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TRINITY COLLEGE

MANIPULATION OF CONSCIOUS AWARENESS USING CONTINUOUS FLASH SUPPRESSION AND VIRTUAL REALITY

BY

Patricia Gaitan

A THESIS SUBMITTED TO
THE FACULTY OF THE NEUROSCIENCE PROGRAM
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Manipulation of Conscious Awareness

Using Continuous Flash Suppression and Virtual Reality

BY

Patricia Gaitan

Honors Thesis Committee

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Introduction

How is it possible that retinal images get transformed in such a way that organisms perceive the outside world? For physical stimuli to be perceived, the image of that object has to travel through the visual pathway and reach one's consciousness. However, the question lies in whether everything that hits the retina makes it to one's conscious awareness. Undertaking the task to study consciousness is a big job and it remains one of the biggest questions that neuroscience researchers aim to explore. Exploring how conscious awareness works intends to answer specific questions that researchers have, such as, can stimuli that we are not aware of still be processed by the brain and therefore affect our actions?

For a stimulus to reach conscious awareness, its retinal image first needs to travel down the visual pathway. The image of stimuli first hits the retina, and the signal it propagates travels to the lateral geniculate nucleus of the thalamus and then heads to the primary visual cortex (Tamietto & Gelder, 2010). However, from the primary visual cortex, that visual information can travel all throughout the brain through the ventral and dorsal pathways (Tamietto & Gelder, 2010). It is important to note that multiple areas of the brain that could be affected by visual stimuli since connections within the brain are all interconnected. This network of connections means that one area of the brain could be affected by the activation of another. A dramatic examples of this is seeing an oncoming car, that perception of the car activates the sympathetic nervous system, the fast acting system that creates immediate responses, which in this case would be jumping out of the way (Kandel, Schwartz & Jessel, 2000). The image of the car that hit the retina had to travel to the primary visual cortex and it set off a domino effect of activation within the brain to result in the action of jumping out of the way. However, imagine if images of stimuli are able to hit our retinas without reaching awareness. What would be the consequences? One outcome could be unperceived stimuli traveling from the primary visual cortex to the prefrontal cortex and influencing a person's decision making.

A person's feelings and actions are largely affected by what they see. Yang and Yeh (2018) investigated whether unperceived stimuli had an effect on how participants reacted to an emotionally charged word. First, participants were shown either a happy or fearful face but it was visually suppressed so that the participant had no knowledge of the nature of the face. Afterwards, they were shown a word that had either a positive or negative meaning and were asked to press buttons on the keyboard to rate the emotional valence. The point was to see if the face could affect how the participants rated the words. If on the trials that they rated it negatively, there were more fearful faces being presented to them, then one could say that the unconsciously processed face affected how they felt about the word shown. The results showed that indeed, there was a link between the fearful faces and the negative words as well as the happy faces and the positive words. Therefore indicating that stimuli not consciously perceived by a person can have an effect on a person's actions. Not to mention that the nature of the stimuli can affect the nature of one's actions; that positive stimuli results in positive actions but also that negative stimuli can result in negative actions.

The brain is always receiving two different images due to the eyes looking out at the world from slightly different locations. However, the images are similar enough that the brain is able to combine them into a single perception of the outside world. Studies have taken advantage of this fact to study conscious awareness. Tong and colleagues (1998) showed participants overlapping images of a red house and a green face. Participants looked at these images through red and green glasses, so that only one eye was receiving the image of the house and the other eye was receiving the image of the face. The images of the house and face were constantly hitting the retinas of the eyes and never wavered, but the filtering of the glasses caused only one of the images to be perceived. Since the images are not alike, the brain cannot combine them and therefore, binocular rivalry is occurring. What is important to note is that the participant was not seeing the images at the same time, the perception was switching back and forth automatically. To show this perceptual switch, researchers used functional magnetic resonance imaging (fMRI), participants pressed one button when they saw the house and another when they saw the face. Researchers saw the activity in the fusiform face area (FFA) increase when participants indicated they were seeing the face and they saw activity increase in the parahippocampal place area (PPA) when they indicated seeing the house. This experiment showed that although the image on the retina never changed and both images were presented at the same time for the same amount of time, there was one point where one of the images was not consciously perceived although the image was being presented to the retina.

The previous study showed that images that are presented to the retina must go somewhere even though they are not perceptually perceived. Another study investigated whether a fear response can be obtained unconsciously through continuous flash suppression (Raio, Carmel,Carrasco & Phelps, 2012). Continuous flash suppression (CFS) is a method in which one eye is presented with a dynamic stimulation and the other is presented with a still image; the interocular suppression will render the static image invisible (Koch, 2008). Participants were put into two groups, an aware group and an unaware group. They were presented with a male or female fearful face, one of which was paired with a mild shock on the wrist for half of the trials in which it was presented and the other that was never paired with a shock (Raio et al., 2012). The images were suppressed for four seconds by the dynamic mask presented to one eye and researchers measured increases in skin conductance because they defined fear as the anticipatory physiological response to a stimuli that predicts an aversive outcome. They confirmed successful manipulation by asking all the participants to say what face they had been presented and to rate the confidence in their answer on a scale that ranged from a guess to completely sure. Researchers found a greater number of changes in skin conductances in the group that was showed the image paired with the shock. This study showed that CFS was successful in rendering images invisible. Although participants could not perceive the images, the images were being unconsciously processed by the brain since their bodies presented with a physiological response in anticipation to the images that were paired with the shock.

A similar experiment, conducted by Tooley and colleagues (2017), exhibited a similar result. Participants were randomly assigned to an aware group or CFS group and were showed positive emotional images (erotic couples) or negative emotional images (mutilations). Skin conductance was recorded and participants completed an addition task to ensure that were paying attention to the display and to determine if the image was being rendered invisible in the CFS group. Superimposed into the mask were a number of dots and the task called for the participants to count the total number of dots. Like Raio and colleagues (2012) found, there was modulation of skin conductance response when participants viewed an emotional image compared to neutral image under the CFS condition.

Another study to show the success of CFS to suppress images was conducted by researchers Sperandio, Bond and Binda (2018) using pictures of the sun. Using a stereoscope and a sheet of cardboard as a divider, participants were shown a series of 13 different images of the sun and a scrambled counter-part that was matched for luminance. The participants were tested in a CFS condition and non-CFS condition . In the CFS condition, the image was shown on the left side of a monitor and on the other side was the dynamic stimulation; while in the non-CFS condition, the images were clearly seen by the participants. The researchers also asked the participants to report if they saw any image besides the dynamic mask in order to ensure suppression. They tracked the participants' eyes to measure the change in pupil diameter in response to the static images. The results showed that the participants' pupils changed in size when they were presented with pictures of the sun and their scrambled counterpart but not when the mask was present. These results further support the idea that CFS can be used to suppress images from awareness.

Interestingly, researchers have used CFS to test senses other than visual. Delong and colleagues (2018), were intrigued by how signals from different senses interact with each other without awareness. Participants were shown a series of targets and masks that were shown on a grey background and they were either in the CFS group or nonCFS group. During the trials with CFS, one eye was shown the target stimulus (a flash) or they weren't, while a dynamic stimulation was shown to the other. In addition to the visual stimulus, an auditory burst of white noise was presented during their trials. The researchers showed that unconscious visual signals influences how the participants construed their auditory world. More specifically, when the visual flashes were shown, they altered the participants' perception of the location of the sound. These results support the idea that it is important to learn more about how stimuli that we are not perceiving, and that we are not aware that we are not perceiving, can affect our other senses and therefore, our actions.

CFS is used to control binocular rivalry because there is not a switch from the mask to the still stimulus due to the dynamic nature of the mask. By being able to keep the stimulus invisible for long periods of time, researchers can investigate what is happening to the invisible stimuli. Previously, administering different images to the two eyes proved to be a difficult feat as cumbersome hardware was required like a four mirror stereoscope and a split computer screen. It required meticulous calibrating for each participant and rearranging the mirrors to ensure that each eye was actually getting different images and there wasn't any overlap.

The idea that CFS can be used to render images invisible begs for the question of practicality to be asked. As interesting as it is to see that people feel like they cannot see images that hit their retina, how can neuroscientists take this finding and apply it to the real world? One way that Oyarzún and colleagues (2018) took advantage of these findings was to incorporate CFS into forms of exposure therapies. They hoped to test whether implicit exposure of certain stimuli could lead to an effective reduction in avoidance behavior with participants that experienced extreme phobias. The researchers tested this hypothesis by having two groups of participants that went through a reinforced threat-conditioning paradigm. Of three fearful faces that they were shown, two were paired with an electric shock to the wrist on 75% trials and the third was used as a neutral stimulus. The following day, one group went through implicit extinction, where one of the faces paired with a shock and the neutral stimulus were presented unconsciously using CFS and no shocks were given. The other group underwent explicit extinction, where one of the faces paired with a shock and the neutral stimulus were presented explicitly, the dynamic stimulation was shown before the face presentation so the faces were fully visible to the participants. On the third day, both groups were shown all three faces without the shocks. Researchers tested the participants' defensive responses by measuring their threat-potentiated startle reflex and electrodermal activity. They found that on the third day, only the group that underwent implicit extinction showed reduced spontaneous recovery of defensive responses. These effects were seen in the results by the threat-potentiated startled reflex measurements but not the electrodermal activity. Oyarzún and colleagues (2018) determined that implicit extinction using CFS could assist in changing the affective components of fearful memories.

To continue discussing CFS being used for possible therapies, Gray and colleagues (2018) investigated the degree to which individuals with autism payed attention to rewarding social stimuli in comparison to individuals without autism. As discussed in the paper, there is a social motivation theory of autism that suggests social stimuli elicits lower levels of reward in individuals with autism than in individuals without autism (Chevallier, Kohls, Troiani, Brodkin & Schultz, 2012). The American Psychiatric Association reports that individuals with autism show abnormalities in their social interactions and communication that is characteristic to the disorder (2013). There were two groups tested, both made up of adults, one with individuals with autism and the other without. Both groups were presented with 16 images that were chosen based upon their cadence and arousal ratings from previous studies. A combination of images were shown, either in grey-scale and matched on luminance and contrast or with negated contrast and inverted as to control for any condition that may enhance the possibility of facial recognition accuracy and detection. Each trial was shown under interocular suppression using CFS and the image was positioned randomly on the left or right side of the screen. On each trial, the participant had to say on which side of fixation they saw something other than the noise given off by the mask and after the experiment, they were asked to rate the stimuli for valence and arousal. The researchers measured response time to asses how quickly the scenes were emerging from suppression. In the group of individuals without autism, researchers concluded that the social stimuli broke through the suppression more quickly than nonsocial stimuli but not when the images were manipulated; both stimuli took the same amount of time to break through the suppression. When the experiment was replicated in those with autism, they did not see an effect by the social content to break through the suppression. This clear difference between the group with autism versus the one without when it came to the time it took for the stimuli to break through the suppression led researchers to conclude that social stimuli does indeed receive privileged access to awareness. While therapies for disorders are not created based off the findings of one study, it is interesting to think of using this method as a way to asses young children for autism. Being able to diagnose children with the disorder at younger ages would allow for the introduction of early interventions, which could lessen any detrimental effects of autism (Rogers, 1996).

Aside from possible therapies, another question pertains to the importance behind these findings. Why does the fact that invisible images make it to our conscious matter? Vetter and colleagues (2019) cited studies in which it was shown that the recognition of emotional expression did not require awareness. Therefore, they sought to test if threat-related emotional stimuli could guide eye movement even if they were rendered invisible. Participants had their eyes tracked and were presented with images of emotional faces (i.e. angry faces, fearful faces and neural faces). However, the faces were rendered invisible using CFS, by presenting the low contrast face to the non-dominant eye while the dynamic stimulation was presented to the dominant eye. The reason for the different faces was because researchers went a step further to see how the different emotional faces were processed and how they affected eye movements. The fearful face was indicative of a threat in the environment, while the angry face presented a threat to the participant. The neutral face was used as a control to see the effects that a face would have on eye movements when it was unrelated to a threat. Results showed that when compared to the neutral faces, participants would look at the fearful faces and away from the angry faces. From these results, researchers concluded that threat-related emotional faces have the ability to guide oculomotor actions even when they are do not reach awareness. These findings are important because they introduce the idea that stimuli that we are not conscious to can have an effect on our physical actions.

For my thesis, I hope to investigate the parameters that will give the maximum amount of suppression using CFS and virtual reality to have a reliable technique to study consciousness in the lab. Virtual reality (VR) works similarly to how people normally see the world. As stated before, each eye receives slightly different images but they are similar enough that the brain can combine them into a single perception. A VR headset does the same thing, there are slightly different images presented to the eyes but they are similar enough that the brain combines them into a single perception. The idea behind using VR in conjunction with CSF is validating a method that could be used to study consciousness in a portable way. A transportable method to study consciousness could open up doors by studying the conscious awareness of diverse populations, like countries that don't have the technology accessible to them or those with a disability who may not be reached by standard methods of recruitment or are in a special facility. In collaboration with Trinity College's Engineering Department, I set out to empirically validate continuous flash suppression with virtual reality as a way to manipulate consciousness in lab. We designed a simple orientation discrimination task to be conducted with and without a continuous flash suppression mask. We hypothesized that task accuracy will be reduced when the mask is present, and if the mask is capable of suppressing the image of the emoji from conscious awareness, participants will be at chance in the orientation discrimination task.

Methods

Study Overview:

Three separate experiments were conducted. In each experiment, participants sat in a computer chair in front of a Windows PC monitor screen and keyboard. Participants were briefed with instructions on how to complete the task before the experiment started. They were told that on each trial they had to discern the orientation of the emoji and to press the up arrow key on the keyboard, if the emoji was upright and press the down arrow key if the emoji was upside down.

To begin, participants put on the virtual reality headset, pressed the spacebar to begin and conducted practice trials, where the emoji was always present, to become accustomed to the button press. Then, they underwent 400 trials; 200 trials with visible emojis and 200 trials where the emoji was suppressed. The distance of the eyes to the lens within the virtual reality headset was 4.1 cm and had a vertical height of 9.356 cm. During the suppressed trials, the mask, a dynamic Mondrian pattern, was presented to one eye while the emoji was presented to the other. The eye to which the mask was presented to alternated between eyes within the 200 suppressed trials. Meaning, the right eye was suppressed for a total of 100 trials and the left eye was suppressed for a total of 100 trials; but the suppression randomly alternated between eyes. The 400 trials were broken up into nine blocks, with 44 trials in each block. After pressing a key discerning the emoji's orientation, the fixation cross would reappear in the center turn green, if correct, or magenta, if incorrect. Participants had the option of pressing the space bar to continue on with the experiment or take a short break and then continue.

Participants:

In each experiment, there were 15 participants (Table 1). Participants were recruited through a printed flyer and word of mouth. Flyers were distributed throughout Trinity College, posted on bulletin boards and showed in classes. Interested volunteers sent an email to the Perception Lab email and scheduled a time to run the experiment. When they arrived at the lab, they signed a consent form and escorted into the lab room where the procedure would take place. After the experiment was completed, participants received $10 for participating and signed a receipt form.

Table 1. Participant Demographics

	Experiment 1	Experiment 2	Experiment 3
Females	13	7	13
Males	2	8	2
Age (M)	20.3	24.1	19.7

Experiments:

Experiment 1: Single Emoji

A fixation period of 1000ms occurred before the onset of the stimuli. During the visible trials, a yellow, smiley face emoji was presented to both eyes for 500 milliseconds (ms) and the participant reported its orientation using the keyboard (Fig. 1). During the suppressed trials, the emoji was presented to one eye, and the mask was presented to the other eye for 500 ms (Fig. 1).

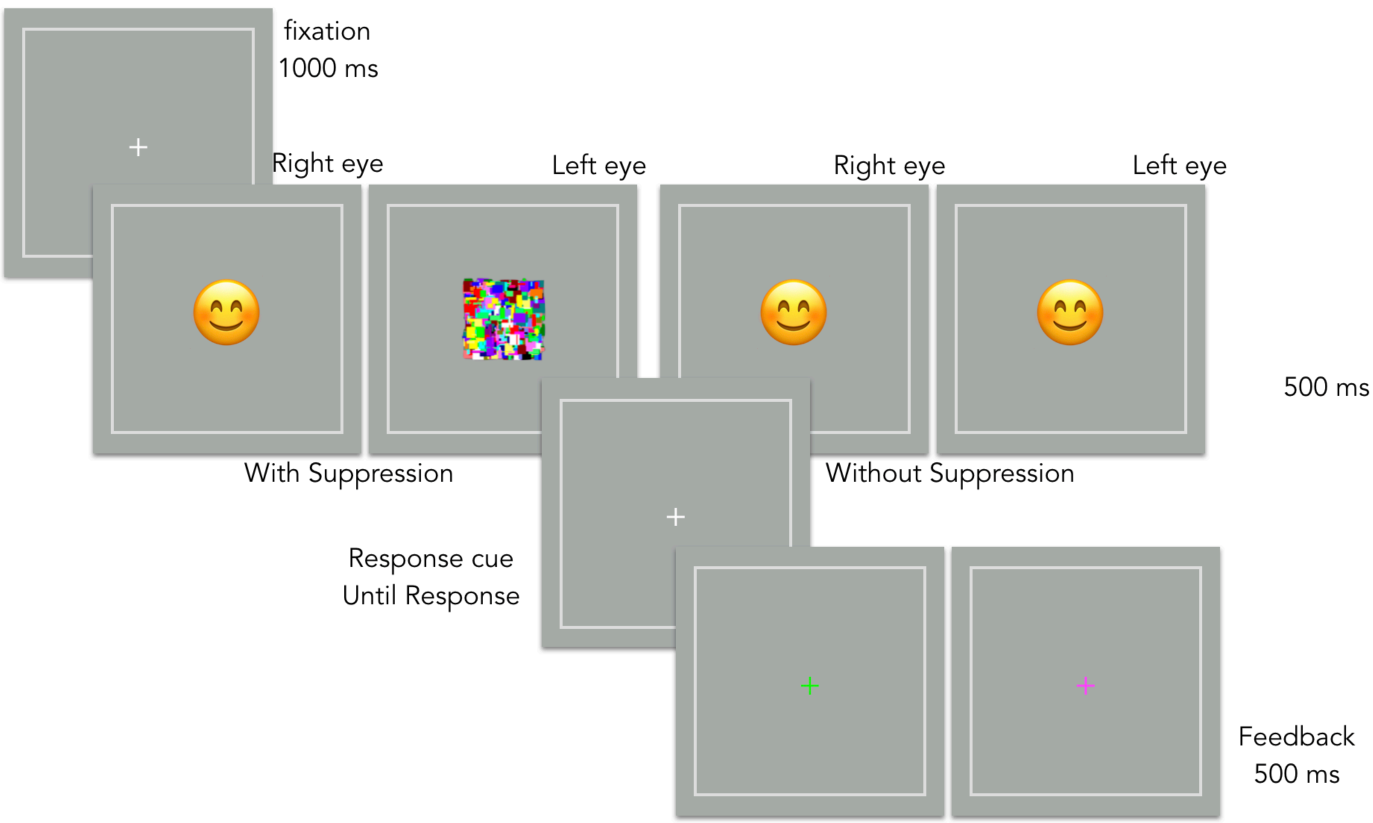

Figure 1. Task Sequence
Task sequence of a with suppression (left) and without-suppression (right) trial. Final perception for the with suppression trial is that of the mask and for the without suppression is that of the emoji.

Experiment 2: Random Emojis

While the target in the first experiment was always the yellow, smiley face emoji, during the second experiment, it was randomized. The different emojis were still faces but were not limited to the yellow type, human faces were included. During the visible trials, the emojis were presented to both eyes for 100 ms. During the suppressed trials, the dynamic mask was first presented to one eye for 500 ms and the still emoji would appear for 100 ms at different points of the mask duration (Fig. 2). This was to ensure that every trial was different and the participant would not be able to learn a pattern and manipulate their eyes to surpass the suppression and clearly see the emoji.

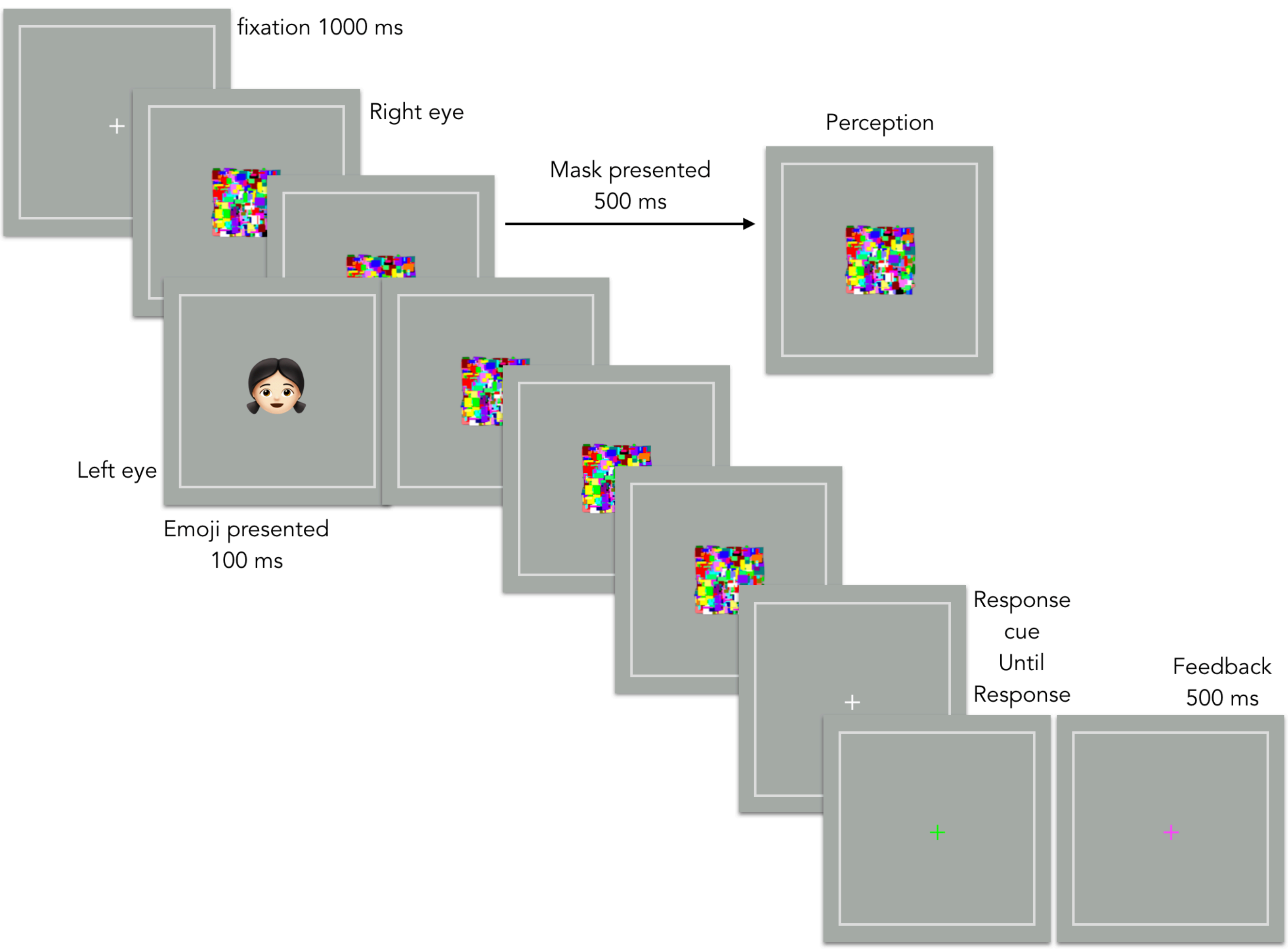

Figure 2. Task Sequence
Task sequence of a with suppression trial. One eye is presented with the emoji for 100 ms and the other is presented with the dynamic Mondrian pattern for 500ms. The onset of the emoji is random within the mask presentation time. The final perception is of the dynamic Mondrian pattern.

Experiment 3: Black and White Emojis

The set up and timing was the same as experiment 2. The only difference were the randomized emojis shown were in black and white, instead of the original color. (Fig. 3).

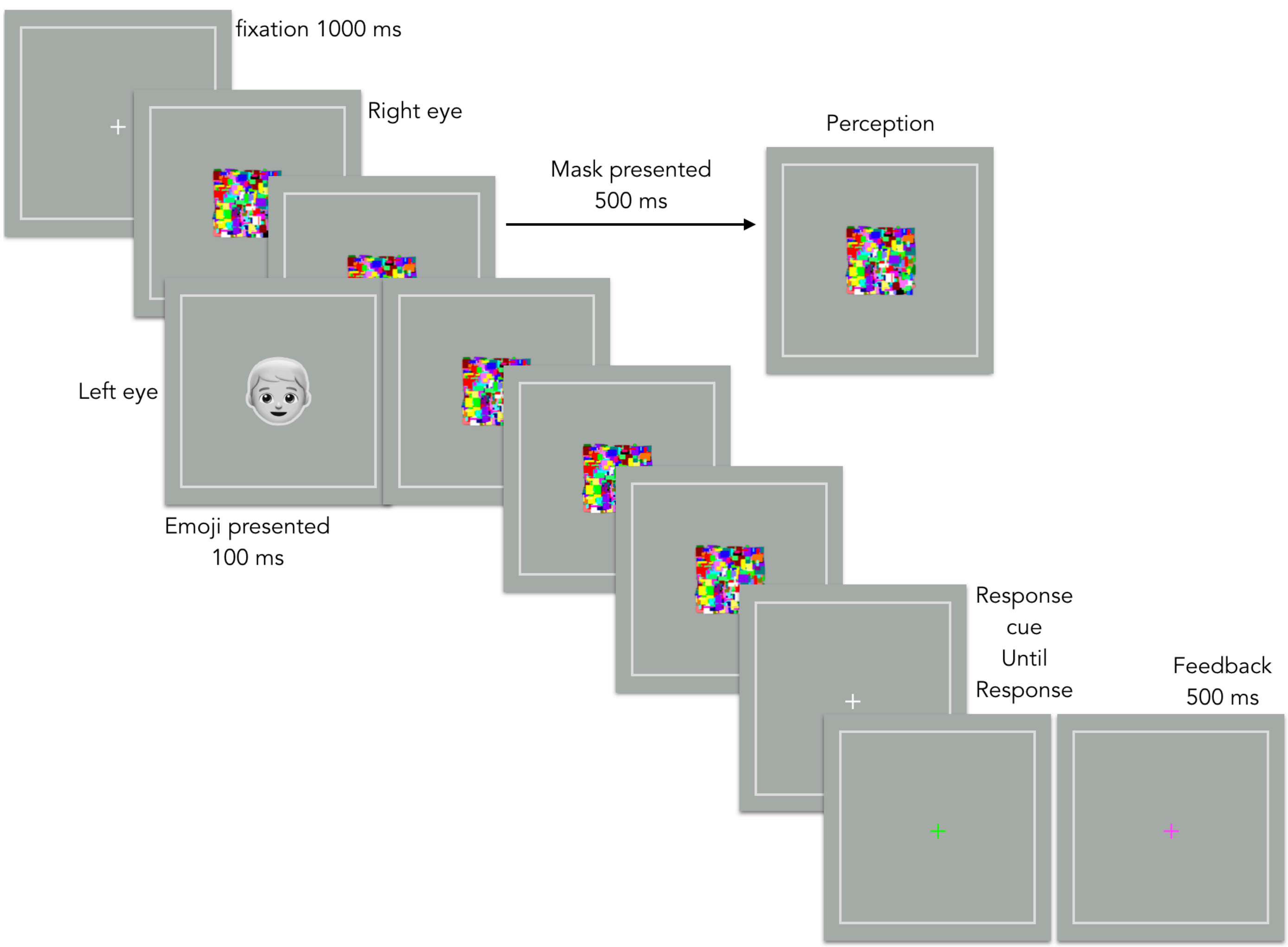

Figure 3. Task Sequence
Task sequence of a with suppression trial. One eye is presented with a black and white emoji for 100 ms and the other is presented with the dynamic Mondrian pattern for 500ms. The onset of the emoji is random within the mask presentation time. The final perception is of the dynamic Mondrian pattern.

Data Analysis:

Data was analyzed in MatLab. The independent variables were whether the suppression was present or absent and when present, which eye was being suppressed, left or right. The dependent variable was the participant's accuracy in the orientation discrimination task (i.e. whether the emoji was upright or inverted). Paired- sample t-tests were conducted to compare the task accuracy in the with-suppression and without suppression conditions. The minimum proportion correct was determined for each eye, due to the possibility that the suppression could be more effective if delivered to the dominant eye, and an additional t-test was conducted to determine if these values were significantly different from 0.5 proportion correct (i.e. chance accuracy in a two-alternative forced-choice task). Since there were only 100 trials for each eye in the suppressed condition, we ran simulations in MatLab and calculated that 0.4-0.6 proportion correct is the range of accuracy a participant could achieve if they were simply guessing.

Due to the rapid presentation of dynamic stimuli, computer processing issues may have resulted in the emoji being not presented on a small subset of trials; future versions using this VR based approach will work to address this potential problem and reconfirm the validity of our findings. We note this here in the spirit of full transparency and scientific rigor.

Results

A paired- sample t-test was conducted to compare the task accuracy in the with-suppression and without suppression conditions. The first version showed a significant difference between conditions (Fig. 4, see Table 2 for statistics). These results indicate that the mask was able to significantly reduce the performance of the participants. To further the investigation, another paired-sample t-test was conducted to determine if the proportion correct within the suppressed trials was different than at chance. The analysis revealed that task accuracy was significantly different than chance (Fig. 5, Table 2). Looking at the 15 participants individually, 6 of them performed better than our range of accuracy predicted from our simulations. There were 6 participants that experienced maximum suppression in their left eye, 7 experienced it in their right eye and 1 showed to have the same proportion correct in both eyes.

In the second version, the same analysis was applied. First, looking at the test accuracy between the two conditions, a significant difference was seen (Fig. 6, Table 2). Again, we were able to confidently say that the mask significantly reduced the performance of the participants. Then, looking within the suppressed trials, the analysis showed that there was not a significant difference between proportion correct when compared to the known at chance proportion (Fig. 7, Table 2). Looking at the 15 participants individually, one performed better than our range of accuracy predicted from our simulations. There were 9 participants that experienced maximum suppression in their left eye, 3 experienced it in their right eye and 3 showed to have the same proportion correct in both eyes.

The same analysis was applied to the black and white version. Again, the with-suppression condition was significantly than the without suppression condition (Fig. 8, Table 2). Comparing the suppressed proportion correct to chance did not yield evidence that participants were performing better than chance (Fig.9, Table 2). In this version, out of the 15 participants, four of them performed outside our range of accuracy predicted from our simulations. There were 6 participants that experienced maximum suppression in their left eye and 9 experienced it in their right eye.

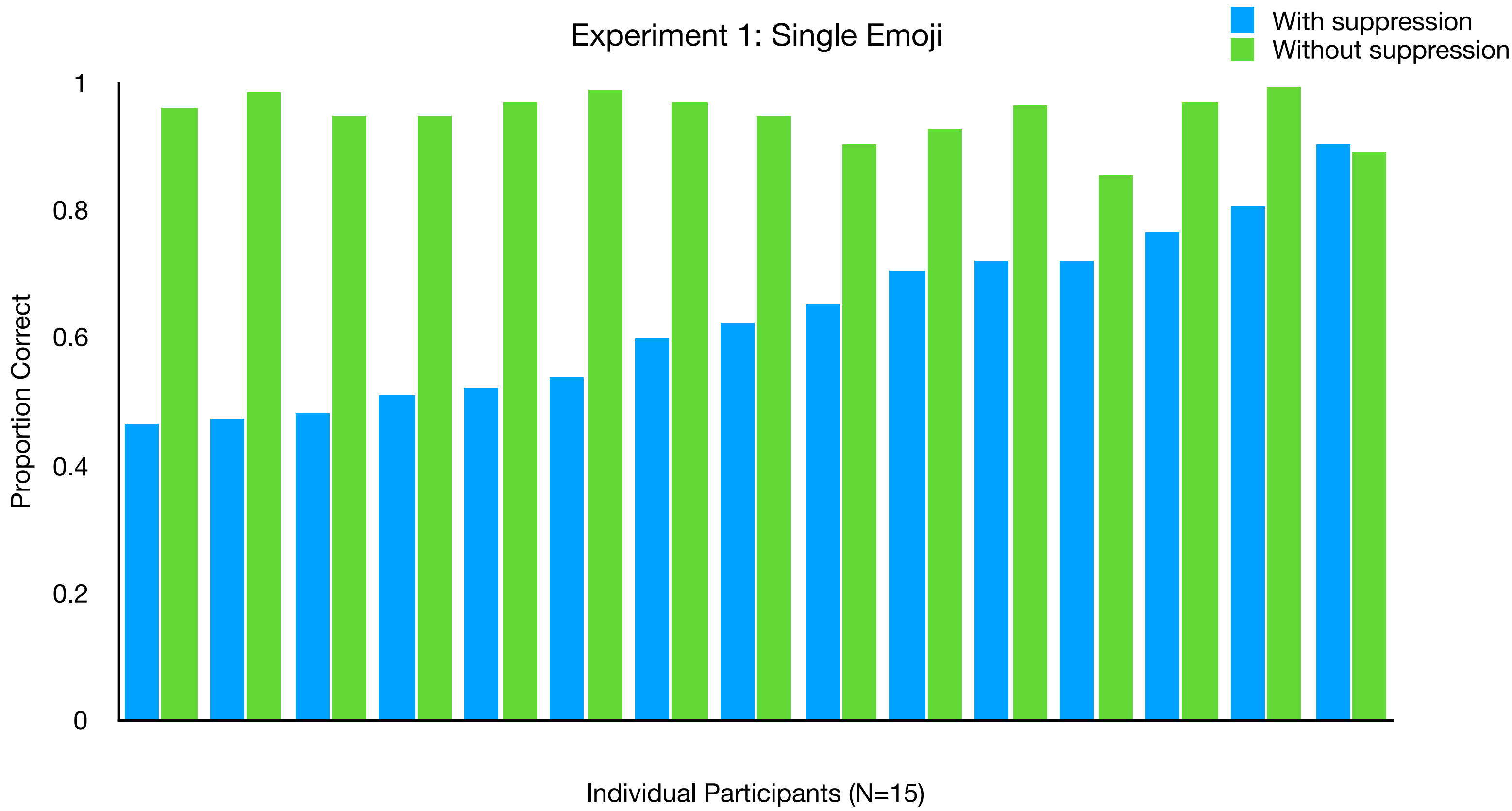

Figure 4. Shows the proportion correct of determining emoji orientation in trials with suppression compared to trials without suppression. A yellow, smiley face emoji was shown upright or upside down. The mask significantly reduced accuracy between groups, $t(14) = -7.93$, $p < 0.0001$.

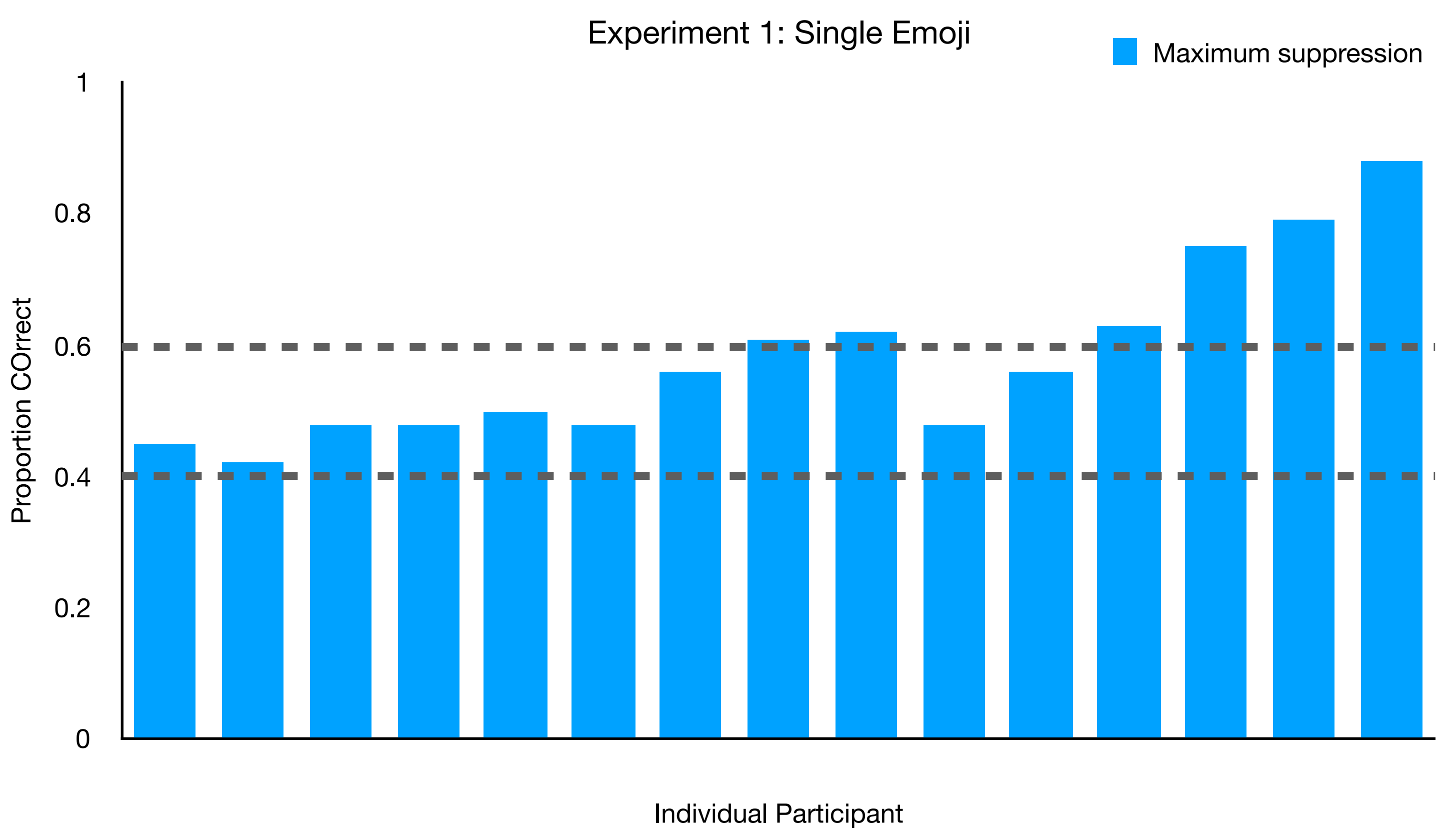

Figure 5. Shows the proportions correct of determining emoji orientation in trials with suppression compared to at chance. The minimum suppression values were significantly different than chance proportion; $t(14) = 2.26$, $p = 0.0399$.

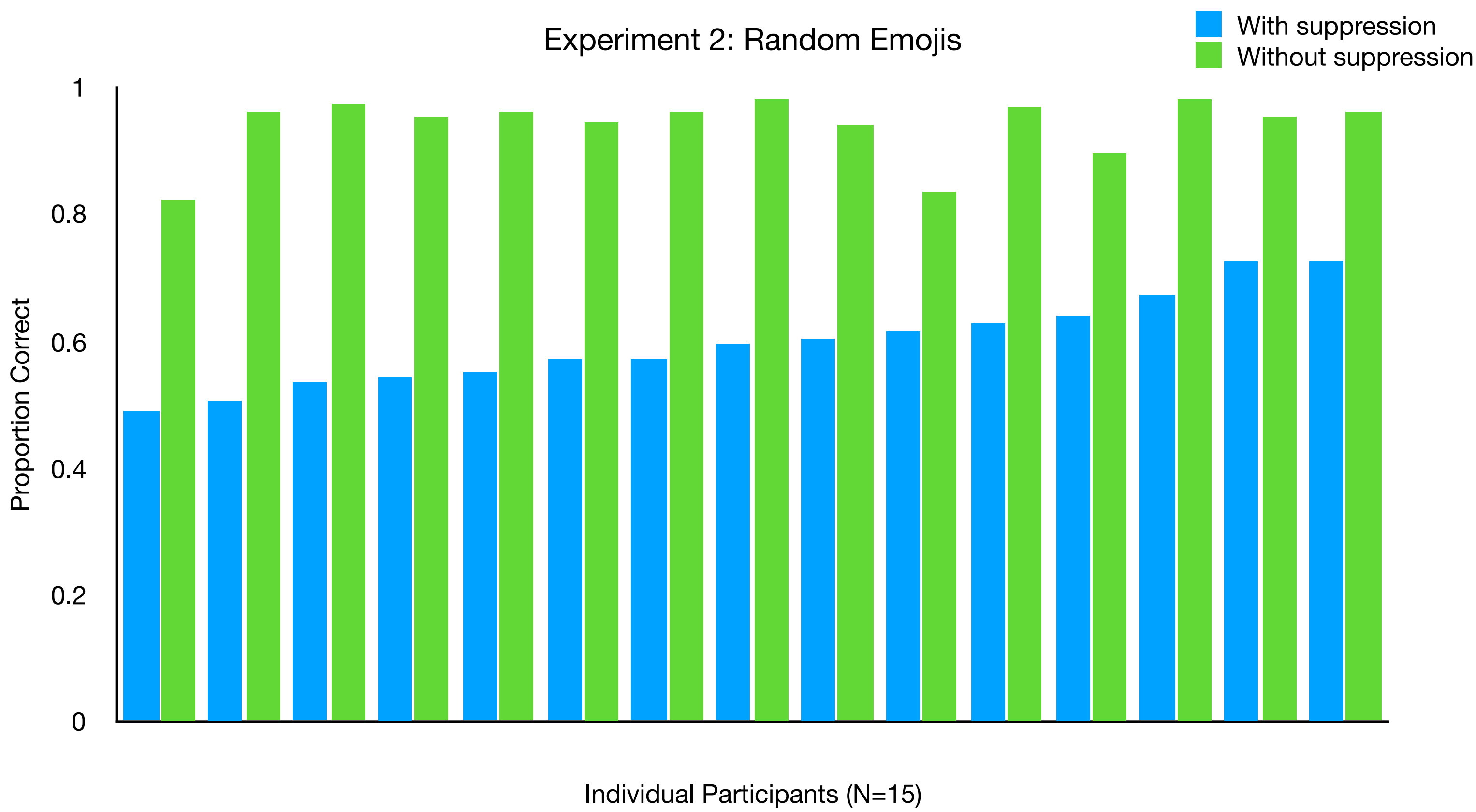

Figure 6. Shows the proportion correct of determining emoji orientation in trials with suppression compared to trials without suppression. A range of different emojis were shown were shown upright or upside down. The mask significantly reduced accuracy between groups, t(14)= -16.99, p< 0.0001.

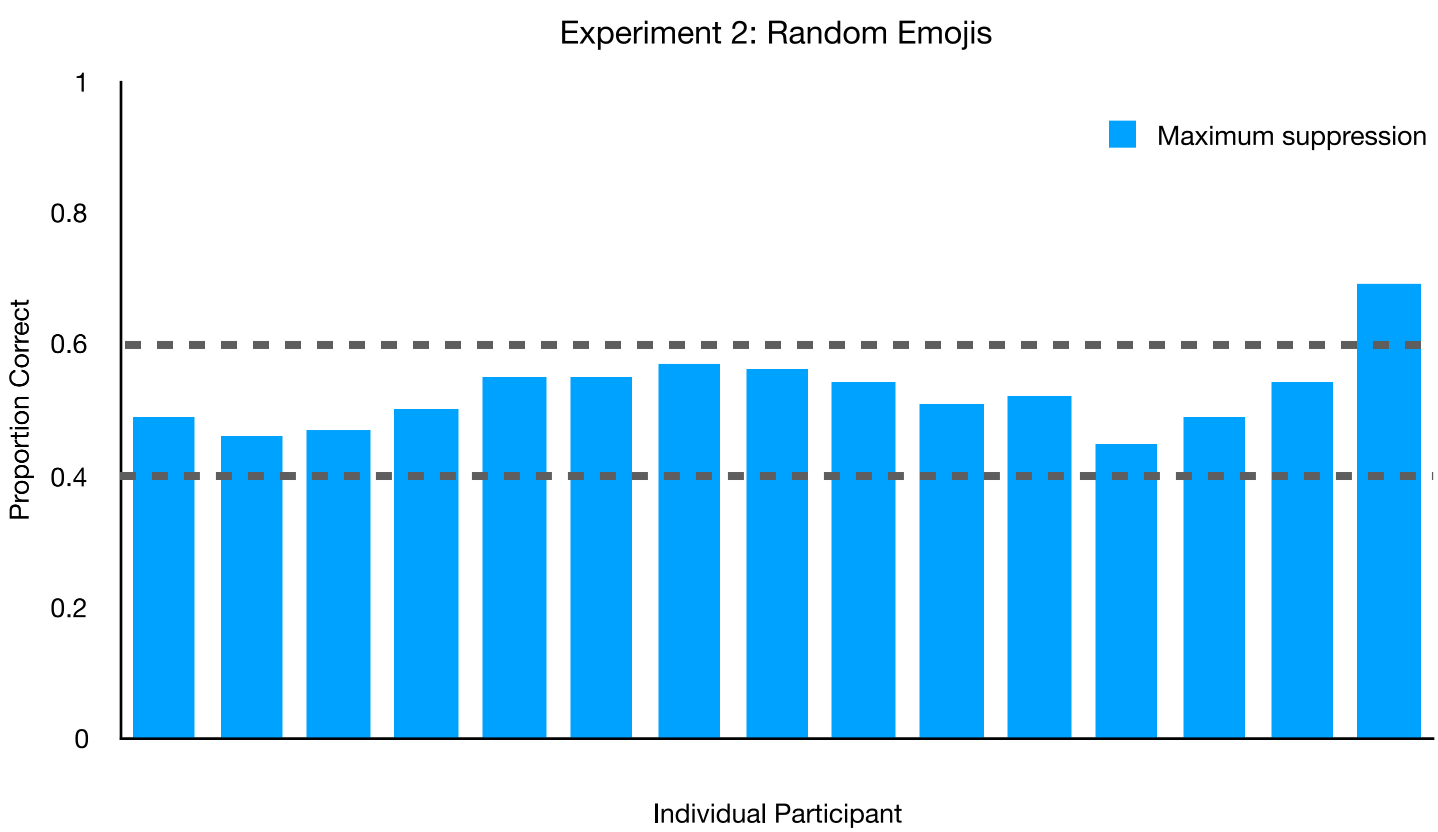

Figure 7. Shows the proportion correct of determining emoji orientation in trials with suppression compared to at chance proportion. There was not a significant difference, therefore, there is no evidence to say that participants were performing better than chance t(14)= 1.71, p=0.1087.

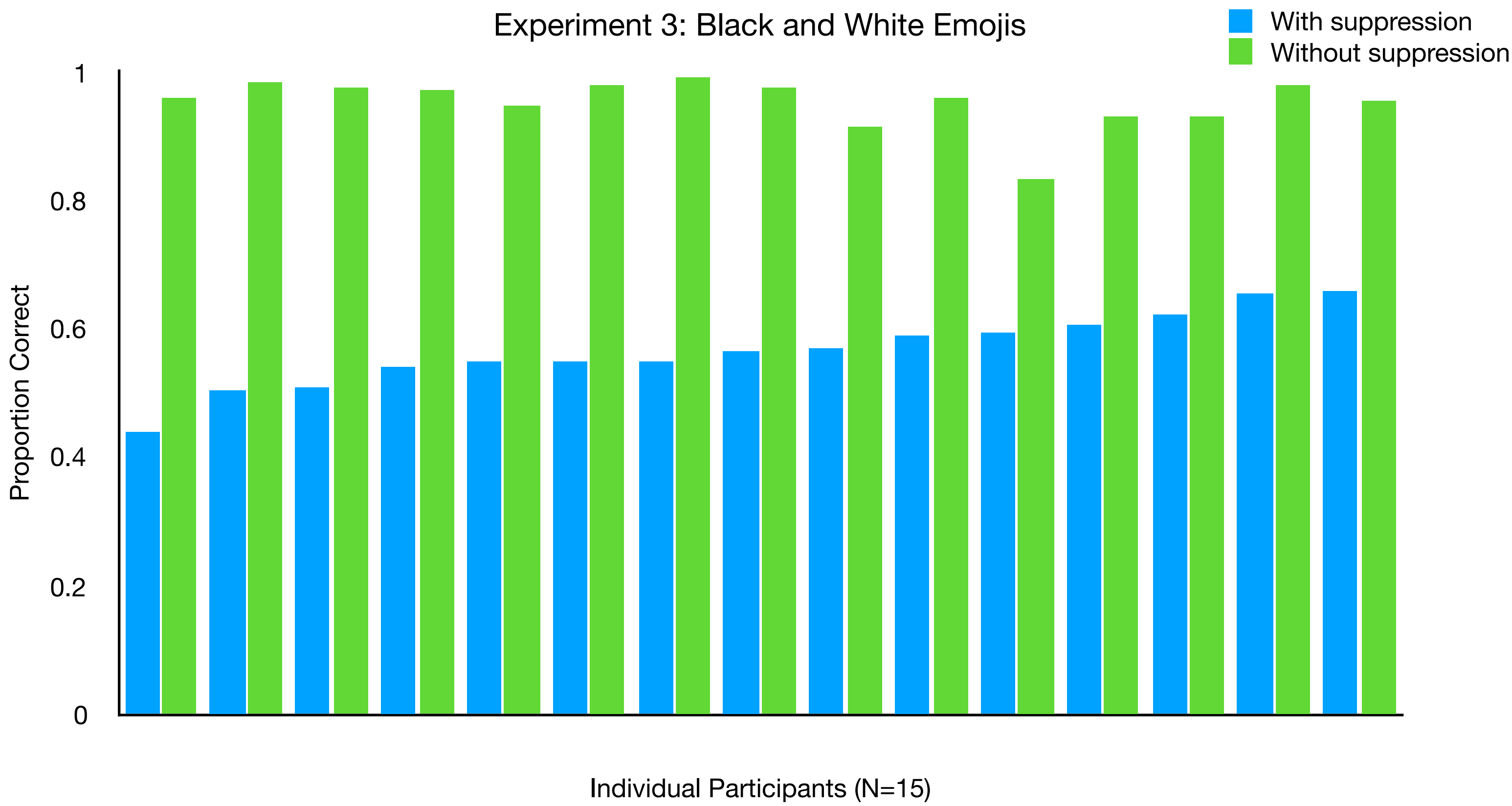

Figure 8. Shows the proportions correct of determining emoji orientation in trials with suppression compared to trials without suppression. A range of black and white emojis were shown upright or upside down. The mask significantly reduced accuracy between groups, $t(14) = -19.13$, $p < 0.0001$.

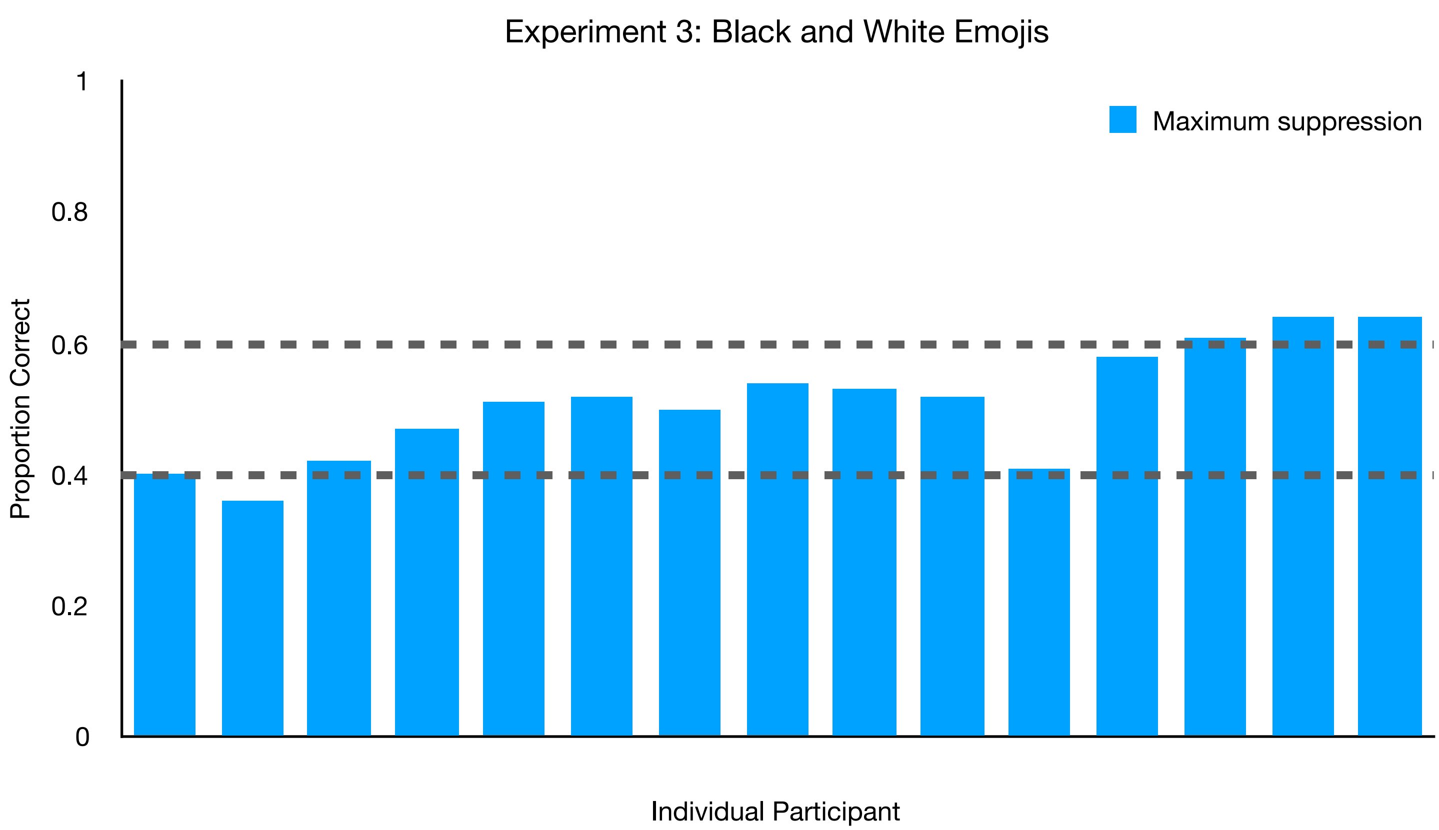

Figure 9. Shows the proportion correct of determining emoji orientation in trials with suppression compared to at chance proportion. There was not a significant difference, therefore, there is no evidence to say that participants were performing better than chance $t(14) = 0.4481$, $p = 0.6610$.

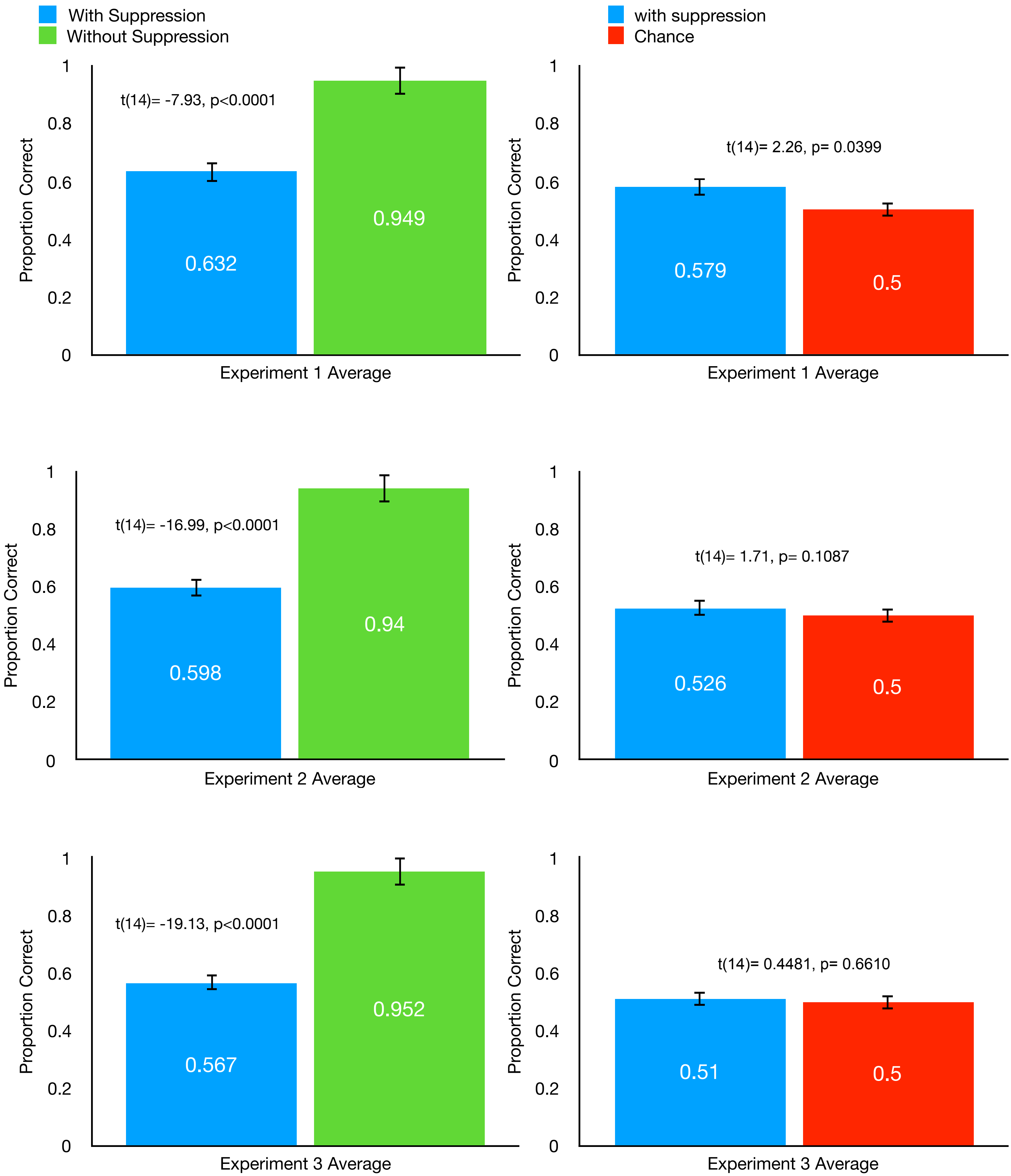

Fig. 10. On the left (blue and green bars) shows the average proportion correct for all participants in each condition. On the right (blue and red bars) shows the average proportion correct for the with suppression condition compared to 0.5 chance accuracy. T-statistics show the significance between bars.

Table 2. Performance Accuracy

	Exp. 1	Exp. 2	Exp. 3
With Suppression (M)	0.6323	0.5983	0.5670
Without Suppression (M)	0.9490	0.9397	0.9523
t	-7.93	-16.99	-19.13
p	<0.0001	<0.0001	<0.0001
Maximum Suppression (M)	0.5793	0.5260	0.5100
t	2.26	1.71	0.4481
p	0.0399	0.1087	0.6610

Discussion

In the course of the last year, we conducted three separate experiments to investigate the parameters that would give the maximum amount of suppression using CFS and virtual reality to study consciousness in the lab. For all experiments, participants were asked to report the orientation of an emoji, either upright or inverted, using the up arrow keys on the keyboard. There were 400 trials in total, 200 trials were suppressed and 200 were not suppressed. During the suppressed trials, a dynamic Mondrian pattern was presented to one eye while the emoji was presented to the other. Due to the dynamic nature, interocular suppression renders the image invisible (Koch, 2008).

In the first experiment, a yellow, smiley face was presented to one eye (with suppression condition) or both eyes (without suppression) for 500 ms. We found that while the mask significantly reduced task performance between the two conditions, the task performance was significantly different from chance within the suppressed condition. In the second experiment, we changed the emoji presented and adjusted the timing of onset and presentation. The emojis were now random and of different types and were only presented for 100 ms at a random point of the 500 ms mask presentation. Again, we saw that the mask was able to significantly reduce task accuracy between the two conditions. However, this time task accuracy within the suppression condition was not significantly different from the at chance proportion. Therefore, it is fair to say that the image was successfully rendered invisible. In the third experiment, the timing and emoji onset was the same as the second experiment except the emojis were shown in black and white. Similar results were found, the mask reduced the task accuracy between conditions and task accuracy within the suppression condition showed that participants were not performing better than chance.

Previous studies verified effective suppression in a number of ways. Vetter and colleagues (2018) tracked the eye movements while showing their participants images of emotional faces. However, the faces were hidden with CFS yet they still saw that participants were looking away from the angry faces even though they were not perceiving them. Oyarzún and colleagues (2018) confirmed suppression by. hiding fearful faces that were paired with a shock and measuring the threat-potentiated reflex. Multiple studies used self-reporting and confidence ratings on images that were shown with CFS, but confirmed the reports using skin conductance (Tooley et al., 2017; Raio et al., 2012). Sperandio, Bond and Binda (2018) recorded pupil size to confirm suppression because they showed participants pictures of the sun. They saw that the pupils changed in size when the pictures were visible but not when the mask was present. Depending on what the study called for, researchers wanted to ensure that the results were a product of unconscious processing. Attempting to study consciousness is a difficult task and without a way to ensure that stimuli are being rendered invisible, then researchers cannot confidently report that unconscious processing is occurring.

Our study had its strengths and weaknesses. With each experiment, the parameters were tightened to produce better results. In the first experiment, in the with suppression condition, task accuracy was significantly different than chance. Due to mask and emoji being presented for the same amount of time, we believed that participants had enough time to move their eyes and break through the suppression. Therefore, in the following experiments, we kept the duration of the mask the same and set the onset of the emoji to be a fraction of the time, at random points during the mask presentation. In the third experiment, we changed the random emojis from color to black and white to reduce the chances of the stimuli breaking through the mask (Gray et al., 2018). However, looking at the 15 participants individually from the last two experiments, there were less participants that performed outside of our range of predicted accuracy in experiment 2 than experiment 3. This could be due to the color of the emoji blending into the mask and reducing the chances of breakthrough. Whereas, with the black and white emojis, the stark difference between the white features and the gray background may have broken through the mask slightly.

We did not implement any measure during or after the experiments to verify successful suppression because recording performance in the task was the most objective way to ensure images were being suppressed. However, it would be interesting to collect a subjective confidence report in addition to our results. Therefore in future experiments, a questionnaire should be presented to the participant at the end asking if they could see the image. However, it is important to keep in mind that the problem with self-reporting is that the participant may not be accurate in their reports. If they are not aware of what they have to watch out for then asking them after the fact may result in some false reports. Another idea may be incorporating a button press into the code that requires the participant to answer a question about the stimulus or just whether they saw it or not after its onset. Again, these are subjective methods of verification that would be interesting to see in combination, but not in place of, our objective method of verification.

Unfortunately, we did experience some technical difficulties in experiment 2 and 3. We discovered a glitch in which the emoji would not load on some trials; this occurred in both conditions. We hypothesize that the processing speed required was beyond the capability of the software program in the lab. Therefore, future studies should work to address these processing issues and reconfirm the validity of our experiment.

In this study, we saw that the mask was able to reduce task accuracy and when random emojis, in color or black and white, were used participants were at chance in the orientation discrimination task. This method could be used universally to study consciousness because the task is simple and does not involve extensive training so it is not exclusive to any one demographic. Using VR allows for the method to be portable and used to study consciousness in a subset of the population that was not reachable before. This includes countries without the available technology or those with disabilities in a special facility. It would be interesting to see whether certain cultures are more conscious of their surroundings because it is necessary to their lifestyle.

Consciousness is important to study because our world is full of stimuli that we may or may not consciously perceive. These stimuli have the ability to have an effect on our actions. It is crucial to know this as consumers because what we choose to expose ourselves to could have a lasting effect. While it does not matter as much when marketers are using this knowledge to sell their products, it does matter when young children are exposed to violent shows. Without meaning to, they could be processing what they see in a way that will later affect their behavior. Studying consciousness is pivotal and can be beneficial to learn more about a process that affects everyone but not one person the same.

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References

Adachi, P. J., & Willoughby, T. (2016). The Longitudinal Association Between Competitive Video Game Play and Aggression Among Adolescents and Young Adults. *Child Development, 87*(6), 1877-1892. doi:10.1111/cdev.12556

American Psychiatric Association (APA). (2013). Diagnostic and statistical manual of mental disorders (DSM-5) (5th ed.). Arlington,VA: American Psychiatric Publishing.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences, 16*(4), 231-239. doi:10.1016/j.tics.2012.02.007

Delong, P., Aller, M., Giani, A. S., Rohe, T., Conrad, V., Watanabe, M., & Noppeney, U. (2018). Invisible Flashes Alter Perceived Sound Location. *Scientific Reports, 8*(1). doi:10.1038/s41598-018-30773-3

Gray, K. L., Haffey, A., Mihaylova, H. L., & Chakrabarti, B. (2018). Lack of Privileged Access to Awareness for Rewarding Social Scenes in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders, 48*(10), 3311-3318. doi:10.1007/s10803-018-3595-9

Kandel, E. R., Schwartz, J. H., & Jessell, T. M. (Eds.). (2000). *Principles of neural science*. New York: McGraw-Hill.

Koch, C. (2008). Rendering the Visible Invisible. *Scientific American Mind, 19*(5), 18-19. doi: 10.1038/scientificamericanmind1008-18

Oyarzun, J. P., Camara, E., Kouider, S., Fuentemilla, L., & Diego-Balaguer, R. D. (2018). Implicit but not explicit exposure to threat conditioned stimulus prevents spontaneous recovery of threat potentiated startle responses in humans. doi:10.1101/304592

Raio, C. M., Carmel, D., Carrasco, M., & Phelps, E. A. (2012). Nonconscious fear is quickly acquired but swiftly forgotten. *Current Biology, 22*(12). doi:10.1016/j.cub.2012.04.023

Rogers, S. J. (1996). Brief report: Early intervention in autism. *Journal of Autism and Developmental Disorders,26*(2), 243-246. doi:10.1007/bf02172020

Sperandio, I., Bond, N., & Binda, P. (2018). Pupil Size as a Gateway Into Conscious Interpretation of Brightness. *Frontiers in Neurology, 9*. doi:10.3389/fneur.2018.01070

Tamietto, M., & Gelder, B. D. (2010). Neural bases of the non-conscious perception of emotional signals. *Nature Reviews Neuroscience, 11*(10), 697-709. doi:10.1038/nrn2889

Tooley, M. D., Carmel, D., Chapman, A., & Grimshaw, G. M. (2017). Dissociating the physiological components of unconscious emotional responses. *Neuroscience of Consciousness, 2017*(1). doi:10.1093/nc/nix021

Vetter, P., Badde, S., Phelps, E., & Carrasco, M. (2018). The eyes react to emotional faces in the absence of awareness. *Journal of Vision, 18*(10), 613. doi:10.1167/18.10.613

Yang, Y., & Yeh, S. (2018). Unconscious processing of facial expression as revealed by affective priming under continuous flash suppression. *Psychonomic Bulletin & Review, 25*(6), 2215-2223. doi:10.3758/s13423-018-1437-6