Processing and Analysis of Behavioral Data During Saccadic Eye Movement Tasks

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Abstract

The human eye constantly moves to bring different objects of interest into focus in order to provide us with large amounts of high resolution visual information. These rapid eye movements are known as saccades. Previous studies have found that there can be perceived compressions of temporal duration for visual stimuli introduced moments near a saccade when compared to other visual stimuli far away from a saccade (Morrone et al., 2005). Here we observed a perceived temporal expansion by subjects when comparing perisaccadic visual stimuli to auditory stimuli far from saccade. The observed temporal effect took place when the delay between the two visual flashes spanned the saccade duration and increased as more of the delay passed the saccadic offset. This gave way to the theory that the magnitude of the temporal expansion was a function of the amount of delay within the saccadic window and the amount past the saccadic offset. The temporal effect appeared to be similar to that reported with chronostasis, a perceived expansion of time for stimulus introduced during a voluntary movement; however, more studies would need to take place to verify its relation. It was also discovered that the effect was maximized when the visual stimulus was presented just below the target and fixation points of the saccade, but more analysis was needed to understand how our perception of time changes during rapid eye movements.

Introduction

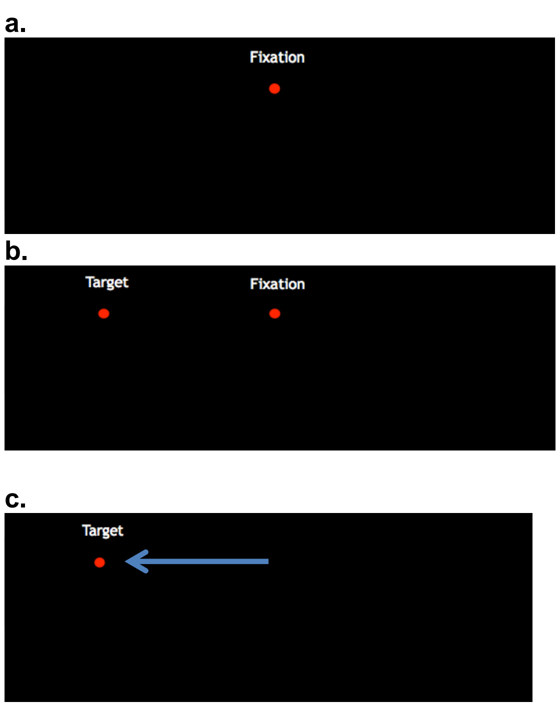
As we walk into a new environment, we constantly make rapid eye movements in order to scan the area around us. These quick eye movements allow the area of greatest visual resolution on our retina, the fovea, to move and focus on different objects of interest in order to provide us with as much visual information about our surroundings and as fast as possible. These rapid, large eye movements are called saccades. Despite the constant motion of the eye, the visual scene perceived by a human is still and stable, but the mechanisms behind the stability still remain under research. Through this search, various phenomena have been observed during saccades and at times near saccades. Previous experiments have found that there is a perceived compression of time for visual stimuli introduced moments before a saccade. This experiment introduced two visual stimuli, one at various times relative to a saccade and one well after a saccade. They found that when the first stimulus was introduced near saccadic onset, its duration was underestimated nearly to a factor of 2. The study also concluded that this effect was not observed with auditory stimuli or blinks (Morrone et al., 2005).

Expanding upon the previous literature, Dr. Nategh and her Ph.D student, Amir Akbarian, designed an experiment to observe the perceived temporal effects experienced when comparing perisaccadic visual stimuli to auditory stimuli at fixation. This study was also designed to find the effects that the spatial location of the visual stimuli could have on the perceived duration. It was able to examine the exclusivity of the effects seen in Morrone's paper and provide further insight into the temporal effects of different stimuli and spatial location around the time of saccade. My project was processing the data signals collected during the experiment and completing a series of data analysis tasks in order to demonstrate the temporal effects seen. This would allow us to see what effects are resulting from the experiment and to be able to expand upon our knowledge of perisaccadic behavior. The goal of my particular portion of the study was to produce the necessary plots of the data to visualize the observed temporal effects and then to provide a possible hypothesis for the cause of the effects based on previous literature.

Methods

The Experiment

The subject was sat down in front of a black computer screen at a viewing distance of 55cm. When a red dot, called the "fixation point", would appear in the center of the screen, the subject was told to fixate on it. Another red dot, called the "target point", would appear 8cm to the left of the fixation point some time later. Once the fixation point disappeared, the subject would move their eyes over to the target point, inducing a saccade, and fixate upon the target point. At varying times relative to the fixation point turning off, a green dot would flash for 60ms and then flash again 200ms later. The location of the green dot would always be 1cm (equivalently 1 degree of visual angle) below the horizontal plane of the target and fixation points but vary between 7 different locations, each 2cm (equivalently 2 degrees of visual angle) apart from one another. 1.6s after the saccade was made, an auditory beep of 35ms would play, then there would be a variable delay of 95ms to 305ms, and a second auditory beep of the same duration would play. The subject was asked if the duration of the visual stimuli was longer than the duration of the auditory stimuli. If the duration of the visual stimuli was greater, the subject would push the right arrow key. Otherwise, they would press the left arrow key. An illustration of the experiment can be seen in Figure 1. During the experiment, the eye position signal from the eye tracker, photodiode signal from the photodiode placed on the computer screen, and microphone signal in the headphones were all recorded.



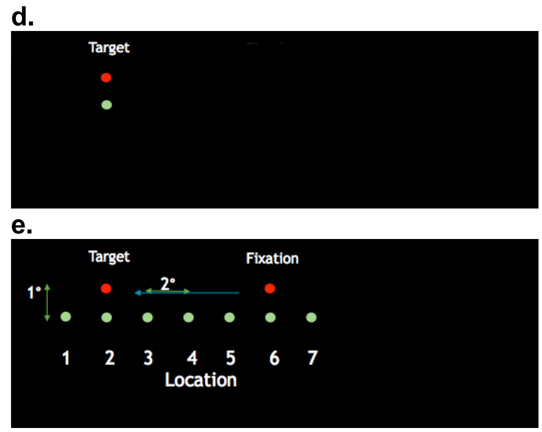


Figure 1: Experimental Setup – a) First, the fixation point would come on, and the subject was told to fixate upon it. b) The target point then came on. c) Once the fixation point disappeared, the subject was supposed to saccade to the target point. d) The visual stimuli would flash for 60ms, disappear for 200ms, and flash for another 60ms at various times relative to the saccade. e) The stimuli could appear in 1 of 7 locations, each of which was 1 degree of visual angle below the horizontal plane of the target and fixation point and 2 degrees from one another.

Signal Processing

Separate Matlab scripts were written for each of the three signals, the eye position, photodiode, and microphone, in order to obtain accurate quantitative data for the timing of certain events. Basing the data upon the recorded signals ensured the data came from the real-life timing of the events rather than the expected times written into the experiment code. Examples of the signals and the events of interest can be found in Figure 2.

With the eye position, the main goal was to find the time of the saccadic onset and the saccadic offset. The script put an average moving filter upon the signal in order to smooth out smaller noise due to random fixational eye movements in the trends of the line. It then began looking for the behavior of a saccade, which would be a consistent downward trend in the eye position followed by a flattened line after about 50ms. It began the search for this behavior at 600ms before the fixation point turned off, due to predictive saccades occurring. The eye position would make a change from between the interval of 2cm to -2cm to between -6 and -12cm from the center of the screen.

The photodiode signal was taken to find the exact timing of the visual stimuli flashes. The search for the stimuli would begin a few milliseconds before the experiment code intended the first visual stimulus to appear. The code looked for a sharp decrease in the signal followed by a sharp increase a few milliseconds later. The sharp increase represented the first visual stimulus offset. The same pattern was looked for between 150ms and 250ms after the offset of the first visual probe, and the sharp decrease would resemble the second visual stimulus onset. The difference between the second visual stimulus onset and first visual stimulus offset was found and taken to be the duration of the visual stimuli.

The microphone signal code utilized a system of thresholds to decipher between noise and auditory beeps. The script would find the most common two auditory magnitudes and set the interval between those values as the window of noise in the signal magnitude. Once the signal passed those thresholds and remained past the thresholds for more than 4ms, it was considered an auditory beep. The onset and offsets were found by looking for the rising and falling edges of the signal, and the duration of the auditory signal was taken as the difference between the second auditory onset and first auditory offset. For trials with auditory signals that were too weak to be read, the duration was set to 0, so they would not play a role in the preceding data analysis.

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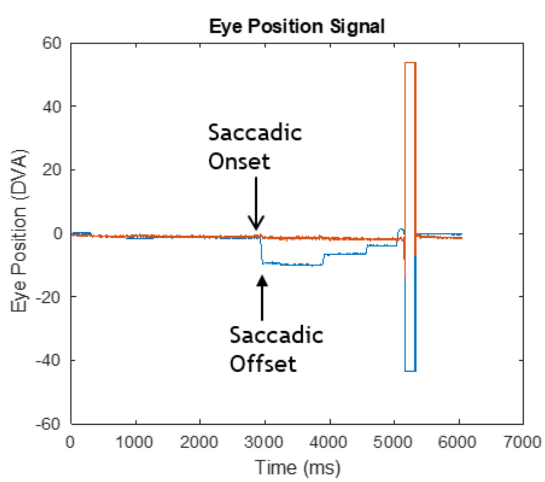

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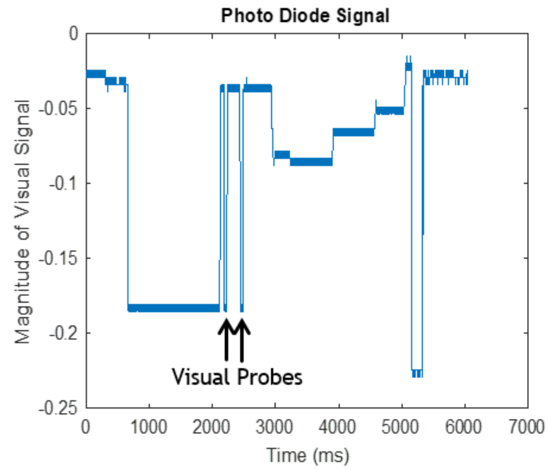

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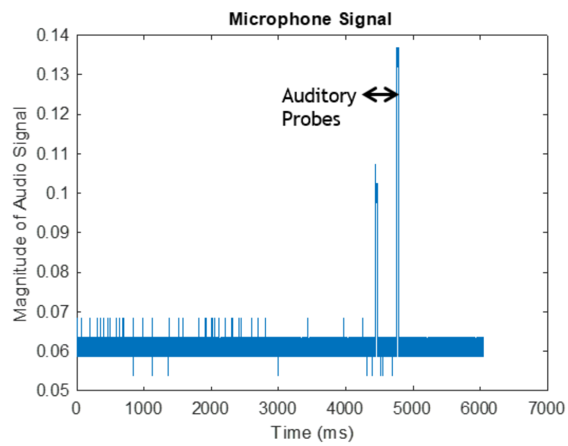

Figure 2: Collected Signals – a) An example of the eye position signal. The saccadic onset and offset were the key events that were found. b) The photodiode signal where the onsets and offsets of the flashes were found. c) The microphone signal, which needed to show the onset and offsets of the auditory beeps.

Psychometric Function

The fundamental means of analyzing data in psychophysical studies is with a psychometric function. An example of the basic psychometric function can be seen in Figure 3. The psychometric function illustrates the relationship between a change in a stimulus and the forced-choice response of a subject. The x-axis would represent the change in the stimulus. The y-axis would represent the proportion or percentage of times the subject responded one way over the total number of times they responded for that particular variation of the stimulus. The measured responses are represented by dots in the plot.

These points are then fitted with a cumulative Gaussian distribution function, which yields a sigmoid-shaped function. The beginning and end tails of the function are generally closer to 0 or 1 (0% or 100%), respectively, because the subject should be more confident in their responses at those extremes. The point that is of real interest is where the subject is equally likely to answer one way or the other, the 0.5 or 50% mark. This point is known as the Point of Subjective Equality (PSE). PSE indicates where the subject is unable to discern between the two options they are given and is generally thought of as where the subject perceives the two options to be the same.

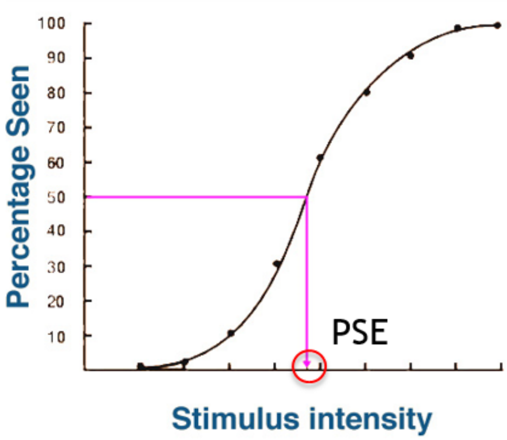

Figure 3: General Psychometric Function – The psychometric function gives a subject's response as a function of a changing stimulus. The Point of Subjective Equality shows when the subject is equally likely to answer either way.

For this particular project, the change in the stimulus was the duration of the auditory stimuli, which varied from 95ms to 305ms. Since the subject was asked to compare the duration of the auditory stimuli to the fixed 200ms visual stimuli, the proportions calculated were the number of times the subject reported the auditory stimuli was longer over the total number of times the subject responded for that specific auditory duration. A Matlab script was written which would divide the trials into their different auditory durations. Then, for each duration, it would find the number of responses where the auditory duration was reported as longer. The proportion could be found be dividing the number of responses by the total number of trials for that duration. A separate script was written to plot the proportions versus the auditory durations and to fit a cumulative Gaussian distribution function. The fit function would also find the mean value (PSE) and standard deviation for the fitted Gaussian function.

In order to isolate the effects of the saccade, a script was made to separate the trials where the first visual stimulus onset was more than 200ms from the saccadic onset, called "fixation trials" from the trials that were less than or equal to 200ms from the saccadic onset, labeled as "perisaccadic trials". The psychometric functions of these two groups were plotted separately as to see the difference between the two. The difference between the PSE of the perisaccadic trials and PSE of the fixation trials was calculated to find the change in the PSE or the shift.

To further isolate the timing of the temporal effect, a 3D model was created which would show the psychometric function of a 50ms window shifted across time from -250ms to 100ms relative to saccadic onset. The Matlab script would find the specific duration of delay between the first visual stimulus onset and the saccadic onset for each trial. It would group the trials with durations more than 250ms together and plot the psychometric function. Next, it would create a window of 50ms starting from -249ms to -199ms, find all the trials with durations of delay within that range, and plot the psychometric function for that interval. The window would then be shifted 1ms towards the positive time until the start of the window reached 99ms. The remaining trials with durations of delay past 100ms from saccadic onset were grouped together, and the psychometric function was plotted. The result was a 3D surface, which could show the progression of the psychometric function across time relative to the saccade.

Spatial Differentiation

The other main goal of the project was to analyze how the spatial location of the visual stimuli could impact the perception of the duration of the visual stimuli. To accomplish this, the trials were first grouped together based on the location of the visual stimuli. The same procedure was run as above to fit the psychometric functions for the fixation trials and perisaccadic trials but for each location's trials separately. The change in PSE was recorded for each location and plotted against the location. The graph could illustrate, which locations yielded the greatest shift and which had the lowest.

The progression of the change in PSE for each location across time was shown as another 3D surface. The trials were again separated into their respective locations. A fitted function was found for the fixation trials to find the PSE as was done before for each location. However, this time, the perisaccadic trials were taken in 50ms windows based on their duration of delay between the first visual stimulus onset and saccadic onset and shifted across time. Starting with the window of -150ms to -100ms before saccadic onset, the trials with durations of delay in this window were fitted with a psychometric function, and the resulting PSE was subtracted from the fixation PSE to find the shift. The window then shifted 1ms towards the positive time until it was 50ms past the saccadic onset. The remaining trials were grouped together to find the final shift. This process was repeated for all 7 locations. The change in PSEs was plotted with the location and time relative to saccade to create a 3D surface, which showed the change in PSE for each location across time. The changes in PSEs were also averaged over all the subjects to produce an averaged spatiotemporal map.

Results

Overestimation of the Auditory Stimuli Duration

For all subjects, the PSE for fixation trials came out to be much less than the fixed 200ms duration of visual stimuli. As seen in Figure 4, the fixation PSE appeared at 143ms for subject MC and 128ms for subject RJ. This baseline suggested that the subjects perceived 200ms of visual stimuli as equivalent to less than 150ms of auditory stimuli. Auditory stimuli seemed to be perceived as longer than visual stimuli even without the influence of saccadic behavior.

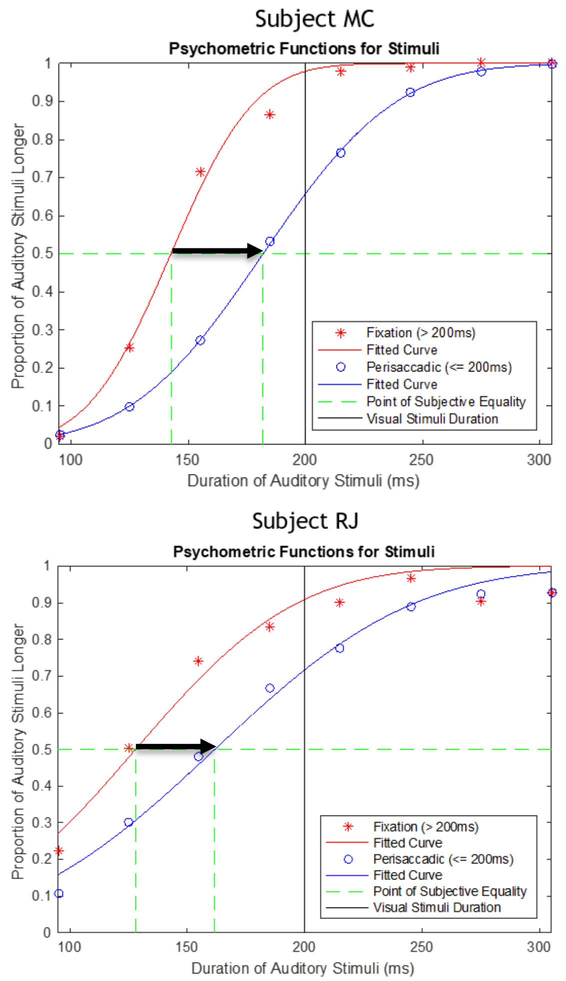

Figure 4: Psychometric Function for Fixation and Perisaccadic Trials – The comparison of the PSE of the fixation trials and perisaccadic trials revealed the perisaccadic PSE was shifted over to the right, suggesting that there was a perceived temporal expansion. This was consistent for both subjects shown.

Temporal Expansion

The comparison of the psychometric curves of the perisaccadic trials to the fixation trials yielded a shift in the positive direction. As shown in Figure 4, the psychometric function for the perisaccadic trials was shifted to the right for both subjects. Subject MC had a PSE of 143ms for fixation trials but a PSE of 182ms for perisaccadic trials. The difference was a shift to the right of 39ms. Subject RJ showed a shift of 34ms to the right as well. This positive shift suggested that there was a perceived expansion of visual duration as the visual stimuli was introduced closer to the saccade.

Figure 5 showed the specific timing of the temporal expansion effect that was previously observed. For both subjects the effect seemed to start around 200ms before saccadic onset, maximize at around 80ms before saccade, and disappear around the saccadic onset. Figure 6 introduced the critical points of the effect and aligned the timeline of the visual stimuli to each of the points. It appeared that the effect began right around the moment the delay between the visual stimuli encompassed the duration of the saccade. The maximum PSE came right as the beginning of the delay reached the start of the saccade, and the effect disappeared once the delay was no longer in the duration of the saccade. This timing led to the idea that the perceived duration of the delay would increase once the delay occurred fully during the saccade. The temporal expansion would be maximized when the maximum amount of delay was past the saccadic onset and the delay still occupied the duration of the saccade. Then, the effect would decrease until none of the delay was within the duration of the saccade. This proposed the idea that it was the timing of the delay, not the visual flashes, which brought upon the temporal expansion.

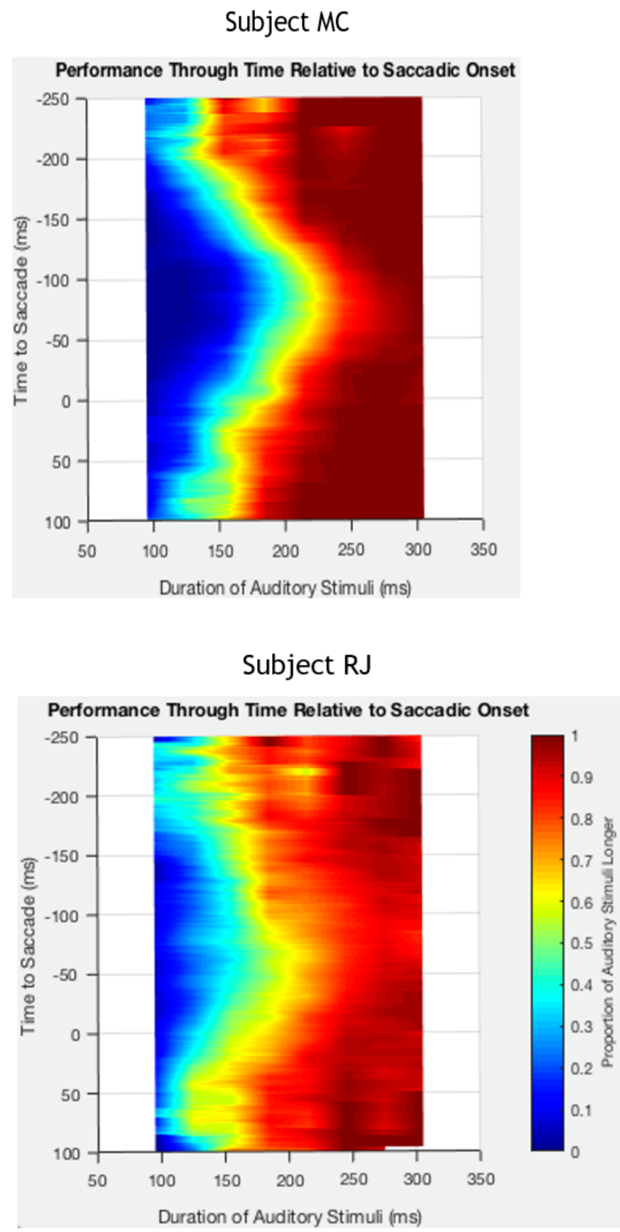

Figure 5: Psychometric Function across Time – The figure showed the psychometric function of a 50ms window shifted across time. For both subjects, the maximum PSE is located between -100ms and -50ms relative to saccade.

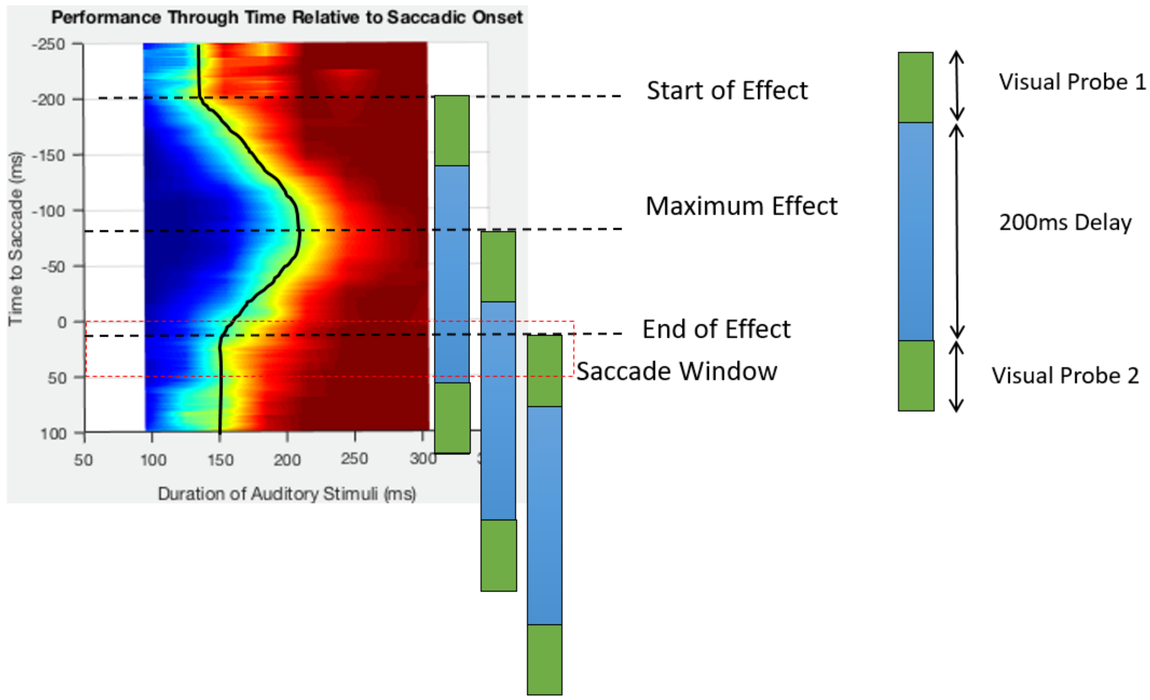

Figure 6: Visual Stimuli Timeline Relative to the Effect Timeline - The timeline of the visual stimuli, shown on the right, was aligned relative to the key points of the temporal effect: the start, maximum, and end. The alignment showed the effect started once the delay between visual stimuli entered the saccade window and increased until the delay almost started on the saccade window. Then the effect decreased until the delay was no longer in the saccade window.

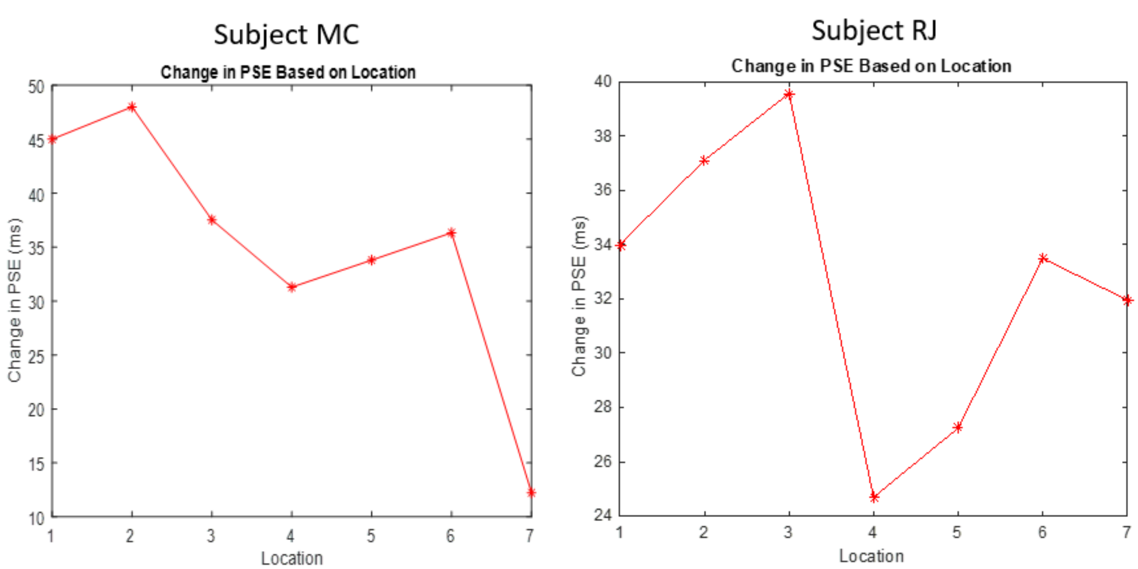

Figure 7: Change in PSE for Each Location – Changes in PSE were plotted against the spatial location of the visual stimuli. Peaks were seen near Locations 2 and 6, which were below the target and fixation points, respectively. Valleys were generally seen at Location 4.

Spatial Location Affects the Temporal Expansion

Figure 7 illustrates the shifts in PSE for each location. The plots for both subjects produced a similar shape in which there were peaks near Location 2 (aligned with the target point) and Location 6 (aligned with the fixation point). Additionally, both plots seemed to have valleys near Location 4, which was aligned exactly beneath the midpoint between the target and fixation points. Figure 8 further accentuated this general shape as it showed peaks at Location 2 and 6 and a valley at Location 4 during the interval of maximum temporal expansion between 100ms and 50ms before saccadic onset. It appeared the maximum temporal effect occurred when the visual stimuli was introduced below the target or fixation points.

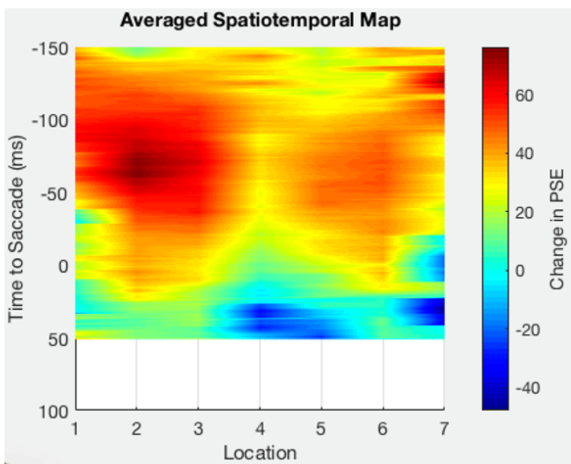

Figure 8: Averaged Spatiotemporal Map – The change in PSE for a 50ms window shifted across time for each location was averaged over all the subjects, producing an averaged spatiotemporal map. The surface showed peaks at Location 2 and 6 and a valley at Location 4 between the interval of -100ms and -50ms.

Discussion

Overestimation of the Auditory Stimuli Duration

Results of this experiment were consistent with previous studies, which found that auditory stimuli was perceived as longer than visual stimuli (Wearden et al., 2006). Other studies have attributed this effect to the ticks of an internal clock. It was believed that the clock ticks faster for auditory stimuli than for visual stimuli. If more clock ticks occurred for an auditory event, it would be perceived as longer in duration than a visual stimulus of the same time.

Temporal Expansion

The temporal effects observed in this experiment did not seem to correlate with the findings of Morrone et al. (2005). Whereas they discovered a temporal compression when the visual stimulus was introduced in the perisaccadic region, our findings suggested a temporal expansion when in the perisaccadic interval. The effects were also observed at different times relative to saccade. The visual stimuli would finish between 50ms and 0ms before saccadic onset in Morrone's study; however, we observed the effects starting when the second visual stimulus began near the saccadic offset. It is possible that the effects seen in Morrone's paper were exclusive to the comparison of two visual stimuli as they had previously stated the same effect was not seen with two auditory stimuli.

Perhaps the temporal effects we observed were more closely related to a different temporal phenomenon, chronostasis. Chronostasis was mostly commonly recognized as the effect responsible for the first second on a clock appearing to take longer than the preceding seconds when one first glances at their watch. A study has shown that there can be a perceived expansion of temporal duration for stimuli after any voluntary movement including a saccadic eye movement (Park et al., 2003). The same study found that the perceived duration of a delay can also occur. While their stimuli or delay was directly caused by the voluntary action in their study, it is possible that the same temporal effect can occur for the perception of stimuli or delays that happen to be during a saccade. They proposed that perhaps the internal clock ticks of the brain speed up during moments near a voluntary movement such as a saccade. If more clock ticks occur during the delay between visual stimuli, it may be perceived as a longer duration. However, this still does not explain the gradual increase and decrease of the effect that we observed across time. Yarrow et al. found that the perceived temporal expansion effect was not proportional to the duration of the target stimulus (Yarrow et al., 2004). However, their study involved the stimulus being introduced at one-fifth of the saccade duration, and the stimulus was the saccade target. This varied with our experiment in matters of the timing of the stimulus (or in this case, the delay between stimuli) and the attention placed on the stimuli as our stimuli were not the saccade target. Our data suggested that there could be a possible connection between the magnitude of the temporal expansion and a variable determined by a combination of the duration of the delay that was within the saccade and duration that was beyond the saccadic offset. Further studies would need to be conducted to see if the duration of stimuli is expanded when the stimuli is not the saccade target and if there is a temporal expansion when the stimuli spans from before saccadic onset to after saccadic offset.

Spatial Location Affects the Temporal Expansion

The spatial positioning of the stimuli appeared to play a role in the magnitude of the temporal expansion. Stimuli located right below the target and fixation point exhibited the greatest change in PSE. As it has previously been found that attention is put upon the fixation and saccade target before a saccade has begun (Gersch et al., 2004) and that attention can result in an expanded perception of time (Tse et al., 2004), it became hard to ignore the possible effects of attention. If attention is directed at both the fixation and target points, then it could be possible that the stimuli introduced closest to those points would yield the greatest temporal expansion effect. However, another study has shown that the effects of attention only play a role when the stimuli and saccade target are the same object (Deubel and Schneider, 1996). They found there was no benefit for their discriminatory tasks when the discrimination stimulus was not the saccade target. Therefore, it was unlikely that attention played a role in the perceived expansion of our stimuli. Perhaps there was a different underlying mechanism, which is responsible for the increased effects near the fixation and target points. More studies will have to be done to examine this characteristic.

Conclusion

The comparison of perisaccadic visual stimuli with fixation auditory stimuli yielded an effect that resembled chronostasis. Visual stimuli presented near a saccade were perceived as longer in duration than the same visual stimuli presented during fixation. Additionally, the maximum temporal expansion was seen when the visual stimuli was presented just below the fixation or target points. From these findings, it was seen that the temporal compression observed in Morrone's study did not apply to the comparison of visual and auditory stimuli durations. However, this study did find a similar effect as chronostasis but for when a stimuli or delay was initiated before saccadic onset and with varying levels of magnitude depending on its timing. The temporal expansion also demonstrated a connection with the spatial location of the stimuli. These results give way to a further understanding of the scope of chronostasis or to possibly a completely new effect. Further studies would need to be conducted to see if the saccade size increases the effect as is recognized with chronostasis. Studies would also need to be done to see if stimuli that span the whole saccade and beyond have similar temporal expansions. Experiment would need to find if the magnitude of the expansion varies based on the timing of the stimuli. These studies would help to verify the findings of this experiment and contribute a level of understanding to the temporal expansion effect.

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