conflicted: some studies claim that CFS abolishes some well-known psychophysical phenomena (e.g. Harris, Schwarzkopf, Song, Bahrami, & Rees, 2011; Laycock, Sherman, Sperandio, & Chouinard, 2017). Others reported high-level semantic processing of suppressed stimuli (e.g., Costello, Jiang, Baartman, McGlennen, & He, 2009; Sklar et al., 2012; but see, among others, Shanks, 2017; Moors, Hesselmann, Wagemans, & van Ee, 2017). Thus, the literature seems to be divided about the scope of unconscious processing of information under CFS. Notwithstanding these controversies, the methodology itself has proved to be highly fruitful in consciousness studies, and opened the gate to new lines of research and new types of questions which necessitate longer-duration stimuli (e.g., studying temporal integration; Faivre & Koch, 2014; or causality; Moors, Wagemans, & de-Wit, 2017) .

Thus far, all previous studies used CFS to suppress two dimensional stimuli, presented on screen (an exception is one study, which used Virtual Reality to present a CFS display and suppress virtual objects; Van Der Hoort, Reingardt, & Henrik Ehrsson, 2017). In this paper we present a novel variant of the classic CFS method, called real-life CFS, which allows suppression of real, three dimensional objects from awareness for periods of time comparable to those of classic CFS. Below we describe the details of this method, and present two experiments in which it was used,¹ as well as an additional experiment conducted using traditional CFS in order to compare suppression between the novel variant we developed and the traditional one.

¹ Though originally we conducted Experiment 2 prior to Experiment 1 (since Experiment 2 was a part of a larger-scale study which we will report elsewhere), we present them here in a reversed order to facilitate their understanding.

Suppressing real objects using real-life CFS - General Description

Our method suppresses real objects from awareness by presenting Mondrians to the dominant eye using Augmented Reality (AR) glasses, while the non-dominant eye is exposed to the real world. As in traditional CFS, when the Mondrians are presented to a region of the visual field in the dominant eye, the subject is temporarily incapable of consciously perceiving the respective region of the visual field in the contralateral eye, even though it is presented without any obstruction. Control of the graphics shown on the AR glasses is done by a computer, via a wireless connection. To display the graphics on the AR glasses in the same binocular disparity as the point in space at which the subject is looking, a short calibration procedure precedes the experimental session.

In the following paragraphs, we describe in general how the paradigm is implemented (for exemplary codes for the experiments - including the calibration and the experimental sessions, see SI), and how it should be used in future studies. Then, we describe specific methods used in each of the experiments included in this paper, mainly focusing on the production and presentation of the relevant real-world stimuli.

The Setup

Par: the glasses we use, how the CFS paradigm is converted to be displayed on them

Our method is applicable to any type of glasses which can display graphics in varying levels of transparency. We use augmented reality glasses produced by Epson (Moverio BT200) to present the subject with the graphics that suppress conscious visual perception of the real world. The graphics to be displayed on the glasses are produced by a computer with MATLAB (MathWorks, 2017) and the Psychtoolbox add-

on (Brainard, 1997), though other software packages could also be used. Graphics are presented on a “virtual monitor” (“ghost monitor”), by extending the windows desktop to an unconnected VGA output, and using this monitor as Psychtoolbox’s target screen. This virtual screen is transmitted to the glasses online using a wireless LAN connection and the MirrorOp pc-software and Android application (Awind, inc.), which effectively mirrors what is displayed on the virtual screen to the AR glasses’ display. The AR glasses are set to “3D” mode, which splits their display such that the left eye sees only the left half of the virtual screen, and the right eye sees the right half. This way, the regions of the screen that are visible to each eye are easily distinguished while programming the experiment. Notably, since the display on the AR glasses mirrors the computer display via WiFi, there is a delay between the displays. To bring this delay to a minimum, we set the quality preferences using the MirrorOp software to be as low as possible. We estimate this delay to be in the magnitude of 400 ms, with some variability in timings (for details, see SI). Thus, we recommend that future studies take that into account when designing their experiment, as we have done (see specific methods below).

Stimuli

In our experiments, the suppression stimuli are presented on the glasses. They include a fusion frame (About 9.5x6.4 DVA, see “calibration” below), a fixation cross, and the Mondrians. The latter are circles ranging in radii between 0.21 and 0.84 visual DVA, in 6 different colors. All Mondrian colors are of 100% value and saturation in the HSV scale, differing only in their hue, to ensure that all Mondrians are presented with highest possible opaqueness. Notably, since the virtual screen is presented to both eyes, half screen to each eye, the display is “stretched” in width. Therefore, the circle Mondrians appear to the subjects as more elliptic, and vertical lines appear somewhat thicker.

Paradigm

Calibration

After the subject puts on the AR glasses, a calibration procedure is needed to calculate the correct binocular disparity in which the on-glasses graphics should be presented. In real-life CFS, it is crucial that the subject's binocular disparity matches the location of the real-life stimuli that are about to be suppressed by the CFS stimulation. To reach such a match, a black fixation printed on a white placard is placed at the location of the to-be-presented real-life stimuli. On the glasses, one green fixation is presented to each eye. Using the mouse, the subject can control the distance between the two on-glasses fixations, while keeping her gaze fixated on the real-world fixation. The subject is asked to change the distance between the on-glasses fixations and, if needed, rotate her head, to reach convergence of all the fixation crosses - both the on-glasses ones and the real one. Once convergence is achieved, the subject reports it by clicking the mouse button. The final position, in screen coordinates, of the on-glasses crosses is used as the center of the fusion frame. The width of the fusion frame is then set accordingly, setting the frame's nasal edge along the middle of the virtual screen, and its temporal edge on the other side of the fixation cross and at the same distance as between the nasal edge and the fixation (Fig. 1).

Figure 1. Illustration of the fusion frames following the calibration procedure as they are presented on the virtual screen. When displayed on the goggles, this screen is divided so that each eye is presented with half of it. Red crosses serve as fixation crosses, red and green frames facilitate fusion. Note that since the fixation is located exactly in the middle of the fusion frame, the fixation-to-nasal and fixation-to-temporal distances are equal.

Trial

Before trial onset, a real-world stimulus is positioned in front of the subject, but is hidden from the subject's sight (see description of our device used for real-world stimuli presentation in **Exp. 1**; different devices can of course be used according to the experimenter's needs). At the beginning of each trial, white background fills the fusion frames presented to both eyes for two seconds. With the Epson goggles we used, this means that the goggles turn completely opaque, and no vision of the outside world is possible within these frames. Mondrians are then flashed continuously at 10Hz to the dominant eye, while the non-dominant eye still sees the white background for one second. During this second, a window opens in our device, exposing the real-life stimulus. Notably however, the subject is still not exposed to the stimulus due to the 100% opaqueness of the white background. Then, the white background presented to the non-dominant eye fades gradually to full transparency, over a period of one second. This fading mimics the "ramping up" of the target stimulus' contrast in classical on-screen CFS paradigms. Once the non-dominant eye's frame background is at full transparency, this eye is completely exposed to the real-world stimulus. Critically however, due to the flashing Mondrians presented to the dominant eye, the stimulus is suppressed from awareness. Depending on the research question and experimental requirements, the subject may then be asked to perform any sort of task relating to the suppressed stimulus: report its properties in a direct or indirect manner (Reingold & Merikle, 1988), report when it is consciously perceived (e.g. for bCFS paradigms; Gayet et al., 2014), and even interact with it. Post-trial subjective awareness may also be measured using a PAS (Ramsøy & Overgaard, 2004) presented on the glasses (see code in SI).

Experiment 1: validation of methodology & assessment of suppression effectivity

As suppression of real objects using real-life CFS was never done before, Experiment 1 was aimed at validating this methodology and make sure we could obtain effective suppression. We used real-life CFS to suppress both real objects and their 2D image representations, which were printed color photos of the objects. A dedicated device (henceforth “theater”, see Fig. 2 below) was constructed to display the physical (“real world”) stimuli to the subject in synchronization with the on-glasses display. Subjects were first asked to report if the physical stimulus (object/2D photo) was placed to the right or to the left of the center of the theater display box (objective measure), and then to rate their level of awareness of the stimulus (subjective measure). We generally expected that the real-life CFS paradigm will be potent enough to evoke a large amount of trials in which subjects report not seeing the stimulus at all. We hypothesized that subjects’ performance would be at chance in those trials, regardless of the type of physical stimulus used (actual object \ photograph). An additional, minor goal of this study was to compare suppression times of 3D and 2D stimuli, based on the results of Experiment 2 which will be described below (see footnote #1 above). We accordingly expected that subjects will more easily perceive real objects, thus marking trials with real object target stimuli as more visible than trials with 2D photographs. Notably, the hypotheses, analysis plan, sample size and methods were all pre-registered in the Open Science Framework website (<https://osf.io/pgjf5/>).

Methods

Subjects

20 right-handed subjects participated in the experiment (10 females, mean age=25.79, SD=3.75, see Open Science Framework pre-registration for power analysis). Nine additional subjects who participated were excluded from the analysis: two due to technical difficulties (lights in the device not working properly, AR goggles malfunction); one due to not completing the experiment; four who reported less than 40 trials as “invisible” in each representation level (first exclusion criterion in the OSF pre-registration); one who reported object location before the CFS display was removed (see methods below), while also reporting he has not seen it, suggesting lack of understanding of the instructions or lack of willingness to follow them (third exclusion criterion in the OSF preregistration), and one due to pressing the same key throughout the experiment. Here and in all following experiments, excluded subjects were removed before group level analysis. All subjects had normal or corrected-to-normal vision using contact lenses (optical glasses are uncomfortable to use with the AR glasses), and declared no past neurological, attentional, mental disorders, or current usage of psychiatric medicines. They participated in the experiment for credit or payment. Subjects signed a consent form and were explained that they can withdraw from the experiment at any point if they wish to do so. The experiment was approved by the university’s ethics committee.

Apparatus

The display theater device was devised so that the presented stimuli could be hidden from the subject between trials (Fig. 2). A computer was used to synchronize the opening of a blind installed in the theater device with the graphics presented on the glasses, such that the stimuli were exposed to the subject only while the CFS masks were displayed. A box containing a small stage was placed behind the blind, and the items were placed on the stage by an experimenter. The inside of the display box was lit by three sets of LED strips arranged along the inner side of the window, covered with parchment-paper to scatter their light

so as to minimize highlights on objects presented inside the box. The theatre device was placed 90cm away from subjects' head, which was stabilized using a chin-rest.

As explained above, the AR goggles were Epson (Moverio BT200), and the experimental code was run using MATLAB (MathWorks, 2017) and the Psychtoolbox add-on (Brainard, 1997). Reporting was done using a mouse.

Figure 2. A schematic description of the experimental setup. The subject is sitting in front of the device, wearing the goggles, her head rested on a chin rest. The device is composed of a wall hiding the experimenter, a display box which includes a window, and a retractable blind. LEDs are used to mark the window position.

Real world stimuli

The stimuli included eleven real-life, common and easy to recognize objects, all smaller than 15 cm in width and 10 cm in height. Two-dimensional photographic reproductions (henceforth, “cutouts”) of the objects were created by photographing the objects inside the display box using a Canon 700D camera, from the subject’s point of view (Figure 3). Each object was photographed both when positioned to the left and to the right of the box's center, mimicking its possible positions in the experiment. The photographs' colors and sizes were then digitally manipulated by a professional digital designer so that when printed, they will closely match those of the objects. Printing of the photographs was done on matte paper (Epson enhanced) to avoid further reflections. Positioning of the objects and cutouts inside the box was kept similar across trials by an array of pins attached to the box's stage, upon which the objects or cutouts could be placed accurately in position and orientation.

Figure 3. An example of a real-world stimulus in both representation levels: The real, actual object (left), and a cutout of a color photograph of the object (right). In Experiment 2, two more levels of representation were used, but are presented and analyzed in another manuscript.

Procedure

The experiment was composed of 176 trials, divided into four blocks, and an additional training block (up to ten trials). Each experimental block thus consisted of 44 trials, in which all eleven objects were presented

in all four experimental conditions: representation level (real object\color photo) X side of the box (left\right). Order of trials was set at the beginning of each block by a pseudo-randomization algorithm, with the constraint that representation level or box side were not to repeated in more than four consecutive trials. Between blocks, the subject could take a few minutes' break. Each block started with a calibration of the on-glasses display (see General Description above). Calibration was done with the inner LEDs of the theatre device set to maximal intensity (yielding a background luminance of 58.5 cd/m^2), such that the placard with the real-world fixation was seen at the best possible contrast.

Experimental blocks. To maximize CFS efficiency, the LEDs inside the theatre device were dimmed to the minimal possible luminance (background luminance of 2.75 cd/m^2), such that the contrast between the background and the stimuli was low. Before each trial, the experimenter closed the blind, and placed a stimulus on one side of the box. The blind which hides the stage and the stimulus opened 400ms after the command to start displaying the Mondrians was given by the computer, to account for the delay between the goggles and the computer (see above). During the trial, on-glasses graphics were presented as described in the “General Description” chapter, with the CFS stimulation presented for four seconds (including the first second in which the opacity of the non-dominant eye goggle was linearly decreased to 0%). Subjects were asked to report the location of the stimulus as soon as possible, using the right and left mouse keys. If subjects detected the stimulus prior to the 4s period, CFS stimulation stopped. On the offset of the CFS masking (either upon subjects' response or after 4s), the experimenter quickly pulled the blind upwards to hide the display box, and the on-glasses display's background turned white (100% opaque) to block any residual percept of the display box while it's being closed.

If the subject failed to report seeing the target stimulus until the CFS stimuli ended, the background of the on-glasses display remained white for 4.6 additional seconds, prompting the subject to guess its position. Finally, the subject was presented with a subjective rating question, using the Perceptual Awareness Scale (PAS: Ramsøy & Overgaard, 2004). The question was presented on the glasses as four circles drawn on a

white background, with a cursor controlled by the mouse, for the subject to select the most accurate description of their awareness of the stimulus where 1 denotes “I saw nothing”, 2 represents “I saw a glimpse of something, but I couldn’t see what it was”, 3 stands for “I saw part of an object or a cutout”, and 4 signifies “I clearly saw an object or a cutout”.

Training block. The goal of the training block was to introduce real-life CFS to the subject and allow her to experience the emergence of stimuli into awareness. Trial sequence in the training block was identical to the experimental block, except for the following changes: (a) it had a longer CFS-only display (20 seconds), (b) the stimulus used in it was a single real object that was not used in the experimental blocks and (c) lighting of the set was set to maximum intensity. After several trials the experimenter dimmed the lights to the level used in the experimental blocks. The experimenter ended the training block after ten trials or less, based on the subject’s understanding of the paradigm.

Results

The analysis was conducted using all trials in which subjects responded to the first question, about object location (on average, 0.26% of the trials were excluded). The efficiency of real-life CFS in suppressing real, 3D stimuli was assessed by calculating the percentage of ‘visibility 1’ trials in which subjects reported they did not see the stimulus. Mean percentage of such trials was 80.31% (SD=17.15), demonstrating the potency of this suppression method (Figure 4). In those trials, subjects were at chance in determining at which side the stimulus appeared, both in overall accuracy ($M=0.50$, $SD=0.06$; $t(19)=0.15$, $p=0.882$, Cohen’s $d=0.03$; Figure 4, right), and in d' (mean $d'=0.064$, $SD=0.243$, $t(19)=1.144$, $p=0.267$, Cohen’s $d=0.26$; hits and false alarm rates of 0 were replaced with $0.5/n$, and those of 1 were replaced with $(n - 0.5)/n$, where n is the number of signal or noise trials, respectively (Stanislaw & Todorov, 1999)). In contrast, performance in visibility >1 trials (for subjects who had at least ten such trials) was well above chance ($M=0.798$, $SD=0.219$, $t(12)=4.717$, $p<.0005$, Cohen’s $d=1.31$, mean $d'=2.028$, $SD=1.632$,

$t(11)=5.05$, $p<.0005$, Cohen's $d=1.46$). Averaged visibility scores and representation levels depended on one another, so that when objects were presented, more trials were rated as visibility 3 and 4, compared to when cutouts of photographs were presented ($\chi^2(3)=27.209$, $p<10^{-5}$, standardized residuals for these cells: 2.044, 2.813, -2.038, -2.803, respectively). In line with this result, when cutouts of photographs were presented, subjects tended to rate these trials more as visibility 1 than when real objects were presented (Figure 4, left; $t(19)=3.115$, $p=0.006$).

Figure 4. Means and standard errors of subjective reports of the visibility of the target stimuli (left), which were either real objects (blue) or cutouts of 2D photographs (orange), and their corresponding objective performance (right). Note that visibility 2-4 were grouped together. Data for individual subjects is denoted by dots. $*=p<.01$, $**=p<.0005$, left: t-test between conditions, right: t-test against chance.

Discussion

Experiment 1 demonstrated that the real-life CFS methodology is indeed successful in suppressing real-life, 3D objects (as well as cutouts of 2D photographs of these objects). The vast majority of trials were

rated by subjects as trials in which they did not see the target stimulus, and their ratings were further corroborated by their objective performance, which did not differ from chance. The data also hints at greater suppression potency for photographs than for real objects, so that the latter may resist suppression to a greater degree.

Experiment 2: assessment of suppression duration

Experiment 2 tested the span of suppression duration that can be achieved by real-life CFS, as well as further examined the difference in suppression efficiency between real objects and photographs. The latter theoretical question was a part of a larger-scale research that will be discussed elsewhere, as it exceeds the scope of the current paper. We therefore focus here only on the methodological aspect of this experiment. To assess the length of suppression achieved by real-life CFS, Mondrians were displayed for a longer duration of 18.6 seconds. A breaking-CFS paradigm was used (for review, see Gayet et al., 2014), in which subjects were asked to report the side of the target stimulus as soon as they saw it. Subjects' reaction times were therefore used as an estimation of suppression duration achieved by real-life CFS.

Methods

Subjects

A total of 20 right-handed subjects participated in this experiment (14 females, mean age=24.35, SD=3.88), all meeting the predefined requirements for participation described above. Three additional subjects who participated were excluded from the analysis: two due to low accuracy (less than 75% correct) and one who did not complete the experiment due to technical difficulties. As this study was exploratory (see footnote 1 above), sample size was chosen based on a common practice for exploratory experiments in our laboratory (N=20). All subjects had normal or corrected-to-normal vision using contact lenses, and declared no past neurological, attentional, mental disorders, or current usage of psychiatric medicines. They participated in

the experiment for credit or payment. Subjects signed a consent form and were explained that they can withdraw from the experiment at any point if they wish to do so. The experiment was approved by the university's ethics committee.

Stimuli, apparatus and procedure

Stimuli, apparatus and procedure were identical to those used in Experiment 1, besides the following changes: First, the experiment included four levels of representation, ranging between (a) real, everyday objects; (b) cutouts of color photographs matched in color and size to the real objects; (c) cutouts of black-and-white photographs created by reducing the saturation of the color photographs to zero; and (d) cutouts of contour-only photographs created by employing a “find edges” filter on the black-and-white photographs. For the purposes of this manuscript and consistency with Experiment 1, we focus only on levels (a) and (b). Accordingly, the experiment included 176 trials, divided into two experimental blocks, and an additional training block (up to ten trials), all presented within one experimental session. Each experimental block thus consisted of 88 trials, showing eleven different objects in eight experimental conditions: representation levels (Real object \ color photograph \ black-and-white photograph \ contours-only photograph) X sides of the box (left\right).

Second, since this was a breaking-CFS paradigm, the flashing Mondrians appeared for 19.6 seconds. Subjects were asked to report seeing the stimulus by clicking the mouse button corresponding to the stimulus' position relative to the center of the stage (left\right). After they clicked a mouse button, or after 19.6 seconds, the Mondrians disappeared and subjects could see the stage without interruption. Then, the blind was lifted and another trial began.

Results

All following analyses were conducted only using trials in which subjects were correct in identifying object location, or provided no response (6.8% of the trials excluded). For the latter trials, reaction time was considered as the whole length of the trial (18.6s). The average suppression duration was 6.38s (SD=2.42). This duration was greater for cutouts of photographs (M=6.68, SD=2.42) than for real-life objects (M=5.58, SD=2.29, $t(19)=4.692$, $p<.0002$, Cohen's $d = 1.04$; Figure 5). To make sure the “no response” trials do not solely drive the effect, we conducted the same analysis on the data when excluding them. The same pattern of results was found (photographs: M=5.53, SD=2.03; real objects: M=5.00, SD=1.96, $t(19)=3.741$, $p<.002$, Cohen's $d = 0.84$).

Figure 5. Suppression duration (means and SEs) for real objects (left) and cutouts of photographs (right). Data for individual subjects are denoted by dots.

Discussion

After showing that real-life CFS can indeed suppress real life objects, Experiment 2 provided a more fine-grained description of the suppression and its duration. We found that this suppression lasts, on average, 6.13 s ($SD=2.3$), but can also last for much longer; in our experiment, the display was removed after 18.6 s, and on average 6.99% of the trials ($SD=5.42\%$) ended without subjects being able to see the stimulus at all. In fact, in additional trials in the lab as well as in public events (namely, the Vision Sciences Society demo night), the suppression sometimes even lasted for 30 seconds, and was able to suppress not only a stationary stimulus, but also a moving human hand and even a face. Thus, this method seems highly potent, much like (if not more) than the classical CFS paradigms presented on monitor. Yet to directly compare its effectivity with that of the classical method, Experiment 3 was conducted.

We further note that the data provides evidence for differential suppression times between 3D real objects and 2D representations of them: real objects showed greater resistance to real-life CFS than cutouts of 2D photographs, as they emerged into awareness about one second earlier. Whether this points at a difference of low-level visual features between the two conditions, or rather at more high-level differences, is an example for a research question one can only explore using the real-life CFS method, which we further develop and describe in another publication.

Experiment 3: Comparison of suppression duration of real-life CFS vs. classical CFS presented using a monitor

Experiment 3 aimed at comparing the novel real-life CFS with the well-known, widely used monitor-based CFS. We replicated the paradigm of Experiment 2 using very similar stimuli, which were now presented on a computer screen instead of as items in the real world. Real objects from Experiment 2 were photographed inside the display (Figure 6a), and their images were then used as target stimuli in a CFS

paradigm presented using a monitor and a stereoscope (Figure 6b). Suppression durations in this paradigm were compared to those obtained in Experiment 2.

Importantly, in classical CFS paradigms, target stimuli are usually presented on a uniform, gray background. However, in real-life CFS this is not the case, as the objects have depth and therefore must be placed in a display box. Hence, in real-life CFS, non-uniform visual information other than the target stimulus is always present - e.g. the floor and back wall of the box. This environment is also influenced by the objects themselves, as they cast shadows on the walls and floor of the box. To make our monitor-presented experiment is as similar as possible to Experiment 2, we tried to simulate the environment in which the stimuli were presented there. In Experiment 3a, we simply presented photographs of the objects placed inside the box, so they appeared within the background in which they appeared in Experiment 2, including their shadows and so on. In Experiment 3b, we wanted to control for individual differences evoked by each of the stimuli (e.g., different shadows) and more closely mimic classical CFS paradigms, in which the background is not at all influenced by the target stimulus. Thus, we used a photograph of the empty box and pasted the photographs of each isolated object onto that background photograph (see Figure 6c).

Methods

Subjects

Twenty subjects participated in experiment 3a (15 females, 16 right-handed, mean age=24.6, SD=2.27). An additional subject was excluded as her performance level was at chance, indicating that she did not understand or follow the experiment instructions. Another subject was excluded because she did not provide any response throughout the experiment. Twenty more subjects participated in experiment 3b (13 females, 19 right-handed, mean age=22.35, SD=2.55). Here too, one additional subject was excluded due to chance performance, and another due to no response. Sample sizes were chosen to match that of Experiment 2.

All subjects had normal or corrected-to-normal vision, and declared no past neurological, attentional, mental disorders, or current usage of psychiatric medicines. They participated in the experiment for credit or payment. Subjects signed a consent form and were explained that they can withdraw from the experiment at any point if they wish to do so. The experiment was approved by the university's ethics committee.

Stimuli

To prepare the stimuli for experiments 3a and 3b, ten out of the eleven original stimuli from Experiment 2 were photographed inside the theater device, with the lights at minimum intensity - identical to the one used in Experiment 2 - on both sides of the box. These images then underwent a color matching procedure using Photoshop (Adobe, Inc.) to closely resemble the appearance of the real objects inside the theater device, when presented on a monitor in a dark room (Fig. 5a). In Experiment 3a, these images were used (Fig. 5b). For experiment 3b, the background of each image, containing the floor and back wall of the box, was removed using Photoshop. A similar, identical background was inserted instead, which was the same for all images, such that the items appeared to cast no shadows on the display box (Fig. 5c). All images were scaled such that they will appear to be the same size as the real display, when presented at a distance of 60cm from the subject.

Figure 6. Preparation and examples of stimuli for Experiment 3. **A.** The real display (left) vs. the on-screen image (right). **B.** An example of a stimulus from experiment 3a - the object is presented with its original background. That is, a photograph of the object placed in the theatre display was presented as is. **C.** An example of a stimulus from experiment 3b - the real background of the object was replaced with a background that was similar in all the stimuli. That is, one photograph of the empty stage was used as background, and the isolated objects were pasted onto it.

Setup

Subjects sat in front of a monitor placed at a distance of 60cm from their eyes, with their head rested on a chin rest. A stereoscope was used to present each of the subject's eyes with a different part of the screen. Subjects performed the task using a mouse to report their experience and a keyboard to advance through the trials.

Paradigm

The procedure closely followed that of Experiment 2, except for the following changes: First, the maximum duration of suppression was 20 seconds. Second, instead of “ramping down” the opacity in the non-dominant eye to expose it to the target stimulus, the non-dominant eye was now presented with a white background which faded to the target image along the course of one second. Note that this mimics the perceptual experience subjects had in Experiment 2. Third, the total number of trials in the experimental block was 40, so that all ten objects were presented on both sides (right\left), for two repetitions. Since this experiment was very short (~20 minutes to complete), no break was given.

Results

All following analyses were conducted only using trials in which subjects were correct in identifying object location, or provided no response (0.9% of the trials excluded in Experiment 3a, 0.5% in Experiment 3b). Mean suppression times in Experiment 3a were 6.98s (SD=3.19; Fig. 7 inset), and in Experiment 3b - 6.23 (SD=2.21; Fig. 7 inset). In 7% (SD=11.9%) and 4.5% (SD=6.2%) out of the 40 trials (3a and 3b, respectively), subjects did not see the stimulus at all. To compare the suppression time for both conditions in Experiment 2 to Experiments 3a and 3b, two ANOVAs were performed: the first compared reaction times for real objects in Experiment 2 with reaction times in both experiments 3a and 3b; this allows us to examine if the suppression evoked by real-life CFS is different from classical on-screen CFS with respect to real, 3D objects. The second analysis compared reaction times for cutouts of photographs in Experiment 2 with reaction times in both experiments 3a and 3b. This focuses on the comparison between real-life CFS and classical CFS, applied to 2D stimuli - the photographs (notably, we could not compare all conditions in one ANOVA because Experiment 2 was a within-subjects design, and Experiments 3a and 3b were conducted on separate and different samples). Both ANOVAs revealed no difference between the real-life

CFS and the classical CFS (ANOVA #1: $F(2,57)=1.44$, $p=0.247$, $\eta^2=0.048$; ANOVA #2: $F(2,57)=0.41$, $p=0.67$, $\eta^2=0.014$). Thus, real-life CFS is as potent as the classical, on-screen CFS.

Figure 7. Vincentized display of the distributions of suppression durations in the real-life CFS Experiment 2 (objects - yellow, 2D cutouts of photographs - blue) and in the on-screen versions (Experiment 3a - green, Experiment 3b - magenta). Polygons indicate 95% CIs. Inset: mean & SEM of suppression time in each condition.

Discussion

Experiment 3 directly compared the potency of real-life CFS to that of the on-screen CFS paradigm. It did so by replicating Experiment 2 using an on-screen display, striving to achieve maximum similarity between the conditions and appearance of the stimuli in both experiments.

No difference in mean suppression duration was found when comparing both real objects and 2D cutouts of photographs presented using real-life CFS, to their representations presented using on-screen CFS. Moreover, this lack of evidence for a difference was found both when presenting the on-screen stimuli exactly as they were in the real-life setup (Experiment 3a), and when presenting them in a manner closer to characteristic figure-ground relations in on-screen CFS experiments (Experiment 3b).

These results suggest that real-life CFS is not essentially different from on-screen CFS, and is probably based on the same mechanisms. This implies that like the on-screen CFS, the real-life one can be used to study both unconscious processing and access to awareness of different types of stimuli (for review, see for example Gayet et al., 2014), hereby extending the range of possible research questions also to the realm of 3D, real stimuli.

General Discussion

In this paper, we present real-life CFS - a novel variant of continuous flash suppression, which allows, for the first time, to suppress the real world from awareness. This is different from all existing methods of unconscious presentation of stimuli, which only suppress 2D on-screen representations of items. In three different experiments, we showed that this new method is potent enough to allow prolonged suppression durations of stimuli that are otherwise easily visible. In Experiment 1, we provided a proof of concept and established the efficiency of the method in suppressing real stimuli. Subjects reported that they did not see the stimuli at all in about 80% of the trials. This subjective measure was further validated by their chance

performance in determining the location of the suppressed stimuli (right/left) in these trials. Experiment 2 showed that this suppression is potent enough to last as long as 6.13 seconds, across subjects. To compare this suppression duration with the classical CFS paradigm, in Experiment 3 we presented pictures of the same stimuli, now on-screen, and measured their suppression durations. The mean suppression times were indeed similar, and overall, it seems like real-life CFS suppression duration is within the ballpark, and even longer, than what is usually found in classical CFS paradigms (Mudrik, Breska, Lamy, & Deouell, 2011: ~1.5s; Sklar et al., 2012: ~1s; Jiang, Costello, & He, 2007: ~1.5s; Stein, Senju, Peelen, & Sterzer, 2011: ~1.5-5s; Yang, Zald, & Blake, 2007: ~2-4s; notably, in the original report of this paradigm, suppression times were much longer, Tsuchiya & Koch, 2005, in the magnitude of several minutes). In addition, Experiments 1 and 2 suggested that real objects may escape suppression faster than their 2D photographs cutouts; this potential difference is directly probed and discussed in another publication (Korisky & Mudrik, in preparation).

The above results thus provide compelling evidence for the ability of the real-life CFS method to suppress real-life stimuli from awareness. This is especially important given the growing acknowledgement of the benefits of using more ecological stimuli in cognitive science in general; for example, in the field of face processing, studies have moved from schematic faces, to real-life images of them, and even to dynamic movies of faces (Bernstein, Erez, Blank, & Yovel, 2017; Pitcher, Dilks, Saxe, Triantafyllou, & Kanwisher, 2011); similarly, in language processing, more studies focus on real-life discourse, presenting long stories rather than isolated words or sentences (Silbert, Honey, Simony, Poeppel, & Hasson, 2014). Our methodology allows researchers to do the same in the field of consciousness studies, using real-life objects. Indeed, real-life, 3D objects were shown to elicit differential processing from 2D representations of them (Snow, Skiba, Coleman, & Berryhill, 2014; Snow et al., 2011; Gomez, Skiba, & Snow, 2017; Freud et al., 2016). This highlights the importance of expanding our investigation to real-life stimuli; first, given the differential processing real-life objects might yield, different responses and new patterns of results might be found. It is accordingly timely to examine if the results obtained with 2D on-screen representations

generalize to real-life objects. Second, because the latter might evoke stronger signals and effects (Snow et al., 2014, 2011; Gomez et al., 2017), using them as stimuli might increase our chances to find effects during unconscious perception. In other words, because on-screen, 2D stimuli are processed in a less direct, immediate manner than the actual entities that they represent, it is possible that real stimuli would be processed to a larger degree, and would accordingly evoke stronger effects. Given the inherent challenge in studying unconscious processing - overcoming the typically weak signal evoked by impoverished stimuli (Greenwald, Draine, & Abrams, 1996) - this might be a fruitful venue of research.

The novel methodology we report here has its limitations, of course, which mainly stem from current technological constraints of the AR hardware used for displaying the Mondrians. For example, at present the technique cannot mask the entire real-world environment around us, but only a somewhat limited area within the visual field, namely - the area that can be presented with graphics. This becomes an issue when trying to suppress objects that are very close to the subject or that are very big. In addition, because eye-tracking solutions for AR are not yet common, the subject's head and its distance from the suppressed object have to be fixed. Finally, for the specific goggles used here, there is a certain delay between the goggles and the computer, causing a delay in presentation times, as well as some jitter (see Supplementary Information for further details). However, as advances in AR technology are common and rapid, we hope it will be possible to overcome these drawbacks soon.

Even with its current limitations, real-life CFS opens the gate for many new possibilities in the study of unconscious processing. Essentially, anything in the real world can in principle be suppressed (notwithstanding the above mentioned reservations). Already now, it is possible for example to suppress animate, moving stimuli, such as hands and faces. Likewise, real, manipulable objects can be suppressed from awareness, permitting the study of unconscious processing of affordances. The difference in unconscious processing between 3D objects and 2D representations can also be studied, as shown above. Importantly, and different from Virtual Reality solutions (Van Der Hoort et al., 2017), the ecologicality of

our method is much greater. It is the first suppression method that allows fully immersive, real interaction with the subject's surrounding environment, without having to re-represent it in any way. Accordingly, it gets as one step closer to the common stimuli the brain has to process in real, everyday life.

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