Social Cognition, Vol. 43, No. 5, 2025, pp. 502–518
 https://doi.org/10.1521/soco.2025.43.5.502

CFS-VR: Software for Studying Unconscious Cognition With a VR Headset Using Continuous Flash Suppression

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Numerous psychological theories emphasize the importance of unconscious cognition. However, research on unconscious processing has faced stigma and methodological challenges, especially in minimizing contaminating influences of conscious cognition. Continuous flash suppression (CFS), an image presentation technique, has the potential to enlarge the window through which we may view the workings of the unconscious mind prior to the onset of conscious cognition. But CFS can be technically challenging and expensive to implement. We have developed software, CFS-VR, that increases access to CFS as a methodological tool using a basic VR headset. CFS-VR allows for the presentation and recording of responses to many different visual stimuli and trial types, and is freely available. This article provides a brief tutorial and explores research domains (evaluative conditioning, priming, and mere exposure) where CFS-VR can address unresolved and novel research questions.

Keywords: cognition, subliminal, continuous flash suppression

Our understanding of unconscious cognition lags behind that of conscious cognition. What are its capacities and limitations? What sorts of computations can it perform, and which ones can it not? We know that conscious cognition can be biased (e.g., confirmation bias, logic fallacies); what sorts of biases affect unconscious cognition? A number of theories, including those in attitudes (Greenwald & Banaji, 1995), emotion (Zajonc, 1980), and cognition (Kihlstrom, 1987), rely on claims about unconscious processing despite continued ambiguity about the nature of the unconscious (Bargh, 2022; Kihlstrom, 2009). This relative dearth of knowledge fuels motivation to develop better tools to study unconscious cognition. A necessary goal in exploring unconscious cognition is to minimize the influence of conscious processing. However, technological and theoretical challenges

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make nonconscious information processing one of psychology's most controversial topics (e.g., Eriksen, 1960; Holender, 1986; Marcel, 1983; Merikle & Daneman, 1998; Moran et al., 2021).

The unconscious may have the capacity to attend and encode some stimuli, but it may benefit from more than a few dozen milliseconds to do it. Historically, ensuring subliminality (i.e., presentation below the threshold of conscious perception) required presenting stimuli for very brief durations (e.g., 10–40 ms; March, 2024; March et al., 2022), limiting opportunities for attention and processing. But such brevity allows little time for attention capture and processing. Furthermore, a blink, attentional lapse, or wandering eye can render trials unusable. Consequently, current techniques render ambiguous both whether a stimulus was attended to consciously or unconsciously, and if the latter, whether it was sufficiently processed to produce a hypothesized effect. Here we describe a relatively new suppression technique known as continuous flash suppression (CFS) that allows for longer presentation durations of subliminal stimuli, in a sense leveling the playing field for unconscious cognition. We explain how CFS may be utilized within several domains of psychological research and issues to keep in mind when considering it. We then provide a tutorial on CFS-VR, software we have developed that provides a platform for designing and conducting research using CFS.

CONTINUOUS FLASH SUPPRESSION

Each human eye perceives a slightly different image of the environment. The visual cortex usually rectifies these differences so we only experience one image consciously. But by presenting different images to each eye, scientists can induce binocular rivalry, whereby both eyes compete for perceptual dominance and access to consciousness. CFS takes advantage of binocular rivalry to occlude conscious perception of stimuli presented to the nondominant eye by overwhelming the dominant eye (Tsuchiya & Koch, 2005). In CFS, the nondominant eye receives a low-resolution static stimulus, while the dominant eye perceives rapidly changing "noisy" stimuli. Due to the rapidly changing noisy stimuli, the static image presented to the nondominant eye remains suppressed for extended periods—sometimes exceeding 3 s (E. Yang et al., 2014).

To illustrate how CFS might be used to address current research questions, we will briefly discuss the utility of CFS to three areas we are familiar with: evaluative conditioning (EC), behavioral priming, and mere exposure.

In EC research, one hotly debated question is whether evaluative associations involving a CS (e.g., a novel object) and US (a known positive or negative object) can be learned without conscious awareness of their pairings (e.g., Moran et al., 2021). Earlier attempts often manipulated stimulus exposure duration as a proxy for consciousness, with "aware" conditions displaying CS-US pairs for, say, a second each, and "unaware" conditions displaying them for as little as 12 ms each. This introduces a confound, as the aware condition allows (and offers) greater opportunity for both attention and encoding, whether conscious or not. CFS might allow for greater stimulus exposure while still keeping conscious awareness of the pairings minimal in relevant conditions (or allow for alternative EC designs; see Högden et al., 2018).

Analogous challenges apply to priming research. Semantic and image priming effects on simple and immediate responses like recognition and reaction times are reliable, even when those primes are subliminally presented (e.g., Draine & Greenwald, 1998). But debate persists about whether priming in general, and subliminal priming in particular, can impact more complex behaviors (e.g., Sherman & Rivers, 2021). As with EC research, attempts at assessing the effects of primes about which people are unaware have led researchers to use brief presentation times, stimulus masks, parafoveal presentations, and distracting stimuli, all of which limit processing. Downstream behavioral effects of subliminal primes might occur with greater opportunities for prime processing, depending on the type of information being processed (e.g., Peremen & Lamy, 2014).

Mere exposure research is another domain in which increased unconscious stimulus exposure afforded by CFS might address ambiguities in the literature. The basic effect—increased liking of stimuli perceived more versus less frequently—is robust, even when stimulus presentation is subliminal. However, there have been some failures to replicate (e.g., Chow et al., 2022; Pugnaghi et al., 2019). The generalizability of the mere exposure effect remains debated; some studies show increased liking for novel stimuli similar to frequently viewed ones (e.g., Monahan et al., 2000; Zebrowitz et al., 2008), while others report limited generalizability (Kramer & Parkinson, 2005; Newell & Bright, 2003). The increased opportunity for unconscious familiarization afforded by CFS might allow for more robust effects and greater generalizability. Variability in mere exposure effect sizes may be determined by either the subliminality of the exposure or the duration of the exposure, and CFS allows for increased unconfounding of these variables.

CONSIDERATIONS WHEN UTILIZING CFS

CFS's primary advantage of extended unconscious stimulus presentation time is a substantial one. It also allows for larger stimuli (encompassing more of the visual field) and is less prone to effects of visual fixation instability and attentional lapses (Kim & Blake, 2005). But like any research tool, particularly one relatively recently developed, CFS has disadvantages. We briefly summarize some of them here; more thorough treatments can be found elsewhere (e.g., Lanfranco et al., 2023; Pournaghdali & Schwartz, 2020; E. Yang et al., 2014).

Apart from the technical challenges of assembling a CFS apparatus (which CFS-VR helps resolve), its primary disadvantage—which is still debated—is the degree to which it inhibits not just conscious processing, but any sort of processing, particularly higher order varieties (e.g., semantic, configural, affective). Some evidence suggests that CFS inhibits all manner of processing of the suppressed stimuli (e.g., Moors, Boelens, et al., 2016). For example, Peremen and Lamy (2014) demonstrated that a backward-masked priming procedure allowed for unconscious response priming effects of directional arrows, but a CFS procedure did not. However, Koivisto and Grassini's (2018) use of a rapid (vs. gradual) prime onset and shorter stimulus onset asynchronies (SOAs) in an otherwise identical procedure succeeded in demonstrating unconscious response priming using CFS. This pair of studies illustrates not only some of the debate over what sorts of processing CFS allows, but also, as detailed below, how much methodological details can matter.

Ideally, CFS would preclude conscious perception but allow for all other processing to continue unabated. Because CFS-VR allows for great flexibility in trial construction, exploring whether there exists a goldilocks zone between oversuppression (where nothing gets in) and undersuppression (where masked stimuli are consciously identified) appears possible for a wide range of stimuli and tasks. Still, regardless of parameters, CFS may restrict at least some higher versus lower order processing (e.g., Pournaghdali & Schwartz, 2020). For example, in their recent review of CFS studies on face perception, Lanfranco and colleagues (2023) describe evidence of higher order processing under CFS (e.g., facial expression discriminability) that turned out to be the result of low-level stimulus confounds. More compelling evidence of higher order processing is provided by breaking CFS studies (bCFS), where stimuli are compared on how quickly they "break" suppression and become consciously perceptible. For example, more dominant and less trustworthy faces break suppression more quickly, an effect that low-level visual features do not explain (Abir et al., 2017). Attractive faces (Hung et al., 2016) and angry faces (Vetter et al., 2019) also break more readily, as may affectively charged words (Y.-H. Yang & Yeh, 2011; see also Zabelina et al., 2013). Thus, like any method designed to occlude awareness, CFS probably impairs some higher order processing, but it does not appear to entirely preclude it. Nevertheless, these examples illustrate how researchers should be mindful of potential low-level visual confounds between stimuli when investigating higher order processing.

A few final considerations are important to note. First, CFS requires a number of seemingly minor decisions that can make a difference. For example, it appears that suppression is relatively weak at the onset of a trial but builds (and may plateau around 500 ms) as masks flash (Tsuchiya et al., 2006). Hence, suppression may fail if the suppressed stimuli are presented too early in a trial (thus, Figure 2 may illustrate a more effective way to induce suppression than Figure 3). Furthermore, the temporal frequency of the masks matters, with 10 Hz (100 ms) a safe choice, but researchers may want to pilot their mask-stimuli combinations using different mask frequencies to maximize suppression (Pournaghdali & Schwartz, 2020). And indeed, the choice of masks matters; for example, those that resemble suppressed stimuli more closely are more effective (Hong & Blake, 2009). Here we call attention to CFS-VR's Mask Maker, which allows great flexibility in the creation of masks. However, individual differences in suppression susceptibility suggest that universal parameter settings may not be optimal (E. Yang et al., 2014). A final consideration concerns how unconsciousness (which, as the absence of a phenomenon, is ultimately unverifiable) is best assessed; how do we know that participants did not consciously perceive some suppressed stimuli? There are pros and cons to both subjective and objective measures of awareness to consider (March, 2024; Ramsøy & Overgaard, 2004; E. Yang et al., 2014), and the debate on how to assess perception without awareness spans decades (for a classic but still relevant discussion, see

Merikle & Reingold, 1998; see also Draine & Greenwald, 1998). As is clear, much has yet to be determined regarding best practices, although the flexibility of CFS-VR will enable researchers to accelerate the exploration of these questions.

CFS-VR

Prior work employing CFS utilized either a mirror stereoscope or a dual display setup that presents distinct sets of stimuli exclusively to the right versus left eye (e.g., Hesselmann et al., 2016; Moors, Wagemans, et al., 2016; Nuutinen et al., 2018). These setups require several finely adjusted mirrors, and the participant's chin must remain fixed on a chinrest. This setup is generally difficult to build for the researcher and uncomfortable for the participant. To address these challenges, we introduce software called CFS-VR, which produces CFS using only a VR headset.

CFS-VR is a user-friendly, fully customizable, and self-contained platform for designing experiments, running studies, and collecting data, enabling researchers to create and conduct complex research designs with ease. CFS-VR requires a Windows PC capable of supporting a Meta brand headset (e.g., Meta Quest 2 or 3) via a Quest Link–capable cable that connects the PC to the headset.

This tutorial will introduce all of the main concepts and capacities of CFS-VR. A more detailed description of each as well as full documentation on all the features not covered here can be found in the Supplemental Materials and on the web. The self-contained zip file and full documentation for CFS-VR can be downloaded from https://www.marchlab.org/cfs-vr.

We recommend that you unzip CFS-VR from the downloaded zip folder and paste it somewhere else. We also recommend that you create and place a shortcut of the main program on your desktop. Within the main CFS-VR folder is a subfolder named *UserGuide*. The UserGuide folder contains the documentation PDF as well as the three CSV files (duplicate read-only versions and editable versions) that you must have and can edit to conduct a study in CFS-VR. Combined, the (1) study, (2) mask, and (3) palette CSVs allow for total customization of the trial structure and the noisy masks. It is not necessary to edit the mask and palette files, because they come preloaded with several palettes and mask variations. But you can, and it is a good idea to get familiar with the ways in which those features are specified. There is a graphic user interface (GUI) associated with each of these three files. The Study Runner is where you load the Study file and administer the study. The Mask Maker is used to customize mask profiles and edit the mask.csv file. The Palette Maker is used to customize palette profiles and edit the palette.csv file that determines the colors used to make the masks. In the following sections, we give a high-level overview of the three necessary files and the GUI associated with each file.

THE STUDY FILE AND THE STUDY RUNNER

The entire study is built within your study CSV file. A sample study file named UserTemplateCFSVR.csv is included in the *UserGuide* folder. We suggest that you make a copy of or move the editable sample file and place it in your study folder before building your study. You can rename the study file to whatever you want. There are many columns that allow you to tailor the study. The first series of columns (A–G) describe the structure of the study in terms of conditions, blocks, and trials, as well as whether there is any within- (i.e., trial-level) or between-block randomization. The next series (H–N) describes the trial structure by defining the dynamics of the suppressed image, the mask and its dynamics, and the length of the trial. The remaining several columns define optional features to further customize the default trial types (e.g., by adding a blank period or by gradually increasing the opacity of the suppressed image). You can rename the column headers, but you must maintain the default column order within the file. It is helpful to think of the study design as divided into smaller subunits, as illustrated in Figure 1. Condition is the highest level of organization. Each study file can contain one or several conditions. Within each condition can be one or several Blocks, which themselves can contain one or several Trials. This nested hierarchical organization allows for several types of randomizations, as randomization is contained within each hierarchical unit.

THE TRIAL

The basic elements of a trial can be broken down into (a) mask images presented to the dominant eye, (b) target stimuli presented to the nondominant eye (i.e., what is suppressed), and (c) the time parameters associated with each element of (a) and (b). In your study file, each trial is defined by the specifications you set. The entirety of a single trial is called the Trial Duration. The Trial Duration contains several cycles of Flash Durations. The Flash Duration describes the length of time a mask image is presented to the dominant eye before changing. Flash Durations can also contain a Blank Period (i.e., the length of black screen ending each Flash Duration prior to the onset of the next flash). It is helpful to think of the trial as divided into multiple cycles. The number of cycles is determined by dividing the Trial Duration by the Flash Duration. Therefore, the Flash Duration must be a divisor of the Trial Duration. For example, if you set the Trial Duration to 1,000 ms, the Flash Duration can be 100 ms (10 Hz), 200 ms (5 Hz), 250 ms (4 Hz), or any number of which 1,000 is divisible. One hundred is a good starting point for determining whether your design results in suppression. Figure 2 displays a 1-s trial, which contains ten 100-ms Flash Durations. The Flash Duration also describes the length of time between increases in opacity of the image(s) presented to the nondominant eye.

In this example, max opacity is set to 40%, which will linearly increase from 0 at the onset of the suppressed image to the end of the trial. The Mask Delay indicates when the mask begins to appear. The Static Image Delay indicates when the suppressed static image begins to appear. As you can see, these do not need to be set to the same value. Both the Static Image Delay and Mask Delay values must be a multiple of the Flash Duration to ensure that each will onset with the start of a new cycle. Figure 2 contains a Mask Delay of 200 ms, meaning that the first mask Flash will begin to appear on the third cycle (after two 100-ms Flash Duration cycles).

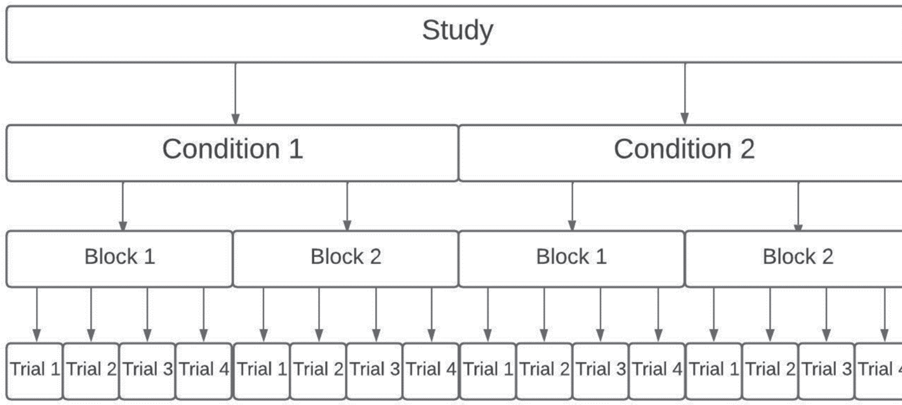

FIGURE 1. Hierarchical structure of a study file.

There is also a Static Image Delay of 400 ms. This means that the first instantiation of the suppressed image will begin to appear on the fifth cycle. If you want the mask to begin appearing prior to the onset of the static image (which may help to maintain suppression), you can set the Mask Delay to a number less than the Static Image Delay, or, as in Figure 3, you can set these values the same and they will onset on the same cycle.

In Figure 3, there is also a Blank Period, which here is set to 20 ms. The Blank Period is the "break" between flashes. The optional Blank Period specifies the duration in milliseconds from the end of the Flash Duration when the mask and suppressed image will be off the screen. This can create a more intense "flash" between cycles. Here the mask and static image will onset at the same point during the trial. This example has a max opacity set to 40%, but there is also a Time to

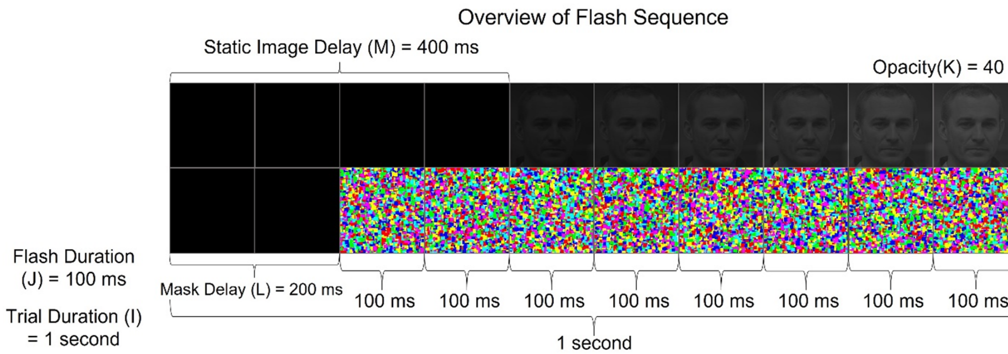

FIGURE 2. Overview of a flash sequence.

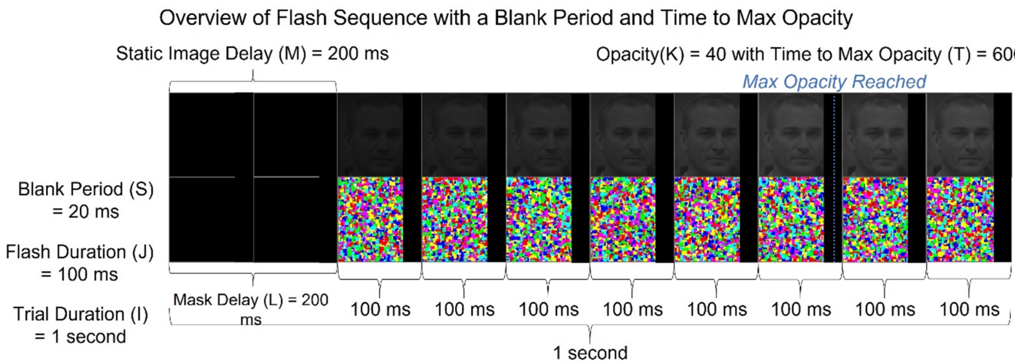

FIGURE 3. Overview of a flash sequence with a blank period and time to max opacity.

Max Opacity set to 600 ms. By adding this parameter, opacity will linearly increase from 0 at the onset of the suppressed image (set here to 200 ms) to reach the max opacity set to 800 ms.

TRIAL TYPES

The various trial types allow you maximum flexibility when designing your study. Some trial types present only images with no flashing. Others present options for participant responses. Some present the noise mask to the dominant eye, whereas others present a static image to the dominant eye. And whereas most trial types present one image to the nondominant eye, there are other trial types that allow you to present two stimuli simultaneously as suppressed images. By using the other parameter options available, you can create many different dynamics within each of these trial types.

Trial Type 0: Instruction Trial. During these trials, the same static image is displayed to both eyes to enable participants to read the content (e.g., text instruction images). Although participant input is necessary to proceed, the image will remain on the screen for a minimum of the duration specified.

Trial Type 1: Break Trial. These trials do not require any input from the participant to proceed. The trial will end at the duration specified.

Trial Type 2: Response Trial. Here participants are required to input a response to proceed to the next trial. The response options correspond to up, down, left, and right on a D-pad or the arrow keys on a keyboard. (Note: Any type of trial in the program can be converted into a response trial.)

Trial Type 3: Noise-as-Mask Trial. These trials present a static image to the non-dominant eye that is suppressed by noisy masks presented to the dominant eye. This trial type might be used for subliminal priming or mere exposure studies.

Trial Type 4: Object-as-Mask Trial. These trials are the same as Trial Type 3, but present an object image to the dominant eye that will flash to function as the mask (instead of a noisy mask image). This trial type may be useful for certain evaluative conditioning paradigms where the CS or US are presented separately (i.e., one to the dominant eye, and the other suppressed by the dominant image; e.g., Högden et al., 2018).

Trial Type 5: Multi-Stimulus, Noise-as-Mask Trial. These trials present two object images to the suppressed eye. By default, the two object images are displayed adjacent to one another. These paired object images are masked by noisy images. This trial type might be used for evaluative conditioning studies to present CS-US simultaneously as pairs.

Trial Type 6: Multi-Stimulus, Object Image-as-Mask Trial. Like trial type 5, these trials present two defined object images to the suppressed eye. Unlike Trial Type 5, Trial Type 6 employs an object image as the mask instead of a noisy mask.

STIMULI

You must provide individual image files for use as static images. There are two ways images are identified in your study file, either as a Single Item or as items drawn from an Image List. All stimuli files and Image Lists must be stored within a folder named "Stimuli," which must be contained within the same folder as the main Study.

Single Items. You can specify a single image file in the image column within the study CSV and it will be presented on that trial.

Image Lists. You can specify a text (.txt) file containing a list of the image files you want to use. You can define several image lists containing completely different or overlapping image files. Any number of trials can use the same image list. The input column must contain the name of the text file along with a leading symbol defining how the trial will draw images from the image list (further defined in the Supplemental Materials). You can specify that it pull images either in the order they are listed or via one of two types of randomizations (*without* or *with* replacement). If the number of trials is greater than the number of image file names in the text file, the list will repopulate once all images have been used. Importantly, within the same block, single image stimuli and image lists can both be used, but only one type of stimulus list randomization can be used.

Defining the Location of the Static Image(s). By default, the suppressed image is presented at the maximum size of 256 × 256 pixels, the same size as the mask image. If you want to present the suppressed image in a specific location, you have several options depending on whether you are presenting a single or multi-stimulus trial. If you are presenting a single-stimulus trial (types 1-4), there are five location-specific options that correspond to specific areas within the mask, including a centered display (see Figure 4).

If you are presenting a multi-stimulus trial (Trial Types 5–6), there are six location-specific options that correspond to specific areas within the mask that include both vertical and horizontal pairings (see Figure 5).

THE STUDY RUNNER AND RUNNING A STUDY

The Study Runner is where you upload your study file, set the participant's eye-dominance, and enter the participant ID (see Figure 6). The dominant eye is the eye to which the flashing mask image will be shown.[1] Once you start the study, CFS-VR creates all of the masks to be used during the entirety of the study. This can take some time, so there may be a 30–60-s delay after pressing Start but before the study is ready to run.

During the study, you will see a Running Study GUI (see Figure 7) displaying what the user is seeing through each eye and an approximate indication of their percentage of progress through the study.

THE MASK FILE AND THE MASK MAKER

Within the study file, you must refer to a mask profile for use on each noisy masked trial. That profile must be contained within the mask file stored in the same directory as your study file. The mask file will reference a palette file that must also be stored in the same directory as your study and mask files. The mask file must be named "mask.csv." Although the program ships with a template mask file, if you wish to make your own masks, we recommend that you first use the Mask Maker program to define and test out parameters that define a mask profile (see Figure 8). You can save profiles to your mask CSV file directly from the Mask Maker or use the values you determine within Mask Maker to manually input them into your mask file.

THE PALETTE FILE AND THE PALETTE MAKER

The palette file must be named "colorPalette.csv" and it must be in the same directory as the study and mask files. It is easiest to simply copy the sample palette file into your study folder. Each grouping of three columns (e.g., BCD, EFG, HIJ) defines a single color within a profile. Each grouping must contain the red, green,

1. There are a number of easy ways one can determine their dominant eye, for example, by pointing at an object and then closing one eye at a time to determine which eye's view best aligns with one's finger.

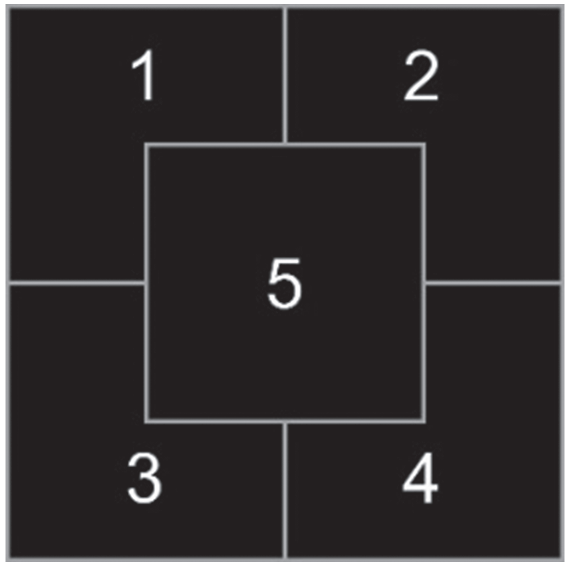

FIGURE 4. Location options for single-stimulus trials.

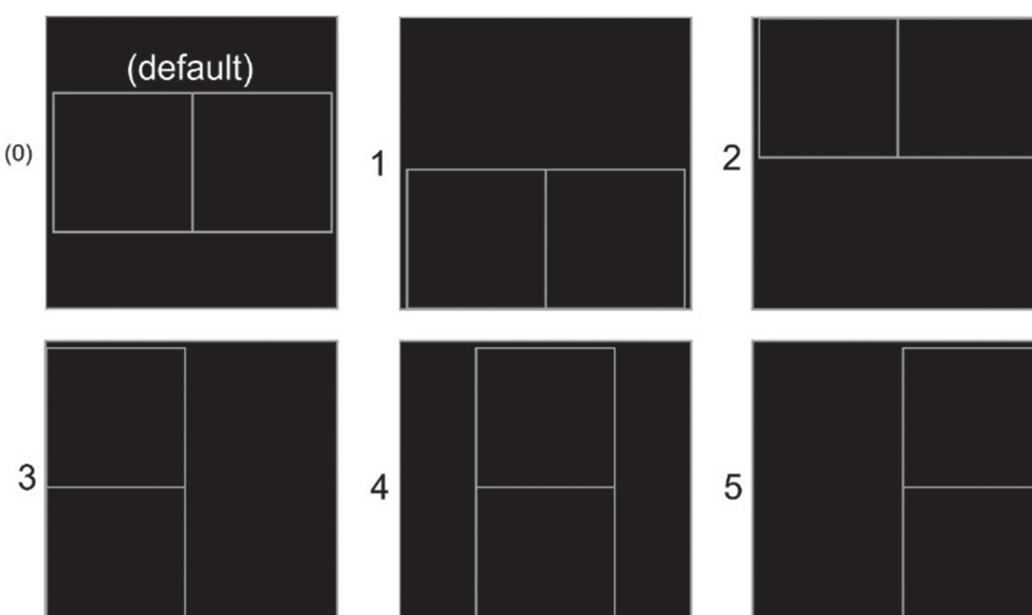

FIGURE 5. Location options for multi-stimulus trials.

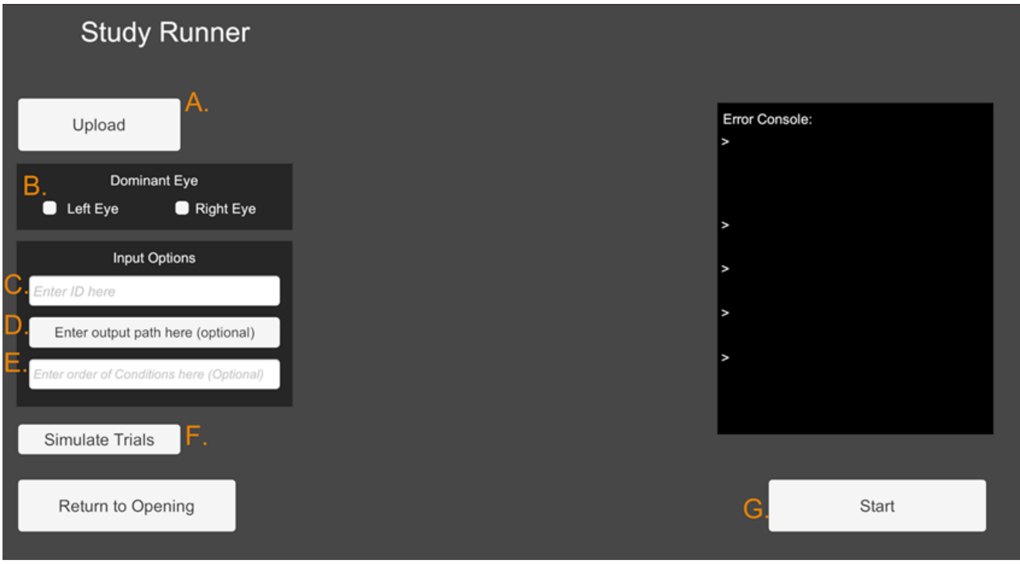

FIGURE 6. The study runner graphic user interface.

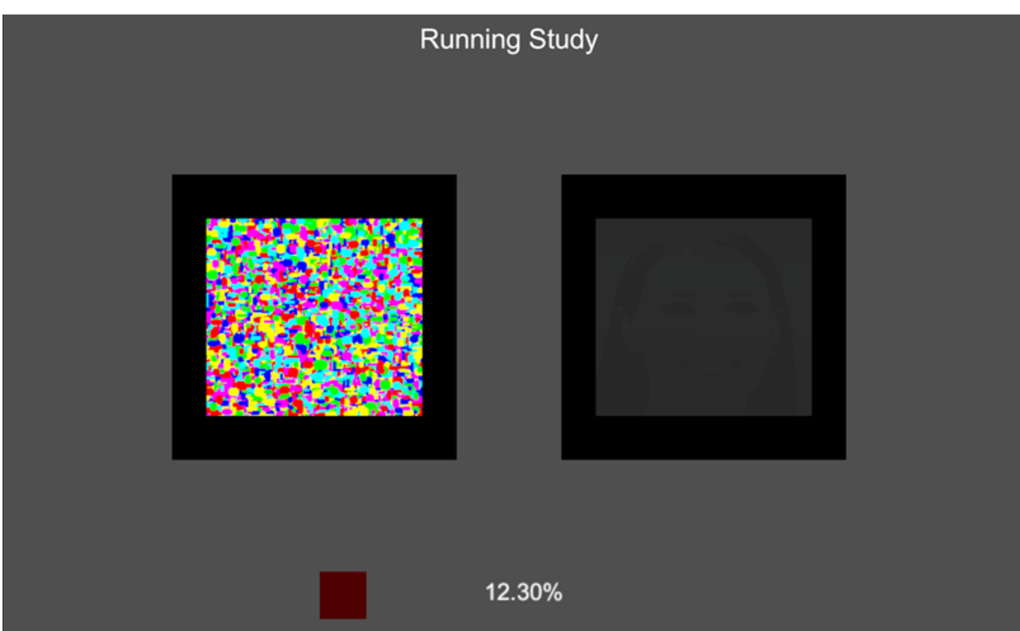

FIGURE 7. What the researcher sees during the study.

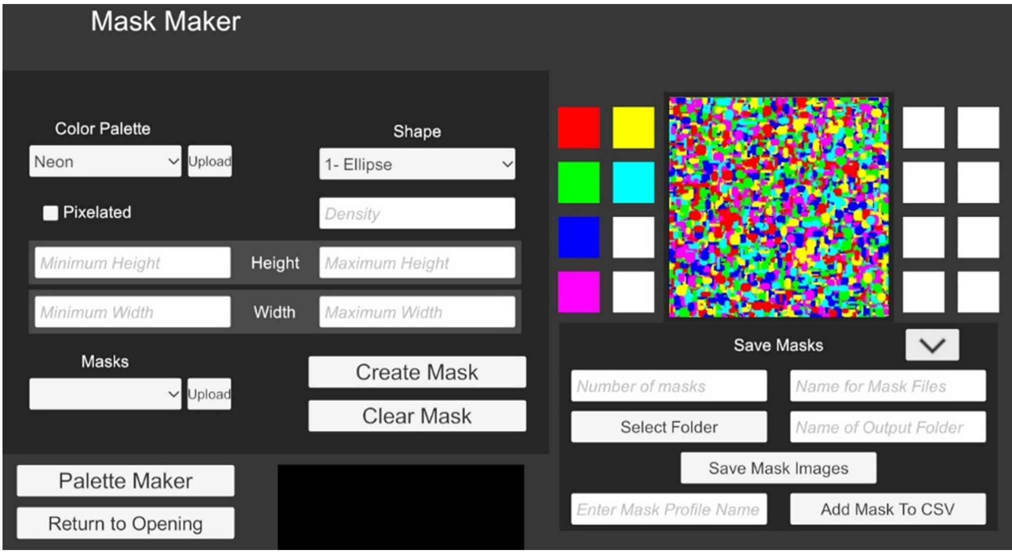

FIGURE 8. Mask Maker graphic user interface.

and blue value of that color, in that order. You can list as many colors as you like, but we recommend limiting the amount to six. To make the organization of the palette file simple, both CFS-VR and the Mask Maker software ignore rows 1 and 2 of the colorPalette.csv file in case you wish to insert notes there. You reach the Palette Maker through the Mask Maker (see Figure 9). Thus, start with the Palette Maker so the palettes you create are available in the Mask Maker. Within the Palette Maker, you can load a palette file to see and edit it, or you can create an entirely new palette file for use in your mask file.

THE OUTPUT DATA FILE

Upon completion of a study session, an output file named from the participant ID is saved to your study directory (or a unique directory if you specified one). The output file contains a log of the structure of each trial as well as a record of any response data, including reaction time and chosen response option on response trials.

A HYPOTHETICAL STUDY

Now that you are familiar with the capabilities and features of CFS-VR, we will walk you through a hypothetical study by highlighting the various decision points you may hit along the way when designing your own studies. To do so, and given our interest in EC, we will highlight how CFS-VR might be used to investigate the hotly debated question of whether EC can occur unconsciously (e.g., Moran et al.,

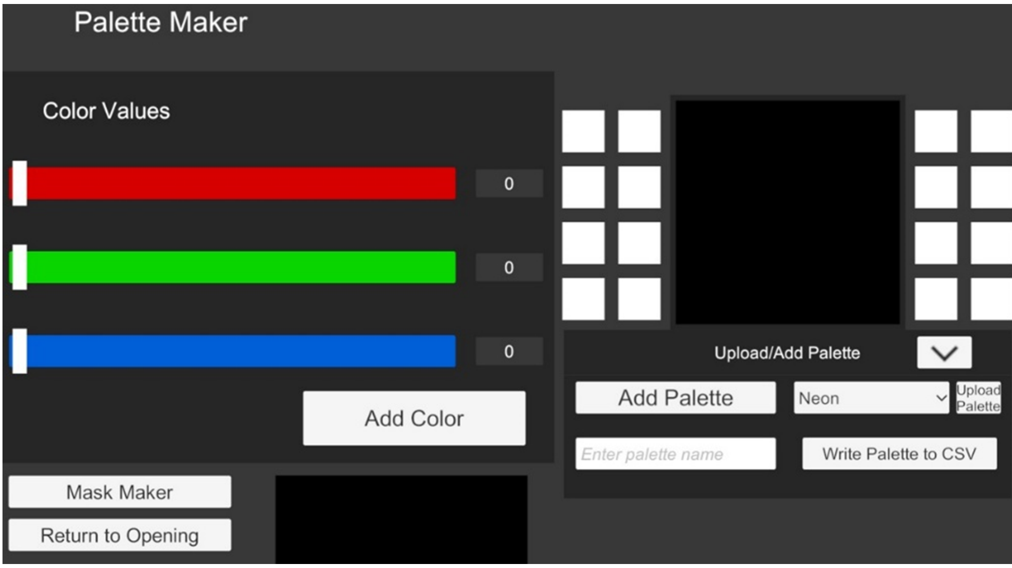

FIGURE 9. Palette Maker graphic user interface.

2021). We would not be the first. A recent study failed to find EC absent conscious awareness (or memory) for the paired associates using CFS. Högden and colleagues (2018) employed grayscale irregular geometric shapes as suppressed conditioned stimuli (CS) and positive and negative animal photos as unsuppressed unconditioned stimuli (US). Several decision points here may have affected this outcome. For example, the basic shape that CS presented to the nondominant eye might not be processed effectively under CFS. They could have chosen to suppress the US instead of the CS, or both the CS and the US. Högden and colleagues also made a number of choices about the EC procedure (e.g., number and type of US, number of repetitions) that might have affected the likelihood of observing an EC effect under CFS. It was a notable first attempt that makes us wonder how it might have been done differently.

Encouraged by other evidence of association learning using CFS (e.g., Raio et al., 2012), we use our own model of EC (The Implicit Misattribution Model [IMM]; March et al., 2018) as a guide to construct an EC procedure in CFS-VR. The IMM suggests that EC can occur nonconsciously via the misattribution of affective content elicited by a US to a CS. Several tenets of the IMM are relevant when designing an EC experiment in CFS. For example, the IMM argues that EC via misattribution is most likely to occur (a) when the CS-US pairing is presented in close temporal and spatial proximity, (b) when the CS are meaningful (e.g., people), (c) when the US are only mildly valenced (so as to reduce correct source attributions), and (d) when CS-US pairings occur repeatedly. Based on these considerations, several design features are made clear.

First, we would suggest suppressing either both the CS and the US, or the US such that the more evocative image is under suppression. It is entirely possible that the evocativeness of the unsuppressed US (and the meaninglessness of the suppressed CS) in Högden and colleagues' (2018) prior study muted any possibility of misattribution. So, in addition to basic instruction trials (Type 0) ensuring that the goals of the study are not overdisclosed, we would use Trial Type 5 to present two stimuli simultaneously to the suppressed eye with a noisy mask presented to the dominant eye. To reduce the likelihood of participants becoming aware of the repeated pairings, we would use the optional multi-stimulus location feature so that each trial showed pairings in unique locations with different orientations. To make the pairings, we would employ separate stimulus lists for positive and negative US. On each randomly ordered critical trial (randomized using a distinct trial_rand value), each US list would be paired with a single explicitly defined CS. For example, were we to name the image (.png) file of the CS+ "csp" and the stimulus list file containing positive US "usp", we would set the suppressed static image as "csp.png_$usp.txt." The use of the $ prior to the stimulus list means that images will be pulled from the list randomly without replacement. We would also use randomly ordered filler trials (randomized between other filler and/or critical trials using a distinct or identical trial_rand value).

This example conveys a few of the decision points you may encounter when designing your own studies. A full accounting of the many options is not possible here, but we encourage you to read the entire documentation.

CONCLUSION

Unconscious cognition looms large in major historical works by James, Freud, and others, and plays a role in several theories in contemporary psychology. Yet, debate remains about whether processes purported to be unconscious actually are unconscious. Techniques aimed at ruling out the operation of conscious cognition in a purported unconscious process suffer from technical and practical limitations. CFS expands the window for studying unconscious cognition without contamination from consciousness, offering significant potential for researchers. However, until now, CFS has been difficult to implement. Because of its relatively low cost and ease of use, our hope is that CFS-VR will allow researchers greater opportunities to tackle longstanding questions about unconscious cognition.

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