No Difference in Sympathetic Responses to Auditory, Visual, and Combined Stimuli

Erica Christensen, Joe D'Amato, Gina Patel, Aisha Prasad, Eric Pynnonen, Kelsey Waier

Key words: Sympathetic Nervous System, Auditory, Visual, Startle Stimulus, Synergy, Respiratory Rate, Heart Rate, GSR, Audio/Visual, Fear Response

Abstract:

The sympathetic nervous system, a branch of the autonomic nervous system, is activated in response to stressful stimuli. The purpose of this experiment was to determine whether audio or visual stimuli work in tandem to elicit a greater response, or whether they work in an unrelated fashion. The experimenters hypothesized that auditory and visual stimuli combined would evoke a greater sympathetic response than the summation of the responses to auditory stimuli only and visual stimuli only. The hypothesis was tested by exposing the subjects to an audio track, a muted movie, or both combined, each with a brief startling stimulus. The research group recorded heart rate, GSR, and respiratory rates and calculated the percent change between the stimulated response and the baseline values for the subject, and performed subsequent t-tests between experimental populations. The results did not show a statistically significant response between solitary or combined stimuli, due to the large variance in the population.

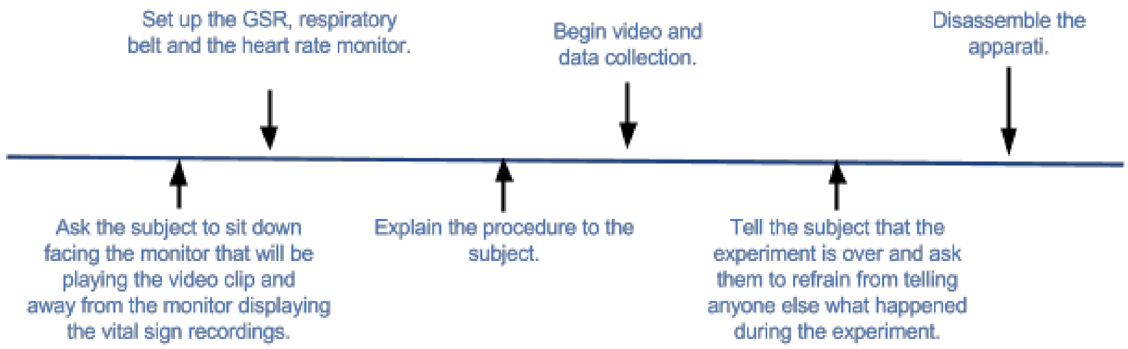
Introduction:

When individuals are in stressful situations, the sympathetic nervous system, a branch of the autonomic nervous system, is activated (Raff 2011). Sensory receptors in the eyes and ears pick up stressful stimuli, which are transduced to the thalamus for processing by the brain (Kandel 1991). The information is then transmitted to the cerebral cortex, and then to the hypothalamus, where information is integrated. The hypothalamus sends signals to the spinal cord, which exit via efferent preganglionic fibers. Preganglionic neurons pass the signal on to postganglionic fibers, which innervate effector organs such as the lungs, heart, and sweat glands. Preganglionic fibers can also activate chromaffin cells in the adrenal medulla, which release epinephrine and norepinephrine (Raff 2011). These hormones are then released into general circulation. They bind to adrenergic receptors, which causes the body to prepare for a “fight-or-flight” response (Hidalgo et al. 2013). This response is characterized by increasing the diameter of respiratory airways, increased heart rate, pupil dilation, increased alertness of the central nervous system, shutting down of non-essential functions (including bladder emptying and digestive activity), along with a number of other effects (McCorry 2007).

This activation of the sympathetic nervous system can occur when an individual experiences fear as a result of an auditory and/or visual stimulus (Ax 2013 and Hori et al. 2005). Waters and McDonald (1973) concluded that visual stimuli resulted in statistically significant autonomic response more often than auditory stimuli. The research team wanted to know whether the combination of auditory and visual stimuli would have an additive effect on the sympathetic response or whether they acted synergistically. If the results were synergistic, the combined response would be greater than the sum of audio and visual responses. Giard and Peronnet (1999) have shown that the combination of auditory and visual stimuli together create a greater response in the somatic nervous system than either stimulus alone. Also, according to Lewis et al. (2000), the combination of auditory and visual stimuli has a summating effect on the somatic nervous system. Auditory and visual stimuli both elicit responses in the lateral parietal cortex, lateral frontal cortex, anterior midline and anterior insular cortex of the brain. Due to shared use of sensory neurons, it is assumed that integration of the auditory and visual stimuli occurs in similar pathways for the somatic and autonomic nervous systems. The superior colliculus of the midbrain contains multisensory neurons that have a synergistic effect on responses elicited when auditory and visual stimuli are presented together (Stein 2008). The superior colliculus receives inputs from the eyes, ears and other areas of the cerebral cortex, and sends signals to the thalamus. When auditory and visual stimuli are present, neuronal output to the thalamus is higher than when only one type of stimuli is present. This shows how visual and auditory stimuli presented together elicit a synergistic response. Similar findings were demonstrated in visual-auditory neurons in the polysensory cortex (Stein 1996). When auditory and visual stimuli were presented together, the likelihood of a visual-auditory neuron firing increased, as did its firing frequency.

From this evidence, the research team hypothesized that visual stimuli combined with auditory stimuli would elicit a synergistic sensory response as measured by a change in galvanic skin response, respiratory rate and heart rate compared to the response both elements would elicit separately. These tests were chosen because when the sympathetic nervous system is stimulated, the heart rate, respiratory rate and electronic generation of the skin are all directly affected. The research team also expected visual stimuli to have more of an impact on the sympathetic nervous system responses using the same three tests than auditory stimuli when either was presented alone. As the research team has not yet found any written evidence that synergism occurs in the sympathetic nervous system, it is thought that the experiment covers new territory in this area.

Materials and Methods:

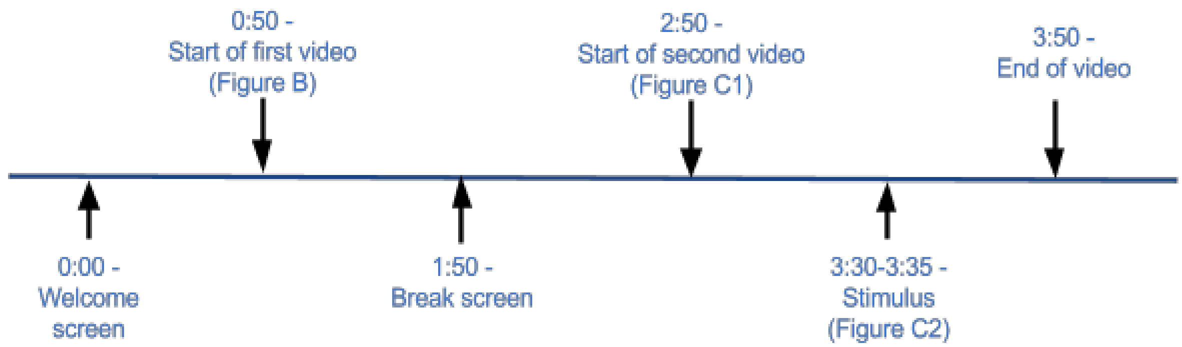


Procedural Timeline

To analyze the effect auditory and visual stimuli have on the sympathetic nervous system, the research team used the galvanic skin response (GSR), a respiratory belt, and a heart rate monitor. The galvanic skin response was measured by the Biopac Systems, Inc. BSL EDA Finger Electrode Xdcr (SS3LA). Test subjects had Biopac Systems, Inc Isotonic Recording Electric Gel applied to their index and middle finger of the left hand and the Finger Electrode attached to those fingers. Respiratory rates were measured by the Biopac Systems BSL Respiratory Effort Xdcr (SS5LB). The strap of the Respiratory Effort instrument was attached in a way so that the sensor was pointed outwards and aligned with the middle of the test subject's chest. Heart rates were measured by the Nonin Pulse Oximeter/Carbon Dioxide Detector, Model number 9843. The apparatus was attached to the test subjects' right index finger. Test subjects were asked to relax with their arms on armrests during the test.

The apparati was set up according to the instructions in the BIOPAC © (Goleta, CA). The test subjects were 18-25 years old, both male and female, and all of normal sight and hearing ability. The research team used four control subjects to gather baseline readings of GSR, respiratory rate and heart rate, as well as readings after sympathetic nervous system stimulation through mild exercise (Figure A in appendix). The experimental subjects were tested for GSR, respiratory rate and heart rate simultaneously, while watching, listening to, or watching and listening to a short video created specifically for the experiment. One experimental group was exposed to only the visual stimuli from the video, another group to only the auditory stimuli, and the final group to both the auditory and visual stimuli from the videos. The same video was used for all three trial types. The computer was muted for the visual trial allowing for only a visual response without the audio track. The screen was turned off for the audio trial allowing for only an audible response without the movie stimulus. The audio/visual trial showed the video with the audio track to allow for a combined response. Initially, a white screen appeared to allow time to calibrate the measurement equipment. The video consisted of three phases. The first phase was a one-minute period of viewing a stimulating but emotionally neutral image using a classic optical illusion using an arrangement of colors in a picture to simulate rotation (Figure B). This optical illusion was accompanied by a slow tempo, new age music track. The second phase was another white screen shown for one minute to prepare the recording apparatus for the third phase. The third phase showed a different stimulating image made up of different colors to simulate slow motion (Figure C1) accompanied by the same music track. At the 160 second mark of the experiment, an emotionally provoking image of a big eyed, pale faced, ghostly figure (Figure C2) was shown while an air horn simultaneously sounded for five seconds to trigger the sympathetic response. Five seconds after the start of the audio, visual, or combined stimuli, the video and audio track returned to the original image and sounds, respectively. Throughout the clips, heart rate was recorded every 10 seconds, and GSR and respiratory rate were recorded continuously. The subject was facing away from the monitor so the recordings were only facing the experimenter who was playing the video.

Timeline of the experimental video:



Video Timeline

To record data, the Biopac Student Lab computer program was used. Lesson 9 was selected to record the respiratory and GSR rates automatically. The average value of heart rate from the last 20 seconds of the first clip were set as that subject's personal baseline, as well as the average GSR and frequency of respiration from a 10 second period during the clip. The research team then examined the 20 seconds after stimulation in the second clip to get the values of the "stimulated" measurements of heart rate, as well as 10 seconds after stimulation to get the GSR and respiratory rate measurements. The baseline was then subtracted from the stimulated value and divided that value by the baseline value to get a measure of the change between videos. These changes were gathered for every subject and treated as a data point for their specific experimental population, and an average was taken for each of these populations. These average values were then run through several t-tests which determined whether or not the means of several groups were significantly different. The three experimental groups were tested (auditory, visual, and combined) against each other for each parameter (GSR, respiratory rate, and heart rate) to yield a total of nine t-tests.

Results:

Based on the results from the t-tests conducted for GSR, heart rate and respiratory rate, there was a statistically significant difference only between auditory stimuli and combined stimuli on respiration ($p=0.03232$). Respiratory rate was increased by 0.718% ± 1.927 in the auditory treatment, while for the combined treatment it decreased by 1.143% ± 0.786 (Figure 2). The respiratory rate for visual treatment decreased by 0.232% ± 1.427, but this was not a significant difference compared to either audio or combined treatments. The galvanic skin response increased by 4007% ± 8854 for the audio treatment, 521% ± 566 for the visual treatment, and 1590% ± 2020 for the combined treatment (Figure 3). There was no statistically significant difference between any of the treatments for galvanic skin response. Heart rate increased by 1.43% ± 6.00 for the audio treatment and 1.75% ± 6.38 for the visual treatment, while it decreased by 1.79 ± 5.03 for the combined treatment (Figure 4). There was no statistically significant difference between any of the treatments for heart rate.

There were general trends observed in the data. Heart rate seemed to slow when the stimuli were combined, however it seemed to increase when there was only auditory or visual stimuli. In GSR, auditory and combined stimuli tended to elicit a greater response than visual alone. Respiratory rate had the largest increase from auditory stimuli while combined stimuli slowed it down.

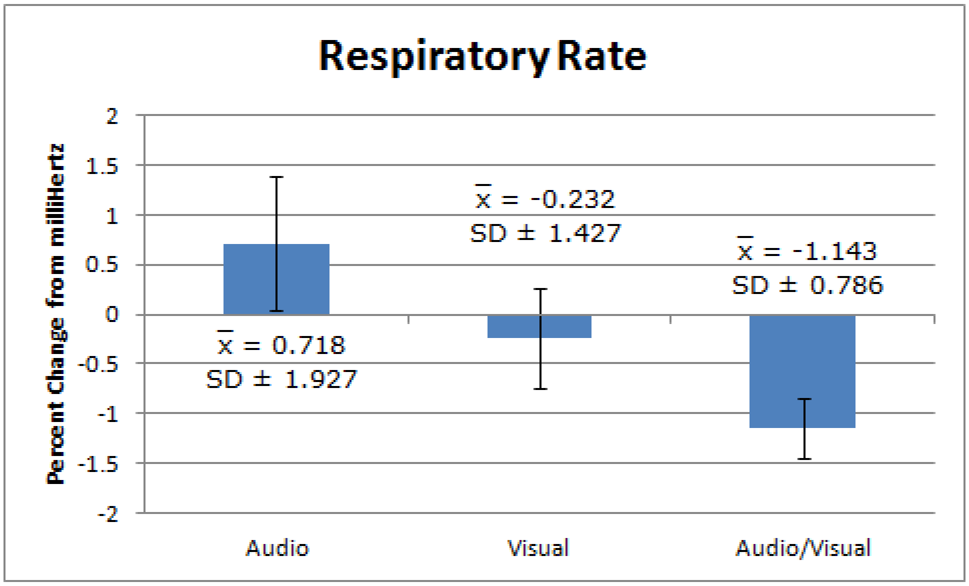


Figure 2. Respiratory rate, measured in microhertz, as a percent change between baseline and stimulated values for audio, visual, and combined experimental groups. Each sample represents the mean ± 1 SE of n=8 for audio, n=8 for visual, and n=7 for audio/visual.

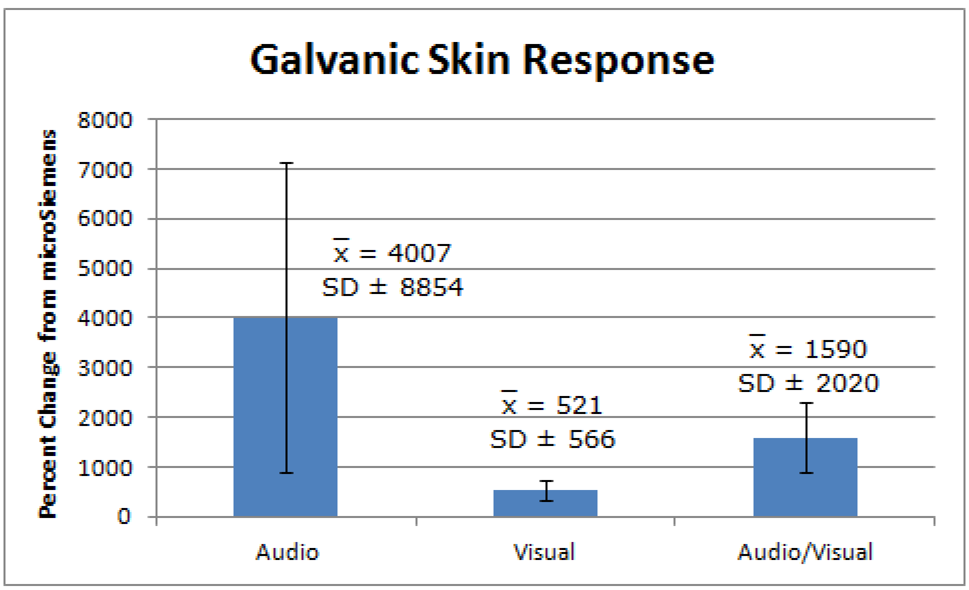


Figure 3. Galvanic skin response, measured in delta microsiemens, as a percent change between baseline and stimulated values for audio, visual, and combined experimental groups. Each sample represents the mean ± 1 SE of n=8 for audio, n=8 for visual, and n=8 for audio/visual.

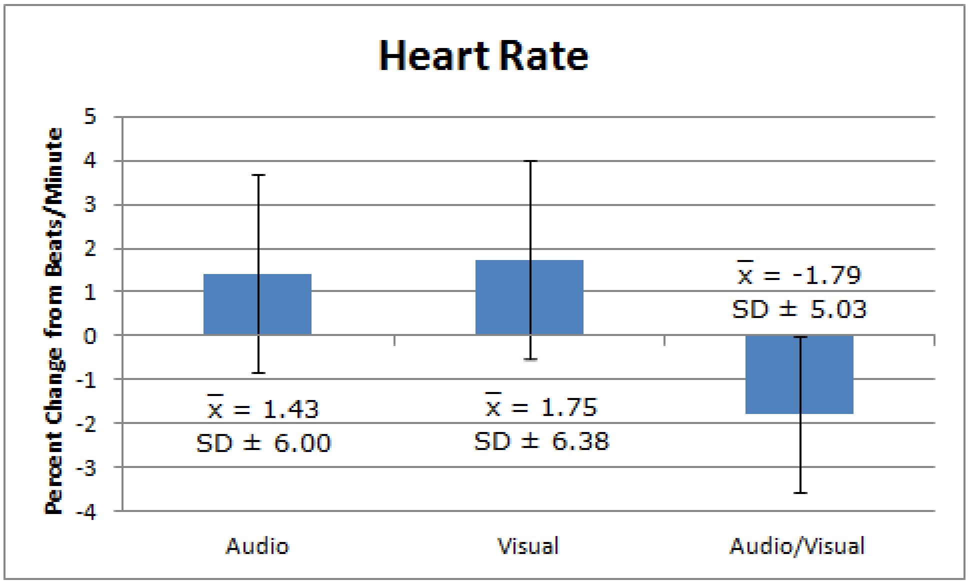


Figure 4. Heart rate, measured in beats per minute, as a percent change between baseline and stimulated values for audio, visual, and combined experimental groups. Each sample represents the mean ± 1 SE of n=7 for audio, n=8 for visual, and n=8 for audio/visual.

Discussion:

The research team postulated that combined audio and visual stimuli would elicit a synergistic sympathetic nervous system response when compared to auditory and visual stimuli alone. The data does not support this hypothesis since the response to the combined stimuli was not significantly higher than audio or visual alone. The only definitive conclusion drawn was that audio was significantly higher than the combined response for the respiratory experimental groups (Figures 2, 3, 4).

The conclusion of auditory having an overall greater response than visual or combined stimulations was different than the results of Waters and McDonald (1973). Visual stimuli were found to be more responsive in the sympathetic nervous system than auditory. Since Waters and McDonald’s experiment was to test desensitization to stimuli using rats (who have more of a visual than auditory presence), this did not necessarily dispute the effect of auditory stimuli being greater. Since the research team specifically tested the effects of auditory, visual and combined stimuli, the results were able to be discriminated between for all three, leading to a stronger conclusion.

To further validate the results, the research team would like to increase the sample size, and be sure the equipment and testing space is consistently uniform. Since the GSR equipment can give inappropriate readings when subjects move their hands, the data may have been influenced by the slightest movement of the subject. Also, the hallway outside of the testing room was occasionally noisy, which may have distracted the subjects that were being tested on visual stimuli alone.

It is believed that the lack of statistically significant results for the other data collected is due to the natural variance within the human population. It is difficult to create a standardized procedure in which all individuals tested would elicit a fear response to the same stimuli. Individuals are varied and diverse, and as such a large variance in reactions is expected. A larger sample size may have minimized this effect.

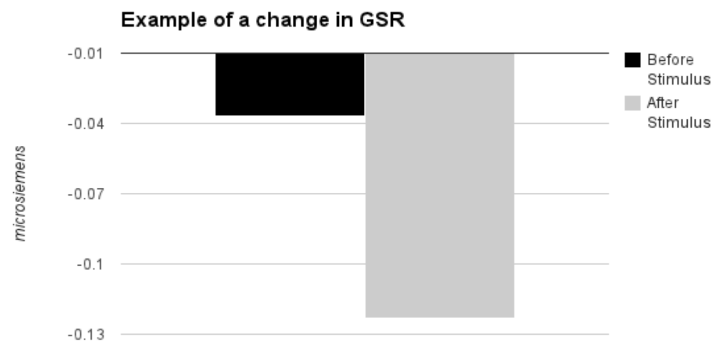
While only the difference between auditory stimuli and combined stimuli in respiration was statistically significant, some of the trends can be accounted for. According to Walker and Sandman (1969) heart rate is related to evoked visual response. It is not certain that the initial video did not illicit a response as well, leading to a decrease in sympathetic response. The dramatic trends in the auditory population could be due to the increased expertise at performing procedures and accurately gathering data when the auditory tests were conducted, as they were the last to be performed.

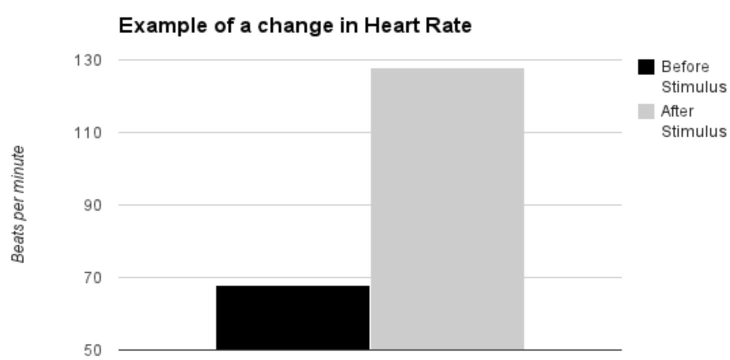
Overall, the data disputes the original hypothesis. These conclusions could be improved by testing more subjects under the same parameters to increase the sample size, and making the procedure more uniform between subjects.

APPENDIX

Figure A.

Example data of each of the testing parameters. Taken from control subjects before and after brief exercise.





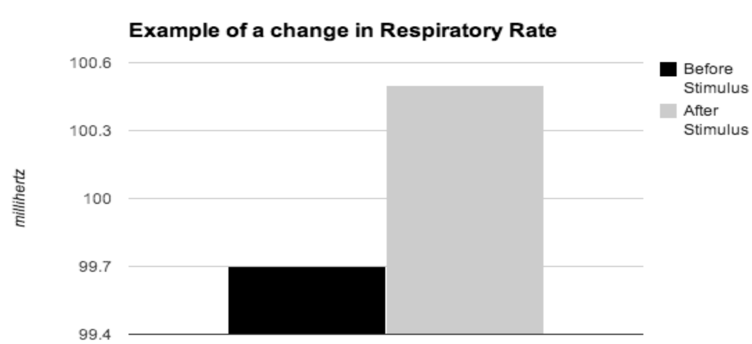
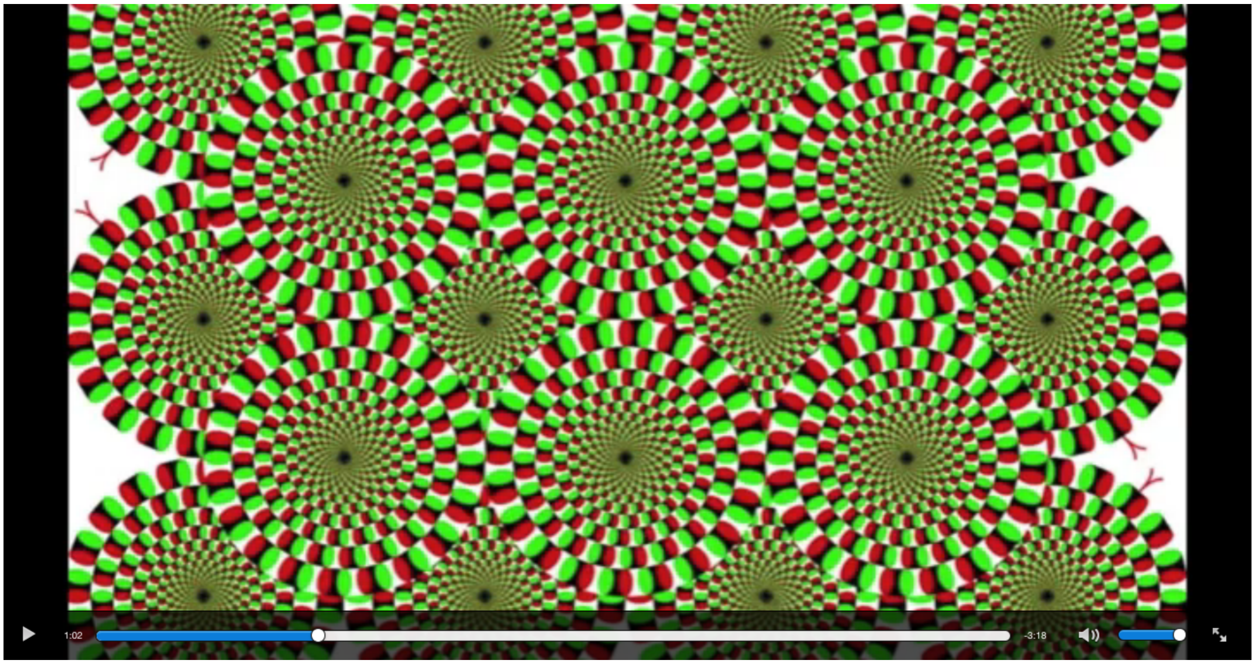
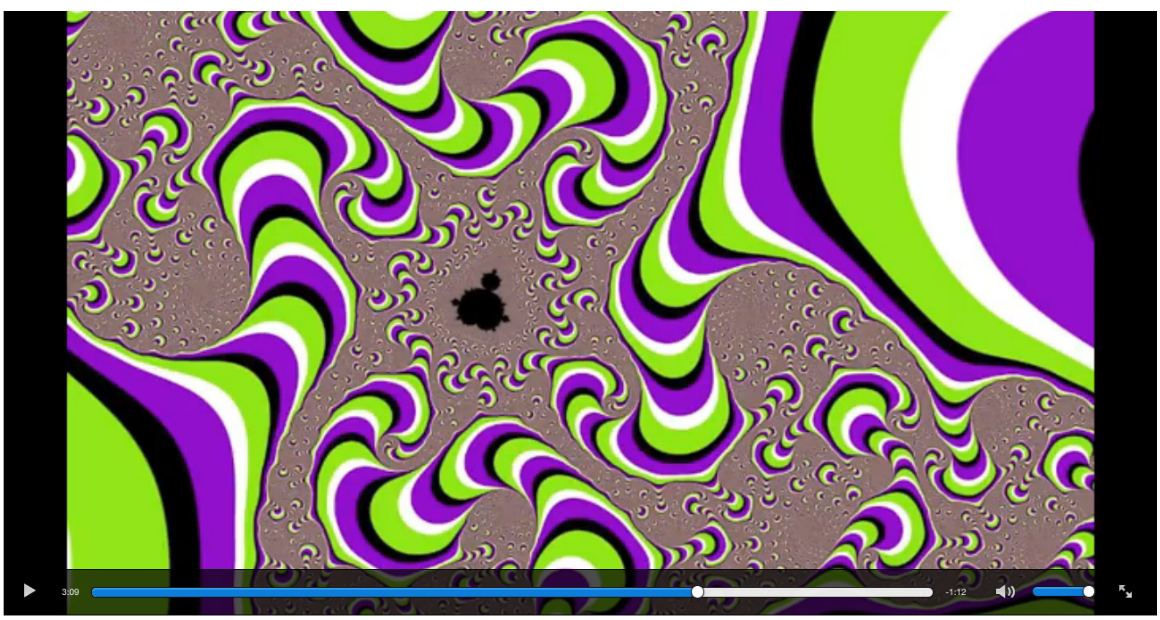


Figure B



Screen capture of the first video shown to test subjects. A track with new age instrumental music accompanied this video for its one minute duration.

Figure C1



Screen Capture of the second video shown to test subjects. A track with the same new age instrumental music accompanied this video for its one minute duration. At the 3:30 mark of the experiment, **Figure C1** was replaced by **Figure C2** which was accompanied by a high-pitched air horn sound for five seconds. The air horn and image in **Figure C2** reverted back to the instrumental track and **Figure C1** after five seconds and continued until the end of the experiment.

Figure C2

This is the image that interrupted the video shown in **Figure C1**. It was accompanied by a high-pitched air horn sound, and lasted for five seconds.

References:

Ax, Albert F. "The physiological differentiation between fear and anger in humans." *Psychosomatic medicine* 15, no. 5 (1953): 433-442.

Giard, Marie H., and F. Peronnet. "Auditory-visual integration during multimodal object recognition in humans: a behavioral and electrophysiological study." *Journal of cognitive neuroscience* 11, no. 5 (1999): 473-490.

Hidalgo, Vanesa, Mercedes Almela, Carolina Villada, and Alicia Salvador. "Acute stress impairs recall after interference in older people, but not in young people." *Hormones and behavior* (2014).

Hori, Kiyokazu, Masanobu Yamakawa, Nobuo Tanaka, Hiromi Murakami, Mitsuharu Kaya, and Seiki Hori. "Influence of sound and light on heart rate variability." *J Hum Ergol (Tokyo)* 34, no. 1-2 (2005): 25-34.

Kandel, E. R., Schwartz, J. H., & Jessell, T. M. (Eds.). (1991). *Principles of neural science* (Vol. 3, pp. 333-5, 764-7). New York: McGraw-Hill.

Lewis, James W., Michael S. Beauchamp, and Edgar A. DeYoe. "A comparison of visual and auditory motion processing in human cerebral cortex." *Cerebral Cortex* 10, no. 9 (2000): 873-888.

McCorry, Laurie Kelly. "Physiology of the autonomic nervous system." *American journal of pharmaceutical education* 71, no. 4 (2007).

Raff, Hershel and Michael Levitzky. *Medical Physiology: A Systems Approach.* Lange Medical Books (McGraw-Hill, 2011)

Schwartz, Jean-Luc, Frédéric Berthommier, and Christophe Savariaux. "Seeing to hear better: evidence for early audio-visual interactions in speech identification." *Cognition* 93, no.2 (2004): B69-B78.

Stein, Barry E., Nancy London, Lee K. Wilkinson, and Donald D. Price. "Enhancement of perceived visual intensity by auditory stimuli: a psychophysical analysis." *Journal of Cognitive Neuroscience* 8, no. 6 (1996): 497-506.

Stein, Barry E., and Terrence R. Stanford. "Multisensory integration: current issues from the perspective of the single neuron." *Nature Reviews Neuroscience* 9, no. 4 (2008): 255-266.

Waters, William F., and David G. McDonald. "Autonomic response to auditory, visual and imagined stimuli in a systematic desensitization context." *Behaviour research and therapy* 11, no. 4 (1973): 577-585.

Walker, Barbara B., and Curt A. Sandman. "Human visual evoked responses are related to heart rate." *Journal of comparative and physiological psychology* 93, no. 4 (1979): 717.