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Deana Maryann Vitrano
Dickinson College

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Comparing Perception and Imagination at the Visual Cortex

Deana Vitrano

Dickinson College

Abstract

Previous experiments have compared the processes of perception and visual mental imagery at the visual cortex. Many researchers have reported that the visual cortex is activated during visual imagery, although some believe that the visual cortex is not activated in a functional manner and that mental images are not actually images, but symbolic representations. However, few experiments have compared perception and imagination. Doing so may shed more light on the mental imagery debate. The purpose of the current experiment was to compare recorded brain activity from the cortex during imagination and perception in 30 college students. The participants were asked to imagine both a red and green sinusoidal grating and a black and yellow checkerboard. First, they were given verbal instructions and were shown a grayscale version of the pattern along with the colors they should use to imagine the pattern. Then, they were asked to imagine the pattern in color in their head. Finally, they were shown the actual pattern and were asked how their imagined pattern compared to the actual pattern. Responses were recorded in all conditions. Evoked potential waveforms were created and visually inspected to look for standard component deflections and to visually compare responses from the perception and imagination categories. It was found that the imagined patterns and seen patterns produced similar waveforms, supporting evidence for the claim that the visual cortex is activated in a similar manner during both imagination and perception.

Key Words: mental imagery, imagination, visualization, electroencephalography, ERP

Comparing Perception and Imagination at the Visual Cortex

Visual mental imagery occurs when a memory is recalled, but the stimulus is not present. It is said to be “seeing with the mind’s eye” (Kosslyn & Thompson, 2003). The neural machinery involved in visual mental imagery has long been debated. Many researchers have reported that the visual cortex is activated during visual imagery (Farah, 1989), indicating that perception, or the act of viewing the stimulus, and visual mental imagery share common processes. However, there are some researchers who believe that mental images are not actually images, but descriptions. According to Pylyshyn (1973), visual imagery may depend on language-like, symbolic descriptions called “propositions”, and not the visual system. This theory, the Propositional Theory, proposes that the visual cortex does not play an active role in mental imagery. Instead, it is possible that the same neural substrates involved in language are also involved in mental imagery (Kosslyn & Thompson, 2003). In contrast, the Depictive Theory states that there are pictures associated with mental imagery, and these pictures have a specific point in space and specific spatial relations (Kosslyn, Ganis & Thompson, 2003).

According to Kosslyn and Thompson (2003), the mental imagery debate is not specifically about whether or not propositions are used in creating visual mental imagery, but rather if solely propositions are used or if depictive representations are used as well. At first, the mental imagery debate focused only on philosophy, but then progressed to systematic approaches to better understand the debate. For example, Shepard and Metzler (1971) used a visuospatial task to assess visualization. Participants were shown pairs of three-dimensional objects, and were asked if the first and second object were the same. The researchers found a relationship between reaction time and degrees rotated, providing evidence for the spatial relations between visual images. Kosslyn, Ball and Resier (1978) also investigated the Depictive

Theory of mental imagery by using a visuospatial task. Participants were asked to recreate visual memories based on a map. Specifically, participants had to visually inspect the map and press a button when they could visualize the specific place named by the researcher. It was found that the further on the map the named place was, the longer it took participants to visualize the place. This also provided evidence for the spatial relations between visual images.

Systematic approaches were also used in favor of the Propositional Theory. For example, Pylyshyn (1981) examined mental imagery using the same visual map procedure as the one mentioned above. However, he focused on the instructions for the experiment, instead of the actual task. He found that if he changed the instructions, the results would change as well. He concluded that the experiment mentioned above (Kosslyn, Ball & Reiser, 1978) did not actually provide evidence for the Depictive Theory, but rather the results were due to experimenter error. However, it was not clear if Pylyshyn was correct in his conclusion, or if depictive representations were a part of visual imagery.

Later on, neuroimaging techniques, such as fMRI and PET scans, were used to examine the debate further. These techniques were used specifically to detect activation in the visual system, therefore providing evidence of depictive representations. If visual mental imagery uses only propositions, the process should not activate V1, the first part of the cortex to receive input from the eyes. These techniques were used to both strengthen the position that perception and visual mental imagery share common processes, and also to question the claim. Several experiments have shown that the early visual cortex is not active. In an experiment by Mellet and colleagues (1996), participants were asked to construct mental images of three-dimensional objects, in which activation was examined using PET scans. The researchers found that the early visual cortex was not activated, but the occipital-parietal cortex showed some activation. In another experiment by Sack and colleagues (2002), participants were asked to visualize certain clock faces. An fMRI found no activation of the visual cortex either, similar to the previous experiment mentioned.

On the other hand, many studies have used neuroimaging techniques to show that mental imagery does activate the visual system. Several studies have used PET scans to show that mental imagery activates the visual cortex, specifically V1 (Kosslyn, Thompson, Kim & Alpert, 1995; Kosslyn, Thompson, Kim, Rauch, & Alpert, 1996; Kosslyn et al., 1999; Thompson, Kosslyn, Sukel, & Alpert, 2001). It was also found that transcrannial magnetic stimulation (rTMS) delivered to the occipital cortex disrupted both perception and mental imagery (Kosslyn et al., 1999), showing strong evidence that the occipital lobe is used in both processes. Similarly, fMRI studies have shown that mental imagery and perception use the same neural machinery (Ganis, Thompson, & Kosslyn, 2004) and that both activate the LGN and V1 (Chen et al., 1998). However, fMRIs and PET scans are lengthy scans resulting in poor temporal resolution that does not allow researchers to compare the timing of activation of the visual cortex. It is not clear if the processes activate the visual cortex in the same way, or if activation can be explained as a feedback system instead, where higher-order activity excites lower level areas through the brain’s massive feedback system.

An electroencephalogram (EEG) has been used to clarify the timing of activation in the visual cortex, because it has high temporal resolution. The EEG measures changes in voltage associated with the brain’s response to a certain stimulus. These voltage changes are what constitute event-related potentials (ERPs), or the measured brain response from a specific stimulus (Coles & Ruggs, 1996). Farah and colleagues (1988) found by recording ERP responses during a task combining imagery and perception that both share a common locus of processing and that damage to areas in the visual system causes imagery deficits that parallel perceptual deficits (Farah, 1989). Page and colleagues (2011) recorded ERP responses to visual patterns that are known to elicit specific signature waveforms and compared responses for both perception and mental imagery. They found that both sets of waveforms were similar, implying that early visual processing stages may play a role in creating mental imagery.

However, all of the studies mentioned above examined mental images that have already been stored in a person's memory. Imagined stimuli, or stimuli that have not been seen before, should also be compared with perception to see if the neural substrates of imagination are similar to that of mental imagery. Imagination can be defined as the capacity to form a mental representation of the world beyond the perceptions of immediate senses (Reuland, 2010). It is thought to be a uniquely human trait, and is important for executive function tasks, such as future planning (Person, 2006). There have not been many studies examining imagination and the visual system.

The purpose of the present study was to compare recorded evoked potentials from the cortex during perception and imagination. The aim was to see if the visual system would be activated by an image that has not already been stored in memory, but rather was described verbally. The study directly tested the Pylyshyn's theory of propositions (1973) of mental imagery by giving participants a symbolic representation instead of asking them to recall a visual memory. Therefore, it is not necessary for the visual system to be active unless the visual system is an integral part of mental imagery. The study used similar visual patterns as Page and colleagues (2011) so that the distinct waveforms can be compared between imagination and perception. It was hypothesized that if (ERP) responses to imagined stimuli are similar to responses to perceived stimuli, the visual system is actively participating in imagination, indicating that the same neural substrates are involved in both imagination and perception. In contrast, if the responses are not similar, imagination may not activate the visual system in the same way as perception, suggesting evidence for the propositional theory.

Method

Participants

Thirty students (18-22 years old) from a small liberal arts college were recruited for the experiment by word of mouth. Each participant provided written, informed consent to participate and was screened for normal visual acuity (tested with the Rosenbaum pocket-viewer) and color vision (tested with the Ishihara 38-plate test). Five participants were excluded from electrophysiological analysis because their ERP amplitude responses were less than 1.0 µV. The response amplitudes of the remaining participants' responses ranged between 5.0 and 30.0 µV, well within the amplitude window for comparative purposes.

Stimuli

Stimuli were classified as either external or imagined. External stimuli consisted of horizontal sinusoidal gratings (1.0 cpd, gray and red/green) and checkerboard gratings (1.0 cpd, empty frame and black/yellow). The sinusoidal gratings were presented in an onset/offset timing sequence (200 ms on, 800 ms off), while the checkerboard patterns were presented in an onset/reversal mode (250 ms on, reversing at 250 ms, 500 ms off). These parameters were chosen since they are known to produce distinct waveform signatures when recorded at the visual cortex (Rabin, Switkes, Crognale, Schneck, & Adams, 1994). Imagined stimuli were generated by each individual participant in an eyes-closed condition by imagining the gratings as explained to them verbally. An auditory tone was created by Stim^2 software (Neuroscan, El Paso, Texas) and was played simultaneous to the start of each stimulus through speakers connected to a Dell Optiplex 780 computer in order to keep the rhythm for the participants.

Electrophysiology

An electroencephalograph (EEG) was used to record ERPs (Neuroscan SynAmps RT amplifiers and Scan software, Neuroscan, El Paso, Texas). The stimuli were presented through the Neuroscan Stim^2 software program on a 19-inch LG flatron screen. A stretchy nylon cap with 64-electrodes pre-sewn into it at specific locations (according to international standard montage) was positioned on the participant and electrode contact with the scalp was formed using the QuickCell system by Neuroscan. All scalp impedances were attempted to be kept at or below 10 kΩ. The visual patterns that were shown and the tone were time stamped into the EEG recording for averaging purposes.

Behavioral Measures

The Vividness of Visual Image Questionnaire (VVIQ) was administered to participants in order to assess individual differences in imagination ability (Marks, 1973). The VVIQ consisted of 16 questions about vividness of visual imagery, and used a 5-point rating scale (1 indicating the image was perfectly vivid and 5 indicating no image at all). Possible scores on the VVIQ range from 16 to 80. Participants were also asked to rate how well they imagined the patterns during the experiment on a scale from 1-10, and if they had ever seen the patterns before participating in the experiment.

Analysis

Each of the ERP conditions (perception and imagination) was first analyzed using the Edit software package by Neuroscan to create averaged response waveforms for each condition. The waveforms were visually inspected to look for standard component deflections and to visually compare responses from the perception and imagination categories. We specifically looked to see if response waveforms from imagining the color grating and perceiving the color grating were similar and imagining and perceiving the checkerboard patterns were similar, as well as if imagining/perceiving the color grating was different from imagining/perceiving the checkerboard grating. A correlational analysis was performed on pairs of waveforms as a test of similarity, but was not used to test significance between the comparisons.

Because the checkerboard stimuli were presented as an onset/reversal mode, and ERP waveforms are averaged from the reversal, the timing of the reversal may be difficult to imagine. A tone was used to signify the onset of the checkerboard stimulus, but there was no tone to signify the reversal of the pattern. Therefore, small differences in response latencies, even by a fraction of a second, can flatten-out responses when averaged. To account for this possibility, the peak of the response deflection of individual responses for the imagined checkerboard stimuli were first identified and then shifted within 30 ms in either direction using a sliding window technique to best fit individual responses to the group. The responses were then averaged to create a more clear grand average waveform (see Fig 1 A & B for comparison).

Procedure

Participants were first asked to sign the consent form, and then were screened for visual acuity by reading the Rosenbaum pocket viewer at a distance of 14 inches from their chin and for color vision by completing the Ishihara color vision task. The participants were then given the VVIQ and a lab sheet asking about vision history and impairments. Then, the cap was placed on the participant’s head and impedance was checked. The participant was positioned 57 cm away from the computer screen that displayed the patterns.

Participants were first shown a grayscale horizontal sinusoidal grating. It flashed on the screen once per second and was accompanied by an auditory tone. It was shown in two blocks of 10 presentations in order to familiarize participants with the grating and timing. Next, participants were shown two blocks of color (one red and one green) positioned next to the gray sinusoidal grating. After familiarizing themselves with the colors, they were asked to close their eyes and imagine the grayscale grating in those specific colors, as a red and green grating. They imagined the grating in five blocks of 10 presentations while cortical activity was recorded and stored. Next, participants were shown a red/green horizontal sinusoidal grating in five blocks of 10 presentations in the colors shown in the two blocks of color presented earlier. Cortical responses were recorded and stored to the red/green grating. Participants were asked if the grating was the same as they imagined, and if they had ever seen such a grating before. They were asked to rate on a scale of 1-10 how similar the actual grating was to the one they imagined.

In the next part of the experiment, participants were shown an empty frame checkerboard grating paired with an auditory tone in two blocks of 10 presentations in order to familiarize them with the new reversing pattern and timing. Next, participants were shown blocks of color (black/yellow) next to the empty frame checkerboard. They were asked to close their eyes and imagine the checkerboard pattern in black and yellow succesively in five blocks of 10 presentations each. The black and yellow checkerboard grating was chosen rather than a black and white checkerboard pattern because it is more likely that participants would be familiar with a black and white checkerboard than a black and yellow checkerboard. The yellow color was a combination of the red and green colors used in the other grating to control chromaticity. Cortical responses were recorded and stored for each of the patterns. Lastly, participants were shown the checkerboard gratings in five blocks of 10 presentations and were asked if the grating was the same as they imagined (using the same 10-point scale as above), and if they had seen the gratings before. Cortical responses were recorded and stored. For half the participants, the order of the stimuli (sinusoidal gratings shown first, checkerboard gratings shown last) was reversed to control for fatigue and pattern bias.

Results

A visual inspection of the data showed that the averaged waveforms for imagining the color grating and perceiving the color grating were similar (Fig 2A & 2B), and imagining and seeing the checkerboard patterns were similar (Fig 2C & 2D). The visual inspection also showed that imagining the color grating and imagining the checkerboard was different (Fig 2A & 2C), as was perceiving the color grating and perceiving the checkerboard (Fig 2B & 2D).

A correlational analysis was performed on perceiving the color grating and imagining the color grating ($r = .46$), perceiving the checkerboard and imagining the checkerboard ($r = .72$), perceiving the color grating and perceiving the checkerboard ($r = -.11$), and imagining the color grating and imagining the checkerboard ($r = .17$). The correlational analysis was used as a test of waveform similarity, not a test of significance as to not violate the assumptions of independence since voltage value changes across time in an ERP waveform are not truly free to vary.

The scores on the VVIQ ranged from 19-53 ($M = 35.7$, $SD = 9.36$), indicating that participants reported individual differences in imagination ability. Participants self-rated their ability to imagine the checkerboard pattern ($M = 5.45$, $SD = 2.62$) as better than their ability to imagine the color pattern ($M = 4.33$, $SD = 1.97$), though not enough to reach significance ($t(29) = 2.02$, p = .053). A correlational analysis was also performed on the VVIQ scores and the average of the color grating and checkerboard pattern self-ratings ($r = -.399$, $p = .03$), showing a significant correlation between the two scores.

Discussion

The results of the experiment showed similar waveforms for imagining and perceiving the color grating, and imagining and perceiving the checkerboard pattern. Specifically, both the imagined color stimuli and the external color stimuli caused a large negative deflection in the evoked responses (Fig 2A & B), and both the imagined checkerboard stimuli and the external checkerboard stimuli caused a large positive deflection in the evoked responses (Fig 2C & D). The waveforms can be visually inspected because the visual patterns used in the experiment are known to elicit these signature waveforms (Rabin et al, 1994).

Although there is no standardized objective method for comparing waveforms (Fjell & Walhovd, 2003), a Pearson correlation was used to assess waveform similarity. The results from the Pearson correlation showed that the *r* values were higher when comparing waveforms that were expected to be similar (imagining and perceiving the color grating, and imagining and perceiving the checkerboard) than waveforms that were expected to be dissimilar (imagining the color grating and imagining the checkerboard, and perceiving the color grating and perceiving the checkerboard). While correlations are not appropriate to test significance between waveform relationships, they can be used to confirm what is visually evident; namely, that some waveforms are more similar than others. In this study, waveform pairs that were hypothesized to be similar had much higher *r* values (.46 and .72) than those that were hypothesized to be dissimilar (.17 and -.11).

The results from this study are consistent with results from previous studies providing evidence that mental imagery activates the visual system in a similar way to perception. Farah (1989) used electrophysiology to show activation of the visual system during mental imagery. Page and colleagues (2011) also found that the visual cortex is active during internal image generation. Specifically, they found similar waveform characteristics when perceiving and visualizing the color grating, and also while perceiving and visualizing the checkerboard grating, but not while seeing or visualizing different gratings. These results, and the results from the current experiment, provide evidence that the visual cortex is activated similarly during perception, imagination and visualization as well. Specifically, the same neural substrates seem to be involved in all three processes.

The large range for the scores on the VVIQ suggest that there may be individual differences in imagination ability. If this is true, certain participants may perform better at the task than others. It is possible that if only participants with low scores on the VVIQ (lower scores indicate stronger visualization ability) participated in the experiment, the waveforms may have been more clear. The self-reported means for the patterns indicated that there was no significant difference in imagining patterns, meaning that on average, it was not significantly harder to imagine one pattern over another. However, a significant negative correlation was found between participants' VVIQ scores and their self-rating of pattern vividness. Specifically, as VVIQ scores decreased, self-ratings tended to increase. Since the VVIQ is a standardized measure of visualization ability (Marks, 1973) and the correlation is significant, it suggests that participants' can correctly estimate how similar their imagined patterns were to the actual patterns they were shown.

The results of this experiment have several implications. First, the results can shed light on models of stress or danger. Specifically, when people under stress claim to see something that is not actually there, it is possible that what people imagine is modulating what they can see. Similarly, Kosslyn and Thompson (2003) discuss the implications for the interpretation of eyewitness testimony. Specifically, if mental imagery and imagination modulate perception, visual reports may be less reliable than previously believed. In addition, evidence showing that mental imagery, imagination and perception all share common processes can have implications in clinical psychology. For example, anxiety disorders are often treated with virtual exposure therapy (Krijn, Emmelkamp, Olafsson & Biemond, 2004). However, if visualizing or imagining a phobia can possibly have the same effect as seeing the stimulus, it may shed some light on therapy based on visualization.

In the current experiment, pearson correlation coefficients were calculated for the averaged waveforms to assess the degree of similarity. Future analysis should include finding an objective way to compare the waveforms. One possible analysis is computing Pearson correlation coefficients for each individual participant in each condition, and then converting the coefficients into *z* scores, and performing a *t*-test on the data (see Page, Duhamel & Crognale, 2011). However, other methods should also be explored.

Future analysis should also look at data collected from other electrodes in different locations on the scalp. It is possible that other areas relating to the visual system, besides the visual cortex are active. In addition, it is possible that other areas besides the visual system are active during imagination of stimuli, such as the language centers of the brain. Language centers should be examined since the propositional theory believes that visual imagery may share neural substrates with language centers (Pylyshyn, 1973). It would be interesting to see language areas of the brain are active in initiating the imagined pattern, and if there are similarities in brain processing in other cortical areas as well.

References

Chen, W., Kato, T., Zhu, X.H., Ogawa, S., Tank, D.W., & Ugurbil, K. (1998). Human primary visual cortex and lateral geniculate nucleus activation during visual imagery. *NeuroReport, 9*(16), 3669-3674.

Coles, M.G.H., & Rugg, M.D. (1996). Event-related brain potentials: An introduction. *Electrophysiology of Mind, 1-27.*

Farah, M.J., Peronnet, F., Gonon, M.A., & Giard, M.H. (1988). Electrophysiological evidence for a shared representational medium for visual images and visual percepts. *Journal of Experimental Psychology: General, 117*(3), 248-257.

Farah, M.J. (1989). The neural basis of mental imagery. *Trends in Neurosciences, 12*(10), 395-399.

Fjell, A. M., & Walhovd, K. B. (2003). On the topography of P3a and P3b across the adult lifespan—A factor-analytic study using orthogonal procrustes rotation. *Brain Topography, 15*(3), 153–163.

Ganis, G., Thompson, W.K., & Kosslyn, S.M. (2004). Brain areas underlying visual mental imagery and visual perception: An fMRI study. *Cognitive Brain Research, 20,* 226-241.

Kosslyn, S.M., Ball, T.M., & Reiser, B.J. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of Experimental Psychology, 4,* 47-60.

Kosslyn, S.M., Ganis, G., & Thompson, W.L. (2003). Mental imagery: Against the nihilistic hypothesis. *Trends in Neuroscience, 7,* 109-110.

Kosslyn, S.M., & Thompson, W.L. (2003). Visual cortex activated during visual mental imagery? *Psychological Bulletin, 129*(5), 723-746. doi: 10.1037/0033-2909.129.5.723

Kosslyn, S.M., Thompson, W.L., Kim, I.J., & Alpert, N.M. (1995). Topographical representations of mental images in primary visual cortex. *Nature, 378,* 496-498.

Kosslyn, S.M., Thompson, W.L, Kim, I.J., Rauch, S.L., & Alpert, N.M. (1996). Individual differences in cerebral blood flow in area 17 predict the time to evaluate visualized letters. *Journal of Cognitive Neuroscience, 8*(1), 78-82.

Kosslyn, S.M, Pascual-Leone, A., Felician, O., Camposano, S., Keenan, J.P, Thompson, W.L., … Alpert, N.M. (1999). The role of area 17 in visual imagery: Convergent evidence from PET and rTMS. *Science, 284,* 167-170.

Krijn, M., Emmelkamp, P.M.G., Olafsson, R.P., & Biemond, R. (2004). Virtual reality exposure therapy of anxiety disorders: A review. *Clinical Psychology Review, 24,* 259-281.

Marks, D.F. (1973). Visual imagery differences in the recall of pictures. *British Journal of Psychology, 64,* 17-24.

Mellet, E., Tzourio, N., Crivello, F., Joliot, M., Denis, M., & Mazoyer, B. (1996). Functional anatomy of spatial mental imagery generated from verbal instructions. *The Journal of Neuroscience, 16,* 6504-6512.

Page, J.W., Duhamel, P., & Crognale, M.A. (2011). ERP evidence of visualization at early stages of visual processing. *Brain and Cognition, 75,* 141-146.

Person, E. S. (2006). Revising our life stories: The roles of memory and imagination in the psychoanalytic process. *Psychoanalytic Review, 93,* 655-674.

Pylyshyn, Z.W. (1973). What the mind’s eye tells the mind’s brain: A critique of mental imagery. *Psychological Bulletin, 80,* 1-24.

Pylyshyn, Z.W. (1981). The imagery debate: Analogue media versus tacit knowledge. *Psychological Review, 88,* 16-45.

Rabin, J., Switkes, E., Crognale, M., Schneck, M.E., & Adams, A.J. (1994). Visual evoked potentials in three-dimensional color space: Correlates of spatial-chromatic processing. *Vision Research, 34,* 2657-2671.

Reuland, E. (2010). Imagination, planning, and working memory. *Current Anthropology, 51,* 99-110.

Sack, A.T., Sperling, J.M., Prvulovic, D., Formsano, E., Goebel, R., Di Salle, F., … Linden, D.E.J. (2002). Tracking the mind’s image in the brain II: Transcranial magnetic stimulation reveals parietal asymmetry in visuospatial imagery. *Neuron, 35,* 195-2002.

Shepard, R.N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171,* 701-703.

Thompson, W.L., Kosslyn, S.M., Sukel, K.E., & Alpert, N.M. (2001). Mental imagery of high- and low-resolution gratings activates area 17. *NeuroImage, 14,* 454-464.

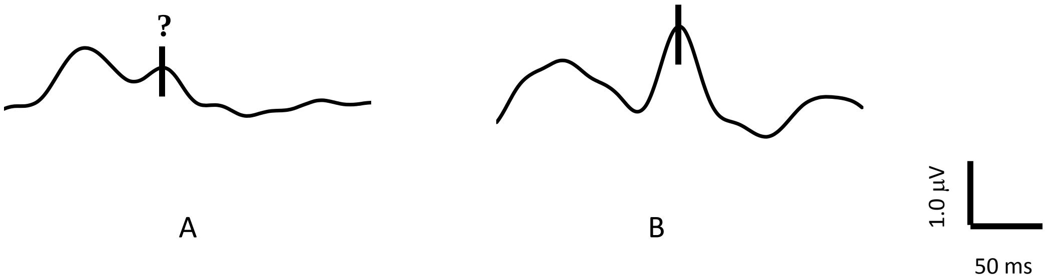

Figure 1. *A*. Non-shifted grand average waveform for the imagined checkerboard stimuli. The question mark symbolizes that without shifting, the response is unclear. *B*. Shifted grand average waveform for the imagined checkerboard stimuli using a sliding window technique.

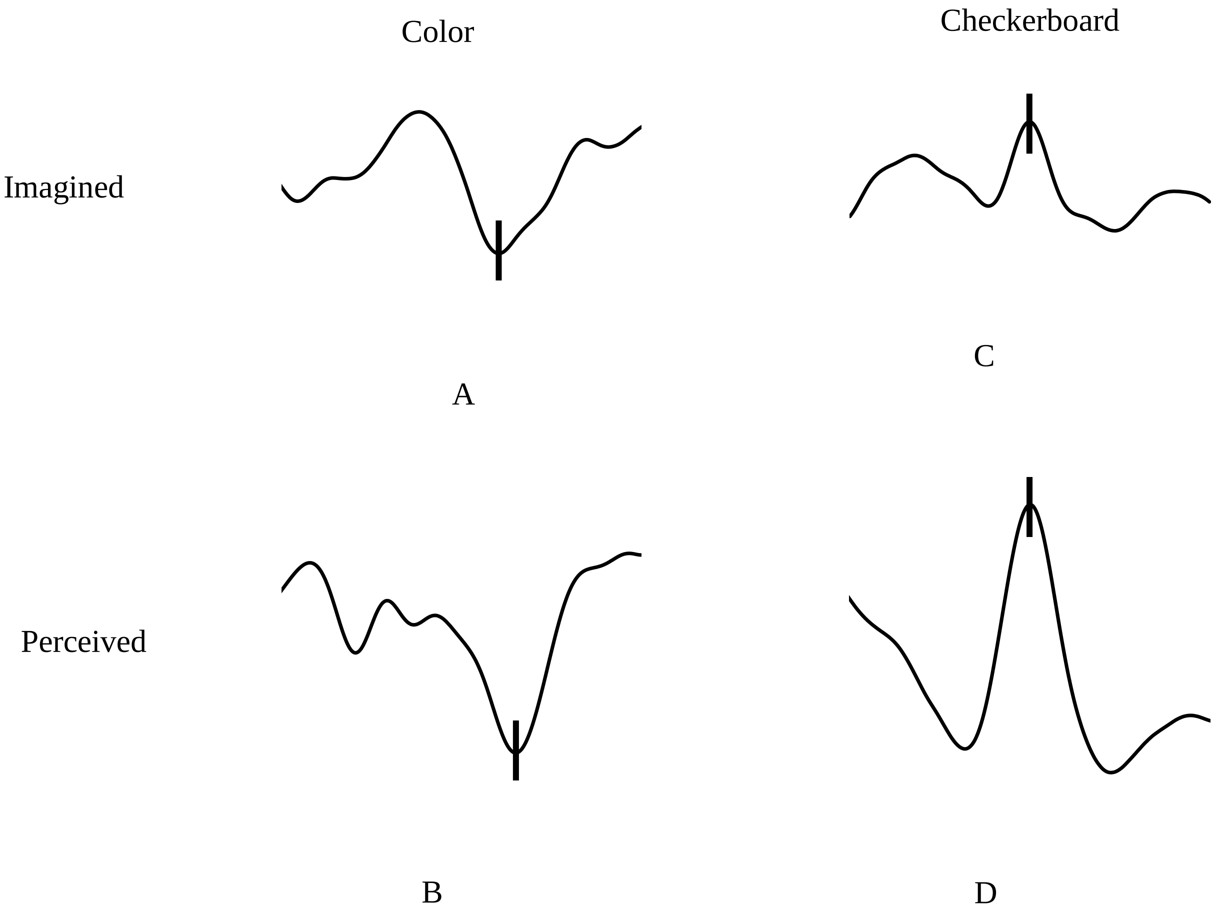

Figure 2. *A*. Grand average waveform for the imagined color grating. Similar to the waveform for the perceived color grating. *B*. Grand average waveform for the perceived color grating. *C*. Grand average waveform for the imagined checkerboard stimuli. Similar to the waveform for the perceived checkerboard grating. *D*. Grand average waveform for the perceived checkerboard grating. Scale is the same as in Figure 1.