Developing a multisensory rehabilitation tool for visual neglect

Author: Mijke Burger
Master Science Education and Communication
Utrecht University

Supervisors: Prof. Dr. Raymond van Ee and Dr. Björn Vlaskamp
Philips Research, Brain, Body & Behavior

November 30, 2012

Abstract

Hemispatial visual neglect a deficit in attention to, and awareness of, one hemifield, that mostly occurs after right-sided brain damage. Its high occurrence and negative effect on the rehabilitation process make it an important disability to attend to during therapy. Previous studies have indicated that audiovisual stimulation can enhance visual detection in both healthy participants and neglect patients, and that presenting a stimulus with a rhythmically congruent sound can strengthen a percept, but a combination of these findings has not yet been used.

Using two pilots and two full experiments, we tested whether rhythmically congruent audiovisual stimuli can reduce neglect symptoms. To obviate the use of patients, we simulated neglect symptoms in healthy subjects. We tried to achieve this by using a method called 'continuous flash suppression' to suppress the left visual fields of the left eyes of healthy participants.

Moving stimuli were paired with either congruent or incongruent looming sounds, or presented without an accompanying sound, and moved from the subjects' right hemifield into their blind hemifield. The duration of stimulus perception was indicated by the subjects and compared for the three conditions.

The results showed a significant effect of the congruent sound on the perception time of the stimulus, indicating that the rhythmically congruent audiovisual stimulus was more salient and harder to suppress. The possibility of using of such stimuli in speeding neglect recovery is discussed. .

Contents

Introduction

Hemispatial visual neglect is defined as a deficit in attention to, and awareness of, one hemifield, that can occur after brain damage. It is characterized by a lack of awareness towards the contralesional hemifield, together with a loss of the orienting behaviors, exploratory search and other actions that would normally be directed toward that side (Driver & Vuilleumier, 2001). The neurological processes underlying neglect remain largely unknown, not in the least because the nature and severity of the symptoms vary from patient to patient. There is no specific site of damage implicated in visual neglect, but lesions are mostly found in inferior parietal, ventral frontal and superior temporal cortex, while the visual cortex remains intact. (Corbetta, Kincade, Lewis, Snyder & Sapir, 2005).

The deficit most commonly occurs after right sided brain damage caused by stroke, but the exact incidence remains debated. Visual neglect has been linked with lesser functional activities, longer stays in rehabilitation facilities and lower scores on the Functional Independence Measure (an assessment of functional and cognitive disability that focuses on the burden of care, lower scores indicating a higher burden of care). Spontaneous recovery can occur in both the acute and chronic stages of neglect, but for most patients recovery is never complete (Brozzoli, Demattè, Pavanic, Frassinetti & Farnè, 2006). Because of its high prevalence and poor functional outcomes in rehabilitation, Ting et al. (2011) stress the need for early recognition and prompt rehabilitation and also point out that current therapies lack clear evidence for significant improvement.

Several factors have been identified that can reduce severity of neglect symptoms or help speed recovery, that can be implemented in therapy. For example Plummer, Dunai and Morris (2006) found that stimuli that moved from the right side to the left side of the visual field significantly reduced the rightward bisection error of neglect patient. The line bisection task is a tool commonly used to diagnose visual neglect; it requires the patient to mark the midpoint of a horizontal line. For neglect patients this tends to be rightwards of the actual midline, indicating that they disregard parts of the left side. Plummer et al. attributed the reduction they found to the fact that a moving stimulus captures attention and draws it to a spatial location, thereby preventing the left side from being overlooked.

Frassinetti, Bolognini, Bottaru, Bonora and Làdavas (2005) studied the effects of audio-visual stimuli on visual processing in patients with visual deficits. They tested patients with hemianopia (in which damage to the visual cortex causes loss of vision in one half of the eye), neglect or both hemianopia and neglect. They found that, for both neglect and hemianopia patients, visual detection in the audio-visual condition was enhanced compared to the visual condition. For patients that exhibit both conditions however, no such effects were found. To asses if this improvement was mediated by a multisensory mechanism, they varied the spatial disparity between the visual and auditory stimuli and found that detection was only enhanced when the spatial disparity was 16˚ or less. For hemianopia patients, the audio and visual signal needed to originate from exactly the same position. These results agree with the three rules of multisensory integration proposed by Meredith and Stein (1993) which state that for multisensory integration to occur the visual and auditory signals have to originate from the same position (spatial rule) and occur at the same time (temporal rule) and that the level of enhancement depends on the strength of the separate signals, enhancement being largest for the weakest signals (inverse effectiveness rule).

It could be argued that the effects found in this study were caused by a spatial cueing effect; the audio cue could have aided in directing attention to location of visual stimulus, making it easier to detect. But in a similar study (Bolognini, Rasi & Làdavas, 2005) in patients with another form of neglect a positive effect on auditory localization was found that cannot be simply contributed to a visual cuing effect In this study a patient with a severe auditory localisation deficit was asked to indicate the direction from which a presented sound was perceived. This task was performed when only an auditory stimulus was presented (unimodal condition) or when a visual stimulus was simultaneously presented at either the same location (congruent condition) or at a different spatial location (incongruent condition). The visual stimulus did not affect performance when it was presented at a spatially incongruent position; no significant differences were found in auditory localisation between the spatially incongruent condition and the unimodal condition. If the visual signal acted as a cue, it would have influenced the localization in every condition.

This positive effect of spatially congruent audio-visual cues on stimulus detection in neglect patients was found in multiple other studies (Van Vleet & Roberstson, 2006; Frassinetti, Pavani & Làdavas, 2002). And similar effects have been found in Hemianopia patients (Leo, Bolognini, Passamonti, Stein & Làdavas, 2008; Passamonti, Bertini & Làvadas, 2009) and in healthy individuals when using visual stimuli that are masked and subtreshold (Bolognini et al. 2005). It seems that multisensory stimuli can have similar effects on healthy individuals when they are presented subtreshold (Làdavas 2007). When using subtreshold stimuli an increase in sensitivity for visual stimuli was found in normal and for audio localization, like in patients, the visual bias was only apparent when they were spatially coincident.

No attempt has yet been made to study the long term effects of audiovisual training in neglect patients, but in hemianopia patients the positive effects have been found to be stable after one month (Bolognini et al. 2005) and even after one year (Passamonti et al. 2009). Furthermore both studies showed a transfer effect to other behavioral assessments and daily activities.

Recently Dent and Humphreys (2011) examined the effect of expanding and contracting motions on extinction, a phenomenon frequently observed in neglect patients. Patients with extinction symptoms, fail to report a stimulus in their contralesional hemifield when a stimulus is simultaneously presented in their ipsilesional hemifield. It is often considered to be an aspect of the visual neglect syndrome (Driver & Vuilleumier, 2001) or perhaps even a milder version of neglect.

In two experiments visual looming stimuli (expanding motion) or receding stimuli (contracting motion) were presented to both hemifields in single-item trials (only one stimulus in either the strong or weak field) or double-item trials (were a stimulus was present in both fields). In the single-item trials all subjects showed evidence of neglect; they were better in reporting the presence of a stimulus in their ipsilesional field than in their contralesional field. But more importantly; all subjects had a bias for looming over receding visual stimuli. In their weaker field, looming stimuli were better detected than receding stimuli. This effect was even larger on the double-item trials; with the extinction symptoms being most prominent when receding signals were presented to their weak fields and looming signals to their strong field.
In the second experiment they also found evidence for grouping effects; the stimulus in the weaker field was identified and localized more often when the stimulus in the stronger field had the same motion pattern.

The combination of looming audio-visual stimuli has not yet been used in therapy, but in healthy individuals positive effects of combining looming with multisensory signals have been found. Cappe, Thelen, Romei, Thut and Murray (2012) found a selective facilitation for multisensory looming stimuli, when they studied the speed of detection for combinations of looming and receding auditory and visual signals. Audiovisual stimuli were more easily detected than visual stimuli and subjects were faster to detect multisensory looming signals than receding incongruent signals, where the audio and visual signals were not both looming or receding. This is in agreement with Maier, Neuhoff, logothetis and Ghazanfar, (2004) who measured the time rhesus monkeys spent at looking at a stimulus that was either looming or receding and that was accompanied by a looming or receding sound. They found a strong attention preference in rhesus monkeys for coinciding auditory and visual looming stimuli, but not for receding stimuli. This bias only occurred with harmonic sounds; it was weakened or even eliminated when broadband noise sounds were used.

Another type of multisensory enhancement that has been studied in healthy individuals, but not yet in patients, is rhythmic congruency. Van Ee Maier, Neuhoff, Logothetis and Ghazanfar (2009) found that in binocular rivalry, the ability to hold one of the two percepts is increased when it is presented together with a rhythmically congruent sound. Subjects were better in holding a looming percept (expanding concentric pattern) when a matching sound was presented (increasing amplitude). This effect only occurred when both the visual and auditory stimuli were attended and when they had congruent rhythms; the frequencies of the looming motion and sound had to be synchronized. We wonder whether rhythmically congruent audiovisual stimuli could speed the recovery process of neglect patients.

Recent developments have made the use audiovisual stimuli for therapy even more feasible.So-called adaptive healing rooms have been developed by Philips, which have several features, like multiple screens, sound and ambient lighting that can be used to offer therapy to stroke patients. In these healing rooms, all factors influencing neglect that were mentioned in the previous paragraphs can be combined and used in therapy. The healing room offers several other advantages. They are designed to control the level of stimuli in the room, and can therefore be used to create a low stimulus-level environment (no clutter or other visual distractions) to optimize the attention for the affected field and prevent extinction. Often a single stimulus, in isolation, can be detected even if it's in the affected visual field (Driver & Vuilleumier, 2001). Using the adaptive healing room also give the opportunity to create a game-like environment, increasing the effects even further. Video games are considered a possible tool that can be used to train visual skills. Training with video games leads to long term effects, in contrast with other training regimens that usually only lead to task related improvements (Achtman, Green & Bavelier. 2008).

To test whether multisensory looming signals can reduce neglect symptoms, without using patients, we adopt a method to simulate neglect symptoms in healthy subjects. One way to achieve this is by using continuous flash suppression (CFS), a method that was first used by Tsuchiya & Koch (2005). In this variant of flash suppression, a fixed image in one eye is completely suppressed by a distinct image (a Mondrian pattern) flashed continuously into the other eye. This method is used to study the mechanisms of conscious and unconscious visual processing and has several advantages over other methods of suppression; it works in every trial, it can be timed precisely and the suppression lasts for longer periods of time. Visual perception during continuous flash suppression resembles neglect in the sense that visual stimuli are processed at a low-level and in the sense that they are not consciously perceived (Driver & Vuilleumier, 2001; Tsuchiya & Koch 2005). A recent study for example, showed grouping effects similar to those in neglect patients also occur in CFS (Wang, Weng & He, 2012).

General method

To test our hypothesis we ran four different experiments; two pilots and two full experiments.

Stimuli

Octave version 3.4.2 with Psychtoolbox was used to create the stimuli. The target used in all experiments was a 30x30 pixel (0.68˚) grey dot that was blurred using a Gaussian filter. The contrast of the dot was varied by increasing or decreasing the RGB value of the dot. The contrast value was determined by dividing the minimum RGB value of the target by the RGB value of the background (180 for the first, 200 for the other experiments). $Contrast = \frac{minmum\ RGB\ value\ target}{RGB\ value\ background}$. Contrast values were varied between 0.016 and 0.091.

The flashing Mondrian pattern used for suppression was created by generating random patterns of 200 differently sized coloured blocks (sizes were uniformly distributed between 2 and 9 pixels) that appeared at random locations between the left edge of the screen and a specified vertical border and were refreshed every 100ms (10Hz). The Mondrian pattern was 11.7˚ wide. Virtually no background was visible.

The screen was 1920 pixels (43.2˚) wide and 1200 pixels (23.5˚) high, the origin being in the top left corner. Fixation crosses (40x40 pixels or 0.9˚) and frames were used to stabilize fusion. All positions were determined relative to screen width and height (0-1).

Participants

Participants were Philips interns and employees recruited from Philips High tech Campus. All had normal or corrected eye-sight and normal hearing. All subjects signed a written consent form; they received no financial compensation.

Materials/apparatus

Stimuli were displayed on a 24 inch monitor (LG Flatron W2420R, resolution 1920x1200, 60Hz), The sounds were presented through wireless headphones, at a volume that was adjusted to the participant's comfort level.

The participants observed the two halves of the screen, in a dimly lit room, through a custom built mirror stereoscope. A chin rest was used to keep their head stable. The viewing distance between the eyes and the display measured 72 cm. The two halves of the screen were separated by a 1.5 cm wide divider to prevent leakage. To make sure that the mirrors were properly aligned and the images were correctly fused a fusion pattern was presented to all participants before the start of the experiment.

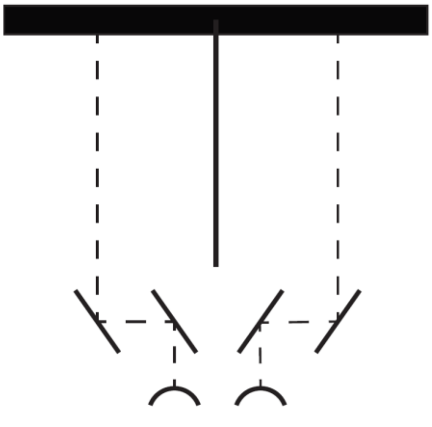


Figure 1 A schematic top view impression of the experiment set up. Participants viewed the two halves of the monitor through four mirrors that were positioned in an angle of about 45 degrees compared to the screen. The dashed line represents the participants' line of sight.

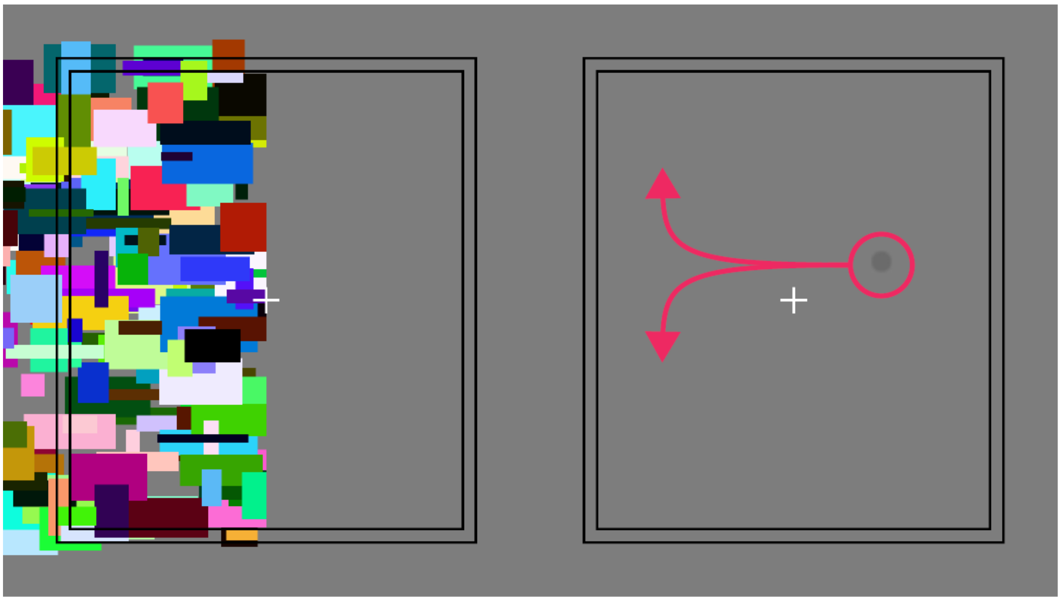
Pilot 1

Method

Participants

Three subjects participated in the first experiment, one male and two females.

Stimuli



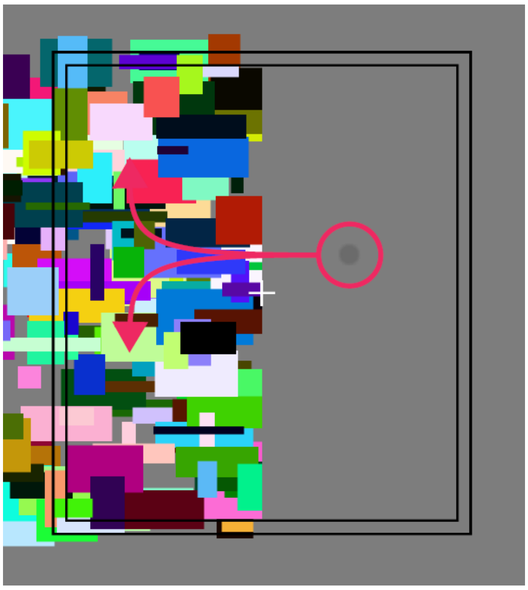


Figure 2 A) Print screen of experiment presented to participants. The left side of the screen was presented to the left eye and vice versa, both sides had to be fused together to form a percept. The flashing Mondrian pattern was presented to the left half of the left eye. The dot moved from the right to the left (indicated by the red arrows)

B) An impression of how the participants perceived the stimulus after they fused the images. The Mondrian pattern appeared to be on the left half of their field and the dot moved from the right half into the pattern were it moved either up or down in a circular motion (as indicated by the red arrow). The center of the dot entered the Mondrian pattern after 9.6 seconds.

At the beginning of the presentation the dot appeared at a specified starting location (at 0.43 of the screen height and at 0.81 of the screen width). It moved from the right side of the frame to the left side with a constant speed of 60 pixels per second (1.35˚/s). After 2.9 seconds (3.9˚) it reached its deflection point, from where it continued at the same speed and went either up or down in a circular path (Figure 2). To create a looming effect, the size of the dot alternately expanded and decreased from 20 to 60 pixels (0.45˚ to 1.35˚) following a sine wave pattern with a frequency of 0.5Hz.

We used three different levels of contrast for each participant. These levels were determined by running a short session of about ten trials prior to the real experiment and using the values that generated about 50 to 60% correct responses.

We used two different sound conditions; no sound or a sound congruent with the looming of the dot. The congruent sound was created combining the sine function and a 300Hz base tone, causing the volume to decrease and increase in sync with the increase and decrease of the stimulus size.

50 trials were generated for every combination of sound type and contrast and a direction of movement (up/down) was randomly assigned to these trials. Each session consisted of 60 trials (10 trials for every combination of the 3 contrast and 2 sound levels). Each participant completed a total of five sessions or 300 trials.

Procedure

The participants were asked to fixate their gaze on the fixation cross at the centre of the frame. The session started when the images were correctly fused together and ended after 7 seconds. After the trial the screen the participant indicated if the target had moved up or down, by pressing the x or z key respectively. After each key press, a new trial started automatically.

Results

As expected all participants showed a lower percentage of correct responses for lower levels of contrast, meaning that following the stimulus into the suppressed field became more difficult when the contrast of the target was lowered. There were no significant differences between the visual and the audiovisual conditions. All percentages of correct responses were well above chance level (50%) for most conditions, only one participant scored below 60% for the visual condition and only for the lowest measured contrast.

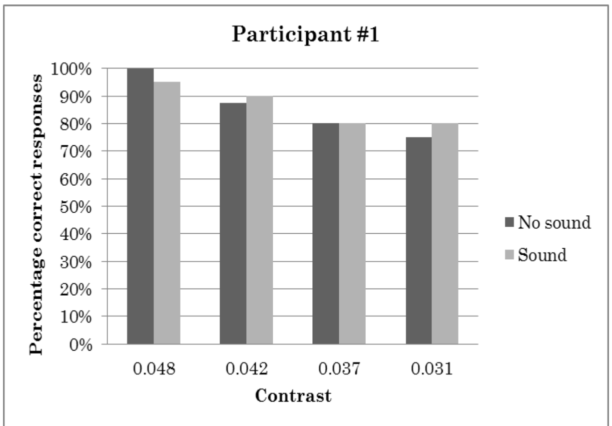
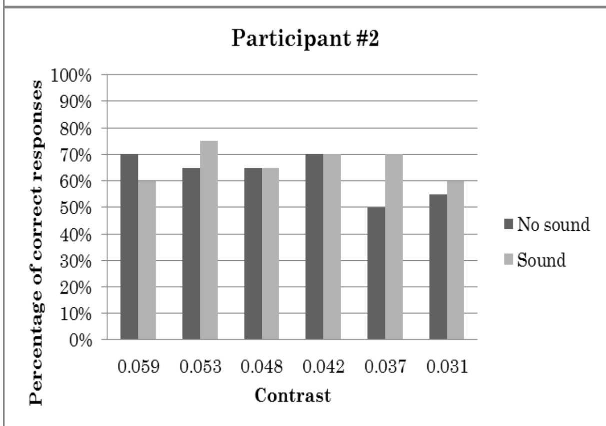
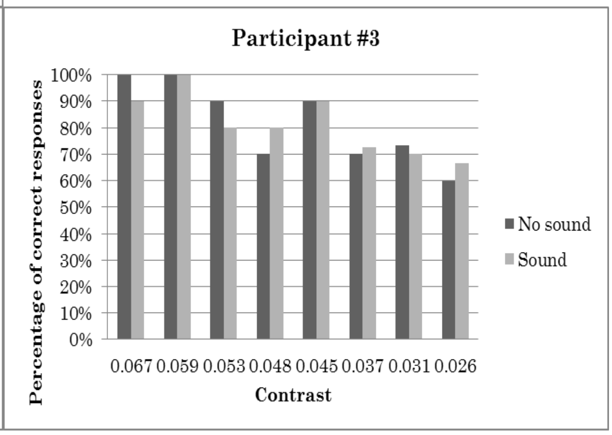


Figure 3 Results of the first pilot experiment depicted in bar graphs for every participant. On the x-axis the used contrasts from high to low are given, the y-axis represents the percentage of correct responses. Chance level is at 50% correct responses. All participants performed better on higher contrasts but performance did not significantly change when a sound was added.





Discussion

In the first pilot experiment no significant difference was found between the performance in the audiovisual and visual condition.

The number of correct responses increased greatly over the course the five sessions. Participants would typically start at 50-60% correct responses and achieve perfect scores by the end of the five sessions. If the suppression level was not important, this effect would not interfere with our data because the increase would be equally distributed over all data. But according to the inverse effectiveness rule stimulus strength can play a large role in multisensory enhancement. As stated by Stein and Meredith (1993, p151) "When the visual cue was sufficiently intense to produce 70-80% correct response alone, the addition of the auditor cue often produced no further increment, thereby giving the impression that multisensory enhancement will not be evident with cues that are already highly effective."

It could be that the effect of multisensory enhancement is only detectable when the stimulus is sufficiently suppressed. One way to increase suppression is lowering the contrast of the target. But because we were already using low contrast levels, further lowering of the contrast would also lower the visibility of the stimulus in the unsuppressed field, making it difficult to follow the target. Therefore we designed a new experiment where we made suppression more efficient by removing the looming feature of the stimulus and projecting the Mondrian pattern across the entire left eye suppressing the stimulus from the start of the presentation.

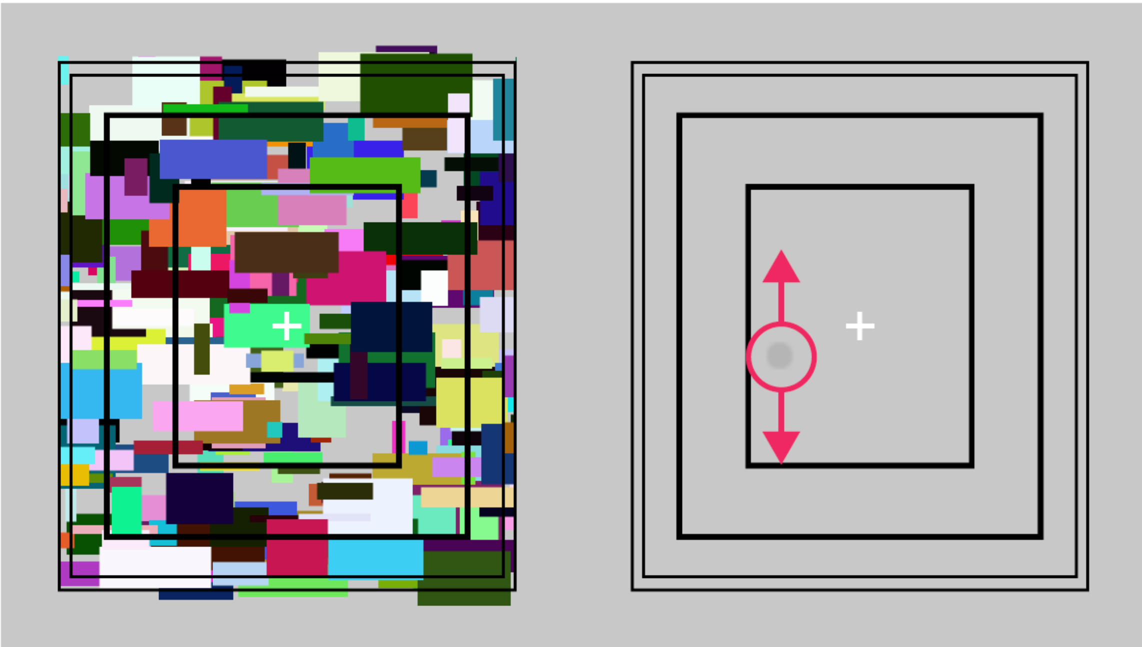
Pilot 2

Method

Participants

Five subjects participated in the second pilot experiment, two males and three females.

Stimuli



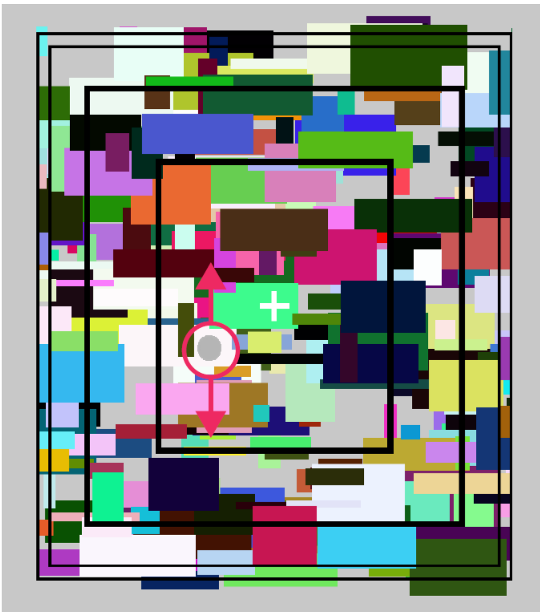


Figure 4 A) Print screen of the experiment presented to participants. The Mondrian pattern was presented to the left eye. The target was presented to the right eye and had a 50% chance of appearing on either side of the fixation cross. The target moved up around a specified position for the duration of the trail.

B) An impression of how the participants perceived the stimulus after they fused the images. The dot appeared to oscillate on top of the Mondrian pattern (as indicated by the red arrow).

The Mondrian pattern from the first pilot was used, but it now covered the entire left half of the screen.

The target randomly appeared on either the left or the right side of the fixation cross and moved up and down with a speed of 60 pixels per second (1.35˚/s), a frequency of 6,28Hz, a vertical amplitude of 9.2˚ and turning points at 0.32 and 0.66 of the screen height. The movement was synchronized with the sound so that the volume decreased when the target moved from the turning points towards the center and increased when it moved from the center towards the turning points.

The target and sounds were created using the conditions from the previous experiments. The contrast was not pre-determined but adjusted after every session of 60 trials, lowering the contrast if the percentage of correct responses neared 90-100% for two sessions in a row.

For the final two participants we use a slightly modified version of the experiment. To see if we could diminish the effects of learning we first trained the participants by conducting a full session of 60 trials. We then chose a contrast that was slightly lower than the 50/60 percent performance and conducted a session with only this contrast (30 trials for each sound condition).

Procedure

The Mondrian pattern and target were presented simultaneously, causing an immediate suppression of the target. After a trial-duration of 5 seconds, the presentation stopped, the target disappeared and the participants had to make a forced choice decision. They indicated whether the target appeared to the left or right side of the cross by pressing the z or x key respectively. A new trial started immediately after one of the two keys was pressed.

All participants completed 4-6 sessions of 60 trials (10 of each contrast/sound combination shuffled as in pilot 1 for the first three participants and 30 of each sound condition for the last two participants). The amount of sessions they completed depended on how many times the level of contrast had to be increased during the experiment.

Results

Again we found that all participants showed a lower percentage of correct responses for lower levels of contrast, meaning that following the stimulus into the suppressed field became more difficult when the contrast of the target was lowered. There were no significant differences between the visual and the audiovisual conditions. The percentages of correct responses were still well above chance level (50%) for most conditions. Even for the last two participants the percentages of correct responses for the no-sound condition were on or above 60%. The small differences between the two conditions varied per subject, but also per contrast. For most participants the largest differences were found for the lower contrasts, which was in line with our prediction that the effects will be most visible at 50-60%.

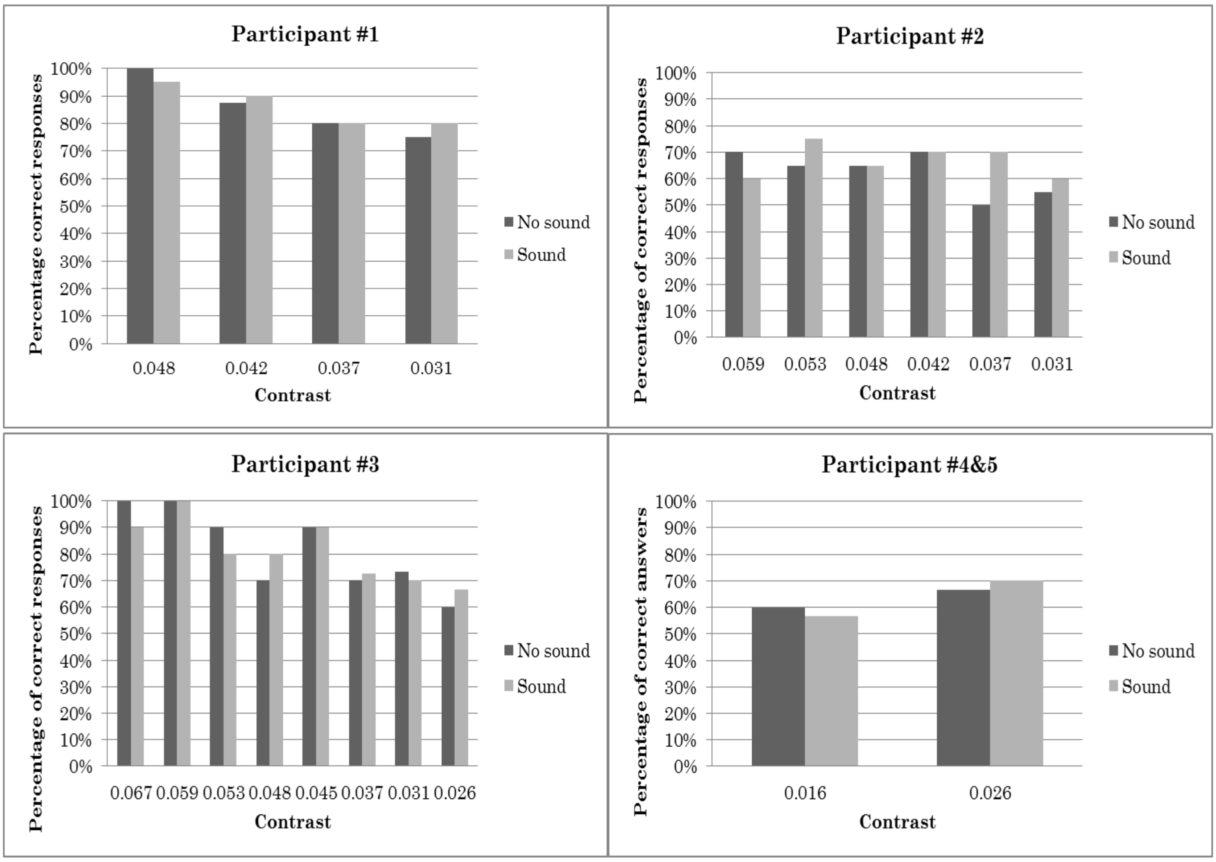


Figure 5 Bar graphs of percentage of correct answers for all contrasts and sound conditions for each participant. The first three participants completed 4-6 sessions for different contrasts. The last two subject completed only one session.

Discussion

As in our first experiment we found no significant differences between the visual and audiovisual stimulus.

It was still very difficult to find a suitable contrast (50-60% correct responses). Often participants indicated that they were not aware of the target and had guessed its location, but their performance would be well above chance level. Also the performance would increase rapidly during a trial, making gathering enough suitable data impossible. The nature of the forced-choice task also made it impossible to make a distinction between seeing the target for the entire duration of the presentation or seeing it appear somewhere for just a second. The duration of target visibility could provide a clue about its strength in suppression.

But more importantly it was not possible for the participant to direct attention to the visual stimulus because the location was not known beforehand. Since previous research (van Ee et al. 2009) indicated this was necessary for rhythmic congruency to have effect, we decided to go back to a modified version of the first experiment were the target was visible for a short duration before it was suppressed.

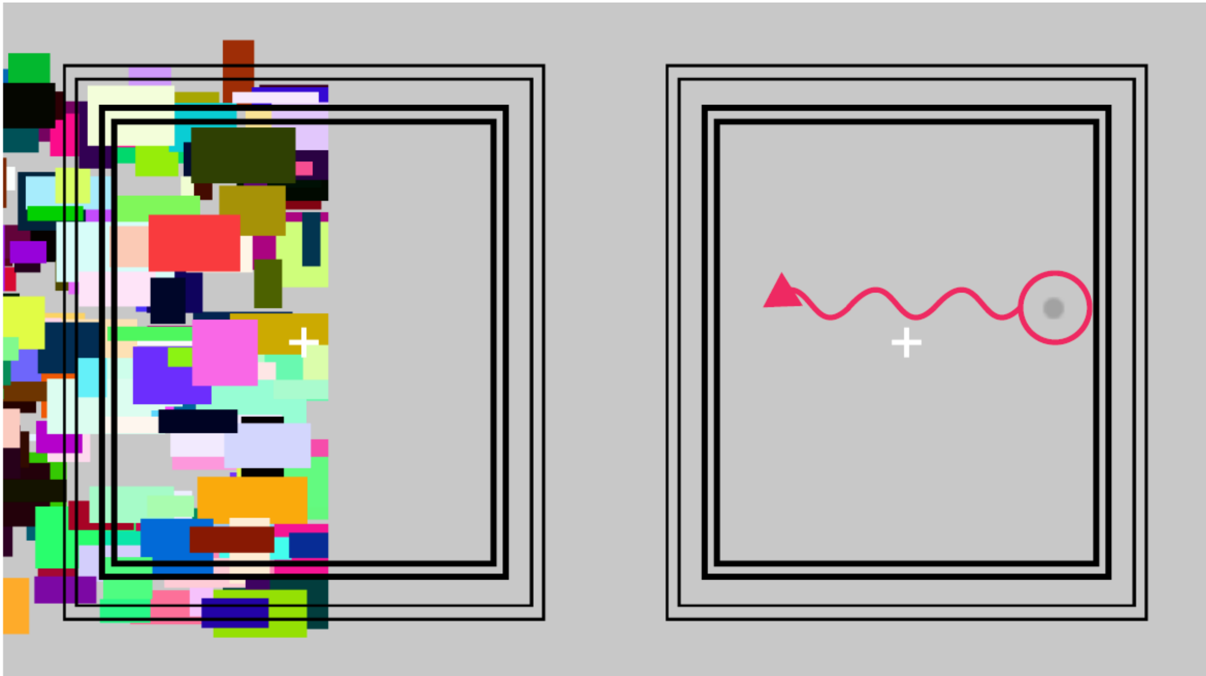
Experiment 1

Method

Participants

Six subjects (2 males and 4 females) participated in the first experiment.

Stimuli



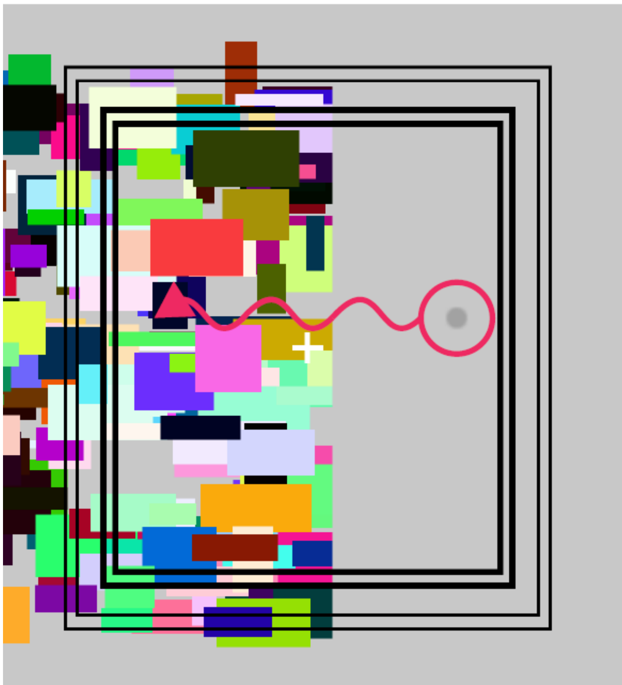


Figure 6 A) Print screen of the experiment presented to participants. The Mondrian pattern was flashed to the left side of the left eye. The target appeared on the right side of the right eye and moved to the left side with constant speed following a sine-wave pattern (as indicated by the red arrow).

B) An impression of how the participants perceived the stimulus after they fused the images. The target appeared to move from the right side of the screen into the Mondrian pattern in a sine-like movement (as indicated by the red arrow). The target seemed to keep moving to left until it was suppressed by the Mondrian and 'disappeared' from sight. The center of the dot entered the Mondrian pattern after 8.32 seconds.

We made the visual and auditory stimuli rhythmically congruent by matching the vertical movement of the target to the sound. For this we used a sine wave with a frequency of 0.5 Hz. The target moved from right to left in a sine-wave pattern, between 0.4 and 0.45 of the screen height, with a vertical amplitude of 1.35˚.

To allow the participants to link the sound to the movement of the dot, it had to be visible for a few seconds before it moved into the suppressed field, so we reduced the Mondrian pattern to 11.7˚ again. The dot appeared in the right field, at 0.9 of the screen width, and moved with a constant speed of 30 pixels per second (0.68˚/s) to the left side of the field. The target disappeared after 19.2 seconds (13.0˚) or at 0.6 of the screen width.

We used three different sound conditions. To make sure that the resulting effect is caused by the rhythmic congruency of the sound and stimulus and not by the adding of a sound itself, we added a second sound condition. This time with an incongruent sound. For the incongruent sound we used a sine wave with a frequency of 1.5 Hz, which was three times higher than the frequency of the vertical component of the movement of the dot.

Two contrasts and three sound conditions were used, 10 trials for each condition were randomly mixed into sessions of 60 trials. All participants completed four sessions, which took approximately 1.5 hours. The participants could complete the experiment over the course of two days.

Procedure

To make sure attention was paid to both the visual and auditory stimulus, the participants were told, at the beginning of the experiment, to try and use the sound to help them perceive the stimulus for longer periods of time.
The appropriate contrast was determined by running test trials to see whether the target was visible into approximately half of the suppressed field (+- 14 seconds).

The target moved from the right field into the suppressed field of the frame with a speed of .5 pixels per frame. Because the target moved at a constant speed and in a constant pattern it was possible for the participants to focus their attention at the location of the target.

The participants were asked to indicate whether the target was visible or not by holding the spacebar for as long as they perceived the stimulus. Three seconds after the trial had started the program checked whether the space bar was down, if this was not the case a new trial started immediately. When the participants felt that they could no longer perceive the target (it disappeared) they released the space bar. Immediately after the release of the space bar, the trial ended and the screen turned blank. The participant could then initiate a new trial by pressing a random key. If they held the spacebar for more than 20 seconds (the duration of a trial) the trial ended automatically.

To check whether the participants were biased or a giving expected responses, six catch trials were randomly presented during a session of 60 trials. In these catch trials the target disappeared a few seconds after it passed into the Mondrian pattern. Release times on catch-trials were used to calculate the time it took for the participant to decide that the target was no longer visible.

Results

Although a slight effect of sound on mean time was noticeable, indicating a positive effect of adding a sound, it was very small and present for both the congruent and incongruent condition.

A two-way repeated measures ANOVA was conducted to compare the effects of the congruent, incongruent and no-sound condition on the perceived stimulus duration. The assumption of sphericity was not violated (Mauchly $\chi^2 = 1.544$, $p>0.05$). A significant effect of contrast on time was found, but not of sound type (F=9.295, p<0.05 and F=.466, $p>0.05$ respectively). There was no interaction effect.

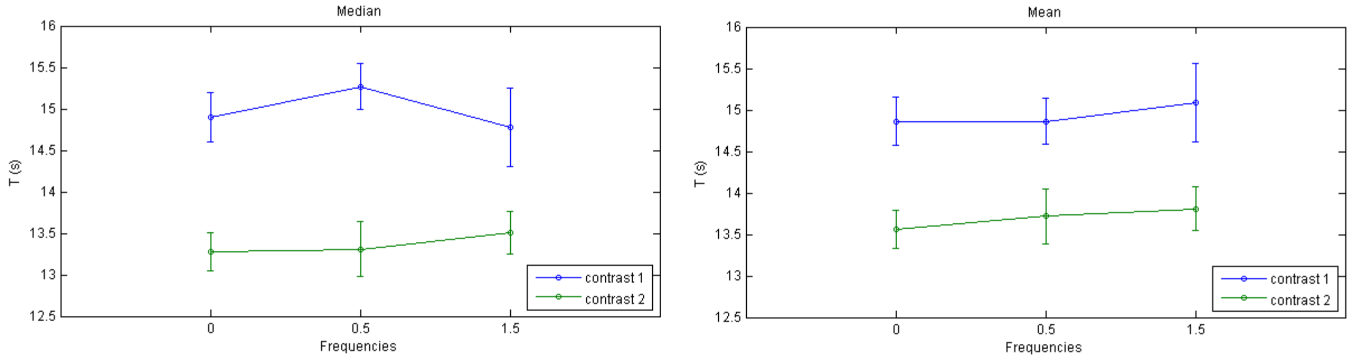


Figure 7 Mean (left plot) and median (right plot) values from all participants were taken together and plotted for the different contrasts and sound conditions. Contrast 1 being the highest of the two contrasts and contrast 2 the lowest. The center of the dot entered the Mondrian pattern after 8.32 seconds and at 8.82 seconds it was completely covered. Errorbars are standard errors.

As can be seen in the figure 8, the catch-trial time varied greatly between participants but was also widespread in some participants (standard deviations ranging from 0.07 on an average of 1.4, to 0.8 on an average of 3.4). This could mean that they took a long time to decide that the stimulus was not visible anymore and that they did not always make the same judgment or perhaps changed their criteria.

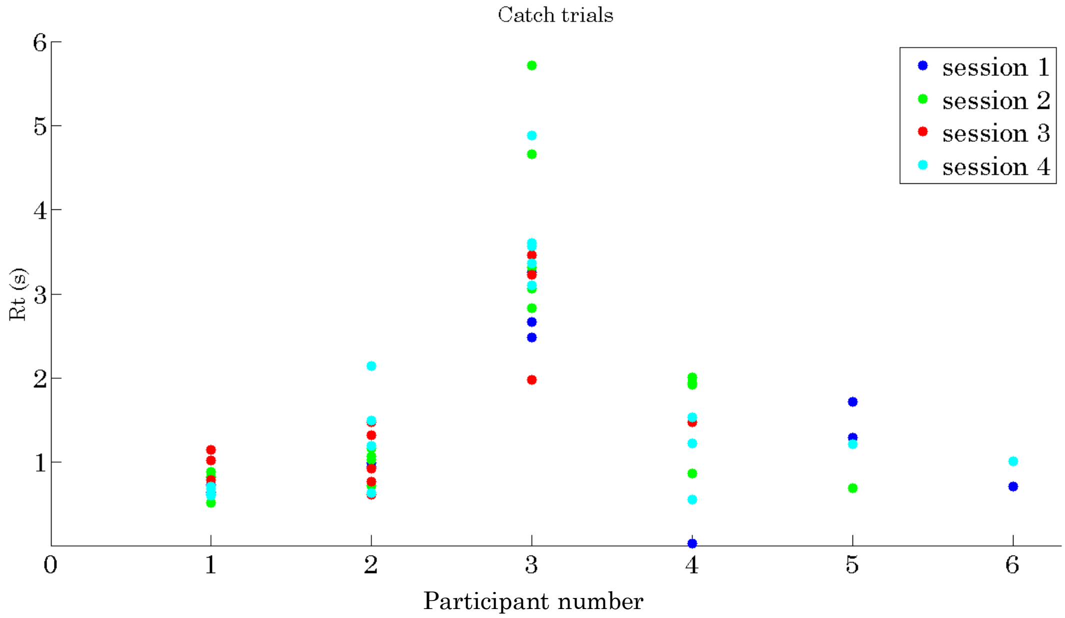


Figure 8 Scatterplot of catch -trial times. Calculated times are the differences between the time of 'disappearance' of the target and the release time of the space bar, Data of trials in which the space bar was releases before the target disappeared were not used.

Discussion

Although a slight effect was found for sound type on time, it did not reach significance. A slight improvement was also visible in the incongruent sound condition.
In this experiment the incongruent sound was much faster paced than the congruent sound. Some participants indicated that they perceived the incongruent sound as alerting, helping them to pay attention to the stimulus. And because the incongruent frequency was exactly three times the frequency of the congruent sound, it can also be argued that it is not completely incongruent, it might still be matched to the movement.

As in the first pilot suppression was weak and hard to increase without decreasing the target contrast too much. During the experiment we found that it the target was suppressed more easily when the eyes were not fixated on the cross but following the stimulus. This could be due to the fact that this eye movement causes the Mondrian pattern to move across the retina with the same speed, the added motion enhancing the suppression. We decided to use this effect in our last experiment to increase the level of suppression of the target.

Experiment 2

Method

Participants

Stimuli

Again two contrasts and three sound conditions were used. Only this time the incongruent sound had a frequency of 0.15 Hz, to eliminate any congruency and to make sure that there was no alerting or general arousal effect. 240 trials were again shuffled and presented in four sessions of 60 trials.

Procedure

Suitable contrasts were determined by running a short test trial. Two contrasts were used; one that was perceived for about 11 seconds and one that was slightly lower to account for possible learning effects. Six catch-trials were randomly presented in every session. Participants could again finish the four sessions in two subsequent days.

Results

An increase in mean time was found for both the incongruent and congruent sound compared to the no-sound condition, but the increase in the congruent condition was much larger (0.23 and 0.45 seconds compared to 0.07 and 0.13 seconds respectively). The same trend was visible for the median (0.36 and 0.25 compared to 0.13 and 0.13 respectively).

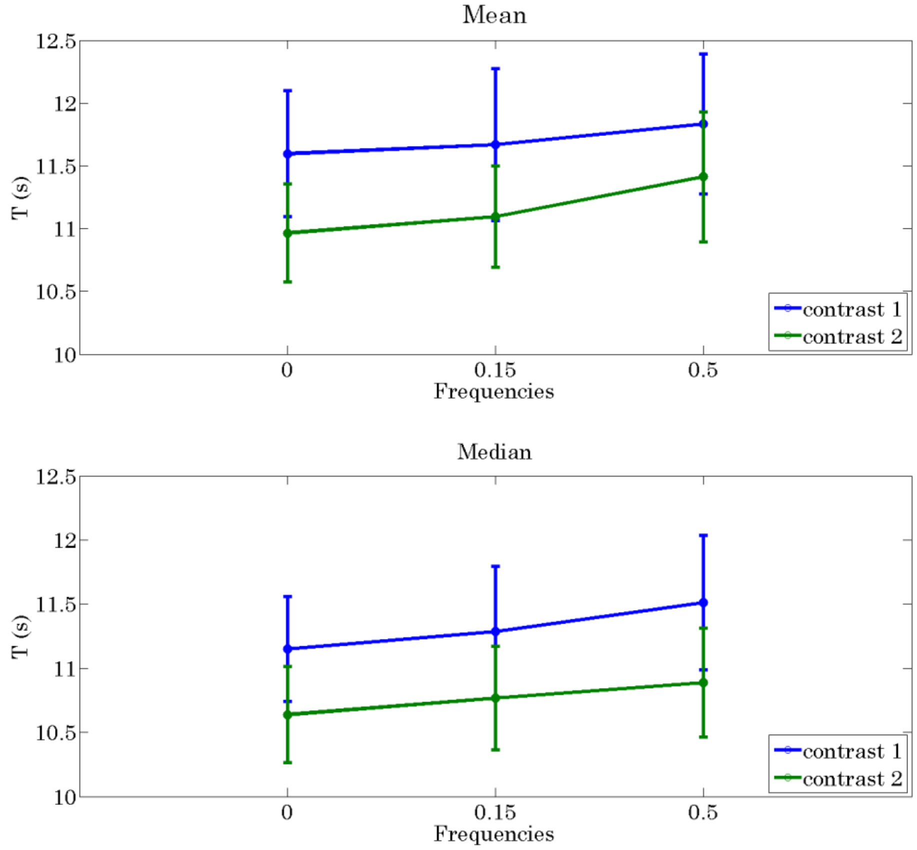


Figure 9 Mean (upper plot) and median (lower plot) values from all participants were averaged and plotted for the different contrasts and sound conditions. Contrast 1 being the highest of the two contrasts and contrast 2 the lowest. The center of the dot entered the Mondrian pattern after 8.32 seconds and at 8.82 seconds it was completely covered. Error bars are standard errors.

The reported times of stimulus visibility were not normally distributed, as can be seen in figure 10. The curve is right skewed, with a steep increase on the left side and a long tail on the right. A second peak appears at the maximum presentation duration because no distinction can be made between targets that are visible for exactly 20 seconds and targets that would be visible for a longer period of time (if the presentation would last longer). If the presentation duration was increased this peak would disappear and the tail would be longer.
To account for the fact that the data is not normally distributed, logarithmic values were used to create a more normally distributed data set and both the means and medians of the times were evaluated.

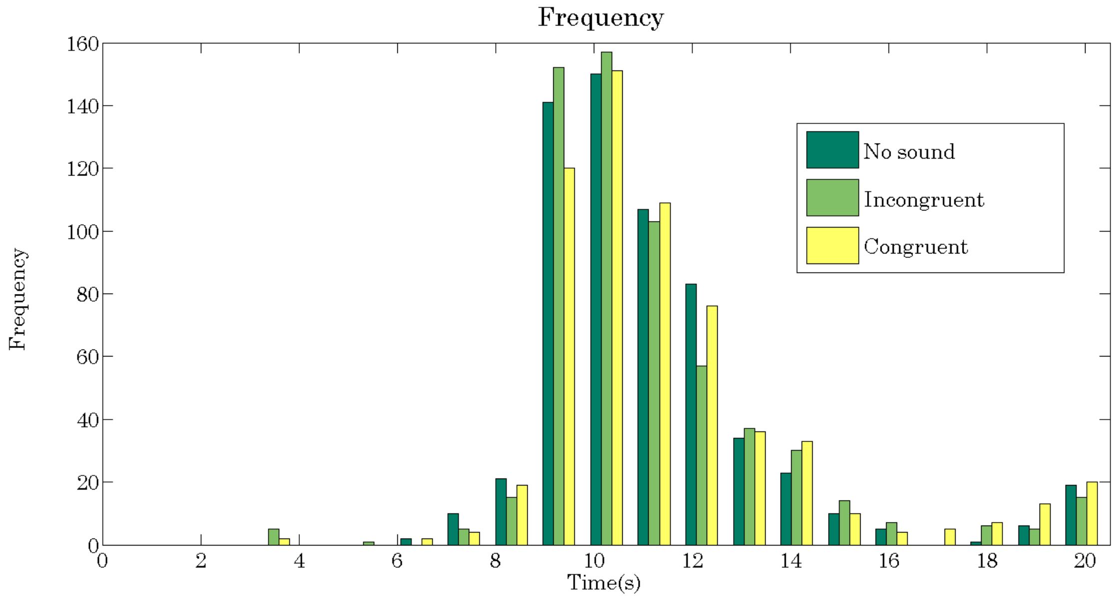


Figure 10. Combined data from all participants. Data from both contrasts were taken together and plotted over the three different sound conditions. The values are not normally distributed, but right skewed and a second peak is visible at the right end. The center of the dot entered the Mondrian pattern after 8.32 seconds and at 8.82 seconds it was completely covered.

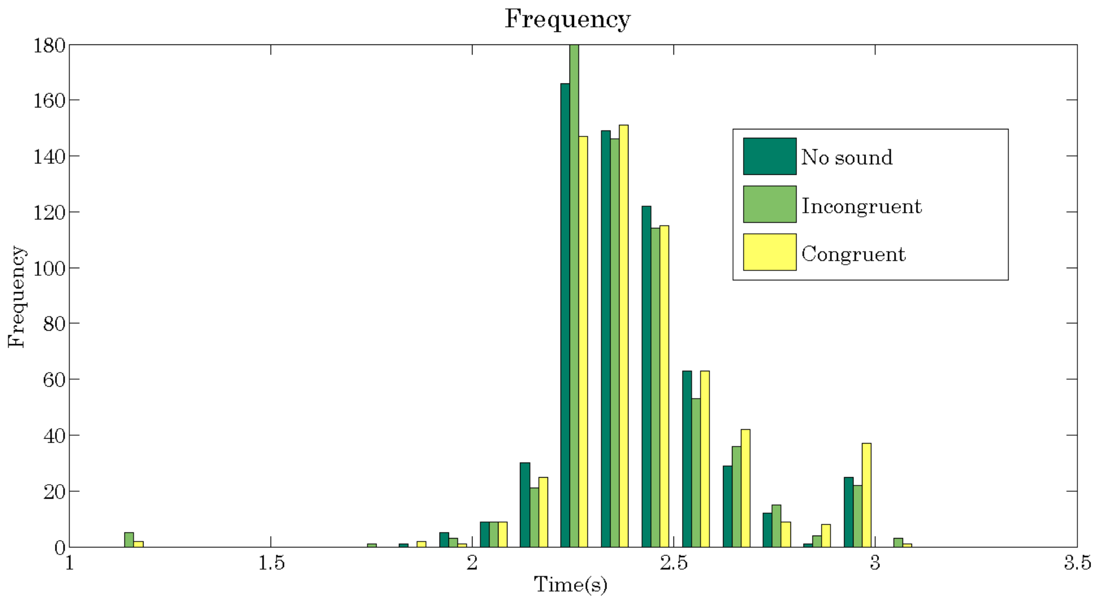


Figure 11. Logarithmic values of combined data from all participants. Data from both contrasts were taken together and plotted over the three different sound conditions. The center of the dot entered the Mondrian pattern after 8.32 seconds and at 8.82 seconds it was completely covered.

When comparing the peaks in figure 10 and 11 for the three different conditions, the congruent condition tends to have higher peaks on the right side and lower peaks on the left side. This means that in the congruent condition, the target is more often seen for a longer period of time. This effect is also visible in the plot of the cumulative sums (figure 12). Here the red line (representing the congruent condition) is mostly below the other two and rises steeply near the end of the trial.

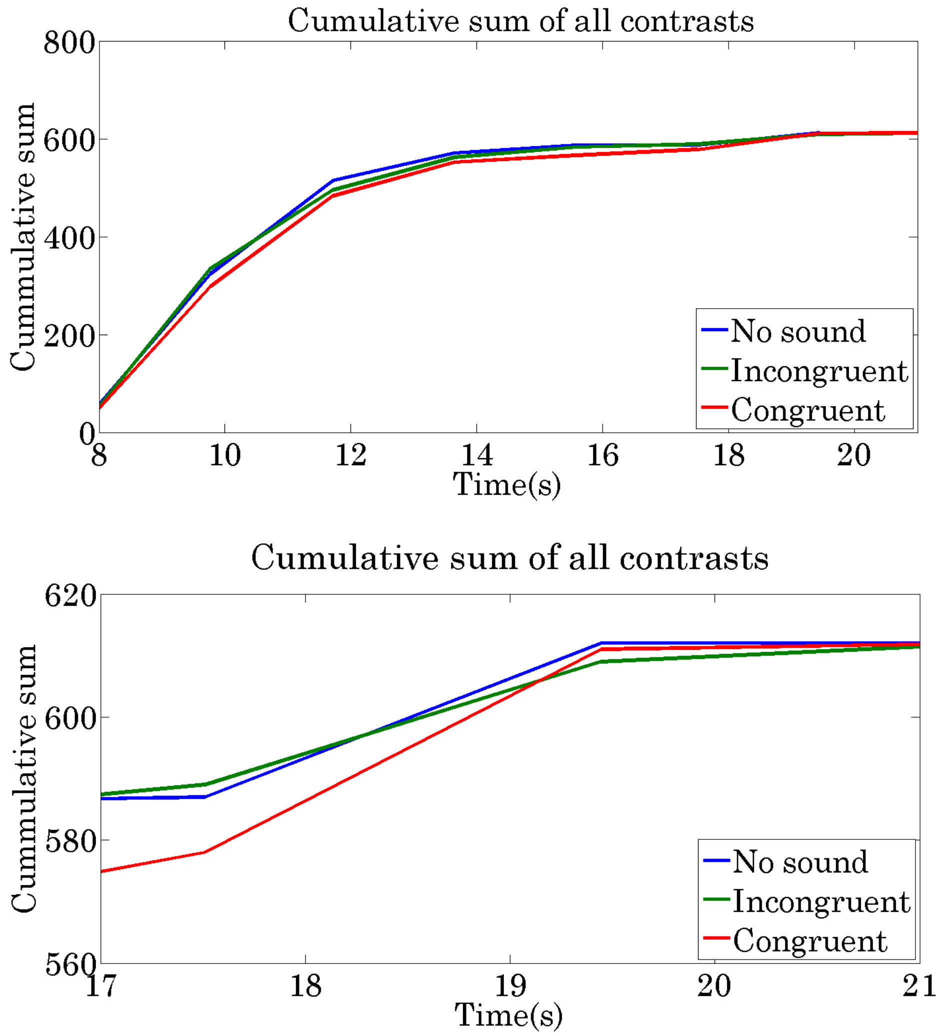


Figure 12 Cumulative sum of all the data from all participants over the duration of suppression (upper plot) and zoomed in only the data form the last five seconds (lower plot). The red line (representing the congruent condition) is below the other two lines until it steeply rises at the end, meaning that for the congruent condition the target is more often seen for longer periods, than for the other two conditions.

A two-way repeated measures ANOVA was conducted to compare the effects of the different sound conditions and contrasts on the mean time that the participants indicated to perceive the stimulus. Mean time differed statistically significantly between both the different sound conditions and the two contrasts. Participants perceived the target for a longer time when it was accompanied by a congruent sound or when the contrast was higher.
The assumption of sphericity was not violated (Mauchly $\chi^2 = 5.535$, $p>0.05$). A significant effect was found for both contrast and sound conditions ($F=5.708$, $p<0.05$ and $F=4.608$, $p<0.05$ respectively). No significant interaction-effect was found.
Paired t-tests revealed that the congruent sound condition differed significantly from both the no sound condition ($p=0.0145$) and incongruent sound condition ($p=0.033$). These results suggest that there was a significant effect of soundtype on time, adding a

congruent sound to a stimulus significantly prolonged the time that the stimulus was visible during continuous flash suppression.

A two-way repeated measures ANOVA was also performed on the median values and showed an effect of sound type (F=3.115; p = 0.072) and contrast (F=4.432, p = 0.068), but no interaction effect. Again participants perceived the target for a longer time when it was accompanied by a congruent sound or when the contrast was higher. A significant effect was found between the no-sound and congruent condition (p=0.0265). Compared to the no-sound condition the congruent sound produces a significant lengthening of the time that the target is perceived by the participant.

Again catch-trial times were quite high and wide-spread in a number of participants, indicating that they took a long time to decide that the stimulus was not visible anymore and that they did not always make the same judgment or perhaps changed their criteria.

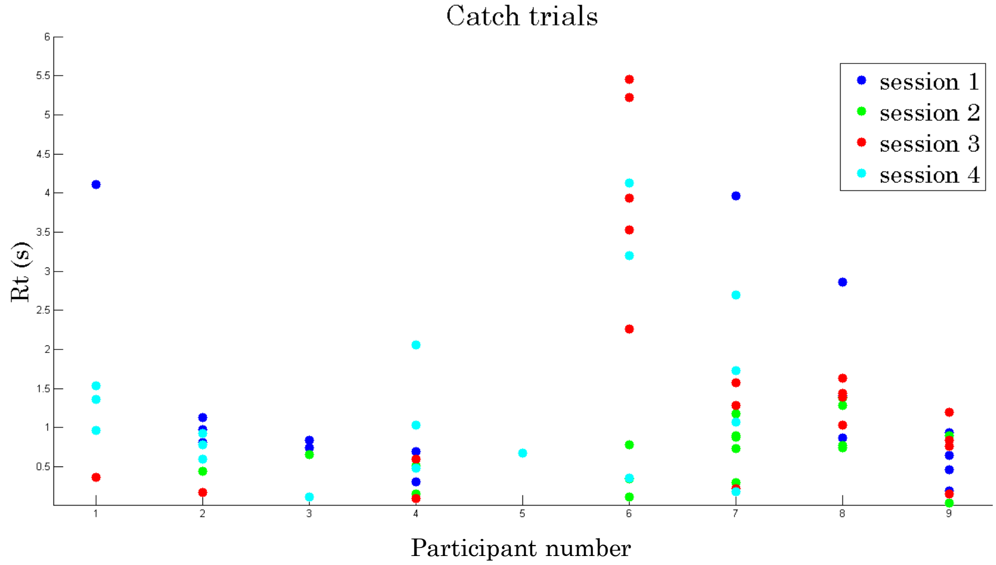


Figure 13 Scatterplot of catch -trial times. Calculated times are the differences between the time of 'disappearance' of the target and the release time of the space bar. If the space bar was released before the target could disappear, no time was noted.

Discussion

In this experiment we found a significant effect of the congruent sound on the time that the target was reported by the participants. The times that the target was perceived were much lower than in the previous experiment, even though the contrast levels were not lowered. This indicates that following the target made it easier to suppress.

Even though the suppression was very strong, learning effects still occurred. As can be seen in figure 13, on average the performance improved during the four sessions. Overall this improvement was slightly larger for the congruent condition than for the incongruent or no-sound condition. This could be an indication that the multisensory condition enhances learning. A similar benefit of audio-visual congruency on visual learning has been shown by Kim et al (2008). To asses if this effect occurs more strongly in the congruent condition the different conditions would have to be presented in separate blocks. By offering the different conditions alongside each other transfer can take place.

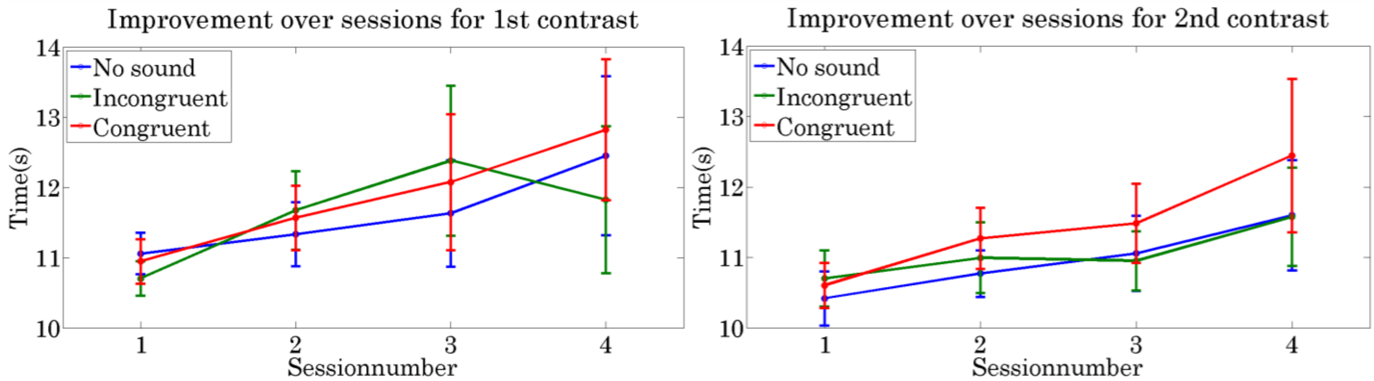


Figure 14 Mean improvement over four sessions for the lowest contrast (on the left) and the highest contrast (on the right).. The decrease in steepness between the 2nd and 3rd session is probably be due to the fact that most participants completed the four trials on two separate days. Error bars are standard errors.

A down-side of the current set-up was that not being able to see the stimulus was rewarded, if the stimulus was visible for a longer period of time the duration of the trials increased. This could have negatively influenced our results.

General discussion

In our final experiment we found a positive effect of multisensory rhythmic congruency on the time participants were able to keep the target form being suppressed in continuous flash suppression. However, there are several limitations to our experiment.

Continuous flash suppression has never before been used to simulate neglect in healthy participants, and even though they have similarities we cannot be sure that the same effects occur. A large difference is that CFS has been mostly used to simulate lack of awareness, while neglect patients also show large deficits in directing attention (Ting et al. 2011). Even though for some patients it is possible to direct their attention to their neglected hemifield when instructed to do so. The current use of CFS in the debate about the relationship between attention and awareness (Boxtel, Tsuchiya & Koch, 2010) implies that only awareness is suppressed during CFS, while top-down attention is still possible. In this article it is also stated that although exact relationship between attention and awareness remains unsure, it is thought that attention is not sufficient for awareness and might not even be necessary. Since we do not exactly now how attention and awareness are related and we do not know the role it plays in neglect, we cannot be certain that CFS mimics neglect.

Another important limitation using continuous flash suppression is that the stimulus saliency cannot be too high. We found that suppression looming stimuli was too hard, so we were not able to test the hypothesis that this has an increased effect in lowering neglect symptoms. Including other factors that are shown to lessen extinction or neglect symptoms, like adding emotion, using a facial target or using grouping or enumerating processes (Driver et al 2001, Dent et al. 2011), could make suppression even more difficult.

CFS has mostly been used to suppress static stimuli, but a recent study used it to examine the motion after effect of vertical moving gratings (Maruya. Watanabe & Watanabe 2008). To successfully suppress these, they used an adapted version of CFS. In this dynamic version of continuous flash suppression, the Mondrian pattern consisted of horizontal moving grating, perpendicular to the moving stimulus. Another difference between their study and our experiment is that they also looked at eye-dominance. By presenting the mask to the dominant eye; a higher degree of suppression can be achieved.

Another important point is the importance of both temporal and spatial congruency of audiovisual stimuli for multisensory integration. In our experiments we did not use a spatial cue, while previous research (Frassinetti et al. 2005, van Vleet et al. 2006) showed enhanced detection of a visual cue when an auditory stimulus was presented at the same spatial location. The importance of this spatial congruency has not only been shown in visual detection tasks but also in auditory localization. For example, Leo et al. (2008) found that in the intact hemisphere of hemianopia patients, like in healthy individuals, visual cues induced a strong bias for/on auditory localization. This effect was independent of spatial or temporal disparities and negatively influenced their performance when the visual and audio signals were not presented at the same location. In their blind hemisphere however, the same effect did not occur. Visual cues were not detected and did not interfere with the auditory localization, unless they were presented at the same position where they greatly enhanced the localization accuracy.

Since neglect patients show deficits in their spatial attention, the spatial component of the cues used in these studies could be necessary to generate an effect. Cueing spatial attention in an intact modality might help them overcome the deficit in the affected modality. It has been suggested that when a signal in one modality is weak the system puts more weight on other modality (Alais & Burr 2004).

Another factor that could explain our difficulty to find significant effects with only a temporal cue could be the nature of the movement. In visual search tasks, effect of temporal congruency without spatial have been shown. But this so-called pop up effect has only been found for sudden, transient changes, it was absent when the visual array underwent sine-wave modulations. The effects of rhythmic congruency could also be larger when the sine-wave movement would be replaced with a more transient movement.

Other modalities, like touch, can also be used to strengthen the effect. In normals enhancing effects of adding touch to audiovisual stimuli have been found (van Ee et al, 2009) and in neglect patients different studies have reported positive effects of activating contralesional limbs (Ting, 2011). Cross modal effects of touch and vision have also been found in patients with tactile extinction, a deficit that is similar to extinction in the visual modality (Làdavas et al., 1998). In these patients tactile stimulation of the hand on their contralesional side inhibits processing of tactile stimulation of their ipsilesional hand. When they presented a visual stimulus near the ipsilesional hand of these patients, it caused the same amount of inhibition that tactile stimulation of that hand did. Interestingly, presenting a visual stimulus near their contralesional hand actually improved the detection of tactile stimuli applied to the same hand. Showing that competition between representations in one modality can be influenced by presenting a stimulus in a different (intact) modality.

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