FACTORS AFFECTING THE SMOOTH PURSUIT OF A MOVING TARGET

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Abstract

In the past few years there has been little study on the role of shape, color, and attention during the smooth pursuit of a moving object. In this experiment, we sought to show that these factors greatly affect the subjects' abilities to accurately follow a moving target. In this paper we review the results from our own recent study using a paradigm modeled after the shell game, where the subjects are asked to follow a specific shell throughout the game and then identify at the end which shell they had been following. The results of this study is consistent with the hypothesis that shape, color, and attention affect the subjects' abilities to correctly identify which shape they followed during the smooth pursuit. However, it was discovered that blinking also had an impact on the final results. Color had a more significant effect than shape in identifying the correct shape, but attention and blinking played a higher role in the subjects' abilities to continue following the shape.

Keywords: attention, smooth pursuit, retinal slip, reaction time

1 INTRODUCTION

Smooth pursuit is basically the tracking of a moving target with an active vision system. Many factors can affect how accurately a subject can participate in smooth pursuit. Not many studies have been done on the effects of color and shape on smooth pursuit, but it is quite obvious that color has a significant effect on the subjects' abilities to follow the target. It is much easier to follow targets of different colors than it is to follow those of the same color. Also, differently- shaped targets are easier to track than those of the same shape. Attention allows us to identify and discretely distinguish selected stimuli while effectively excluding others. Certain stimuli can distract the subject from being able to concentrate on the moving target.

Attention and smooth pursuit eye movements

Although much study has been done on the role of attention in saccades, less is known about its role in eye tracking smooth pursuit. As shown in other studies, there is, however, evidence that shows attention contributes to processes underlying smooth pursuit. Studies have shown that in order for a subject to accurately pursue a visual stimulus, the central nervous system must determine the velocity. Neurological studies have shown that neurons in the middle temporal and medial superior temporal areas are triggered by visual motion stimulation [9] and that they contribute to smooth pursuit output [5]. In this study, however, the moving targets of each study are moving at the same constant velocity so this does not directly affect the results.

During smooth pursuit, attention is focused just ahead of where the object is moving [1]. It is easier to detect peripheral targets just ahead of a pursuit stimulus than it is to detect a target behind the stimulus. Also, detection occurs faster during pursuit maintenance rather than during pursuit onset or pursuit offset. This implies that pursuit maintenance is less attention demanding than pursuit onset and offset. The reason for this could be that the subject must determine the speed and direction and when motion begins at pursuit onset. These results suggest that attention is not distributed evenly across either space or time during pursuit output.

Donkelaar et al. performed an experiment where a manual button was pressed when a subject saw a peripheral target that appeared either ahead or behind a moving stimulus. Their results show that the peripheral target was seen more quickly when it appeared ahead and during pursuit than any other case. Also, targets that appeared ahead were generally seen faster than those that appeared behind. Donkelaar et al. conclude that attention during pursuit is focused just ahead of the moving stimulus. They also tested subjects varying the speed of the moving object and number of peripheral targets.

In the second experiment, subjects were asked to press a button when an object changed from an 'x' to an 'o'. The results from this experiment show that subjects tended to have a shorter latency for targets that appeared up to 2 degrees ahead of the stimulus than any other target eccentricities. When the speed was varied, the latency of the responses increased. This suggests that maintaining pursuit at higher velocities is a more attention-demanding task. Finally, the faster the stimulus moved, the further away the focus of attention moved resulting in lower latencies at that point. I.e. at 15 degrees/sec the focus was 2-3 degrees ahead compared to 5 degrees/sec the focus was at the stimuli.

How is attention and smooth pursuit related? Attention helps us pursue a moving target more effectively and accurately. Evidence shows that subjects can perform search and following tasks more easily for target displays that are being pursued than for those that are not [2]. Also, when subjects are asked to allocate their attention to the moving target, pursuit gain actually increases [7].

Target selection for pursuit and saccadic eye movements

Pursuit is what moves the eyes smoothly and slowly in order to maintain retinal images stationary, while saccades move the eyes quickly to foveate eccentric retinal images [4]. When subjects are instructed to make a saccade to one of several stimuli, the latency and accuracy of saccades can be manipulated by the presence of distractor stimuli [6]. It seems when a target stimulus is distinguished from its surrounding distractors, saccades typically are made directly to the target, whereas, when the identification of the target stimulus is less obvious, saccades are made to the distractors. This suggests that saccade endpoints are determined by spatial distribution of attention rather than by the particular location of the stimuli.

In a study by Krauzlis et al., the selection of targets for pursuit and saccades, as well as latency, was examined by presenting target stimuli which differed from its distractors by factors like shape, color, or both. When the stimulus was accompanied by a distractor moving in the opposite direction of the target's motion, the latency of pursuit significantly increased, probably due to subjects briefly following the distractor. In the presence of an oppositely moving distractor, the amount of increase in latency depended on whether the target differed from the distractor by color and shape (24 msec) versus just by shape (30 msec) [3]. The lower latency times observed when the target stimulus differed in color and shape was consistent with previous observations that color is an effective cue in guiding visual movement [8].

Overall it appears that subjects may confront a trade-off between accuracy and speed in determining their pursuits, and how they resolve the conflict could account for their particular pattern of behavior. It was also determined that the initiation of pursuit and saccades had similar inputs. Yet since they both exhibited differing dependencies on the eccentricity of the tracked stimulus, the shared inputs may have acted through different mechanisms [3].

2 METHODOLOGY

Apparatus

In our set-up, eye tracking is performed by an ISCAN RK-726PCI High Resolution Pupil/Corneal Reflection Processor. The system, like most eye trackers used in labs, uses a camera that shines an infrared light on one eye and then processes the video image of the eye.

From this image, it is possible to ascertain the center of the pupil and the reflection of the corneal. With this information along with a calibration process it is able to compute the visual Point of Regard (POR). The calibration process is quite brief, but is necessary for each user in order to computer the POR into screen coordinates. The eye tracker operates at a sample rate of 60Hz. The eye position of a subject may be determined with an accuracy usually better than 0.3 degrees over a +/- 20 degree horizontal and vertical range using the pupil/corneal reflection difference. The maximum spatial resolution of the calculated POR provided by the eye tracker is 512 x 512 pixels per eye.

The eye tracking camera is positioned underneath a Sony 27-inch flat screen, NTSC television set. Subjects were seated in a chair with an adjustable chin rest in order to steady the head and minimize head movements. The experimenter sat to the left of the subject along with the eye tracking computer and other controls. The experimenter used these controls, including two monitors, to keep the subject's eye in view. One monitor displayed the subject's eye as the camera sees it, while the other monitor displayed the same screen as on the subject's monitor but with crosshairs that indicate the POR of the subject as it is superimposed on the scene monitor. If the eye tracker were to lose track of the subject's eye, say due to a rapid movement of the subject or of their eye, the experimenter will see this on the monitors. If it is just a blink of the eye, or some other minor disturbance, the eye tracking system will auto recover its track. However, if the disturbance is major, the experimenter will need to recalibrate the system.

Participants

Six undergraduate volunteers participated in this study. More students would be picked, however, due to time limitations on the project, a smaller number of participants were chosen. Three of which are males and three are females. The participants are all between the ages of 18 and 24. All of the subjects have normal vision.

Procedure

There are six combinations in which the experiments could be administered. Before calibration, each subject was asked to pick a random order in which they would perform each task. The subject then sat down and allowed the experimenter to calibrate his or her eye. This process is short, but may need to be repeated until the eye tracking equipment is properly calibrated, especially if the participant does not sit still. Once the system is calibrated, three randomly-ordered trials were conducted on the subject. Each trial lasted for approximately 20 seconds are conducted one after the other. In each trial, the subject was shown three polygon figures. The participants were instructed to focus on a "target" shape out of the three displayed. The experimenter then explained that the shapes will be put in motion, and the subject should keep his or her eyes on the target polygon and follow it throughout the trial. At the end of a trial, the subject was asked to tell where they think the target shape was located.

The three trials differ in that the first trial displayed three polygons of the same shape, size, and color. The second trial displayed squares of different colors, and the third trial displayed polygons with the same color and size but of different shapes. The x and y coordinates of the target shape were recorded along with a timestamp in certain intervals during the trial. Visual POR was also tracked during the whole trial and recorded into a log file for each trial per participant.

Stimulus

The stimulus, in each trial, was a screen with three shapes, which were put into motion after the subject was told to keep their eyes on a "target" shape. Below are screenshots for each of the three trials. Figure 1 shows one of the trials, which is three polygons of the same size, shape (square), and color (red). In figure 1, the lower square of the 3 was the current shape in motion at the time this screenshot was taken.

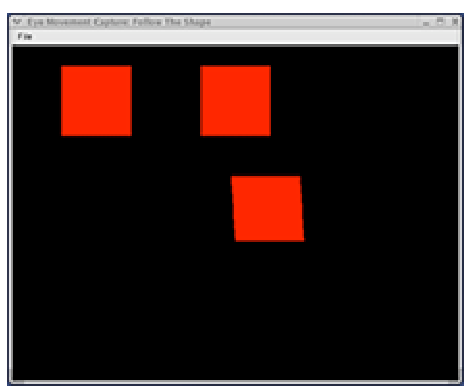


Figure 1. Trial A: 3 shapes, same color, size and shape

Figure 2 displays a screenshot of what another trial may look like when run. The colors (green, blue and red) of the shapes are the only elements which vary for this trial. The shape and size of the 3 polygons stay the same.

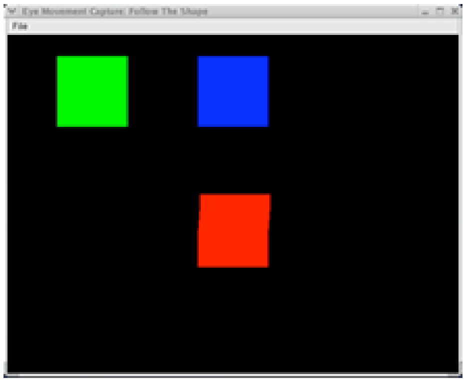


Figure 2. Trial B: 3 shapes, diff. color; same size and shape

Figure 3 is a screenshot of the last trial. The actual shape of the polygons is the differing factor in this case. The color and relative size of the three shapes, however, are all the same.

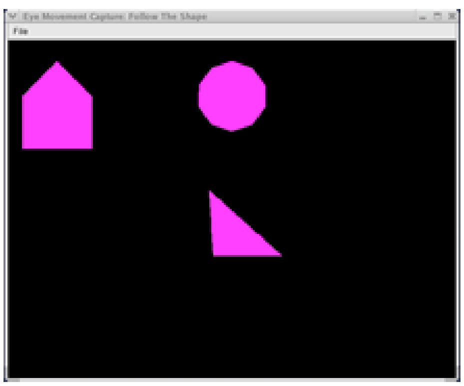


Figure 3. Trial C: 3 different shapes; same color

The orders in which the three trials are administered are randomly selected. Note that the three screenshots were taken while the shapes were in motion.

Design

Six subjects (3 male and 3 female) were used in this experiment with each having three trials conducted on them. Since the participants involved were men and women, the design is between-subjects oriented. The primary factors that are varied in the experiment are the color and shape of the polygons.

The study included three trials in which one of the factors was changed. For the first trial, three squares of the same size (50 x 50 pixels) and same color (red) were used. Thus, in the second trial the color of the squares were changed to one red square, one blue square, and one green square. The size and shape both stayed the same for all of the polygons (still 50 x 50 pixels and still squares). In the third trial, the relative size and the color were kept the same, while the actual shape of the polygons was altered. As in Figure 3 above, the varying shapes include a pentagon, a triangle, and a decagon (10-sided polygon).

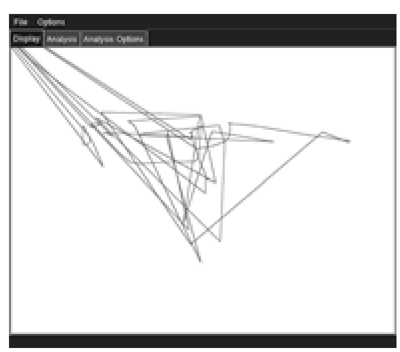
The six subjects, along with the three different trials, gave a total of 18 trials in the experiment. Thus, it has a 2 x 3 factorial design. The factors held constant during each trial are time (trials are approximately 20 seconds each) and speed (the polygons move at an interval of 0.5 at a time). Trials are set at 20 seconds in order to give enough time to record valid data while trying to avoid discrepancies like eye strain or fatigue. The main purpose of the design is to measure and record eye tracking data, specifically the visual POR of the subject, to later compare it to the actual coordinates of the "target" shape during the trials. Observations of how each subject reacts to the trials are recorded during the trials by the experimenters.

3 RESULTS AND ANALYSIS

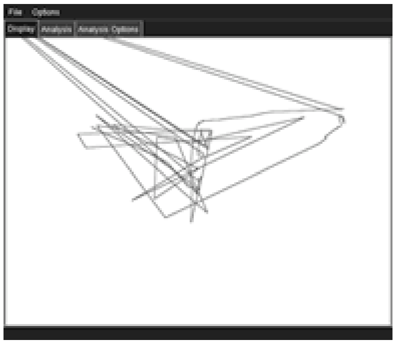
Out of the three different trials, the only trial that seemed to have an impacting result would be the trial with the three red squares. The trial with the different-colored squares and the trial with the different-shaped polygons both gave obvious results. All of the subjects, except for subject two, which is the outlier, were able to identify where the shape was located after the target stopped moving.

The trial with the red squares gave the most promising results. The results were comparable between subjects.
Subject 2 is considered an outlier because the subject correctly identified the position of the target one out of three trials. The correct one was the trial with the three red squares. The position of the square could have been a guess or could be the result of the subject paying more careful attention to the square because of the difficulty of the task.

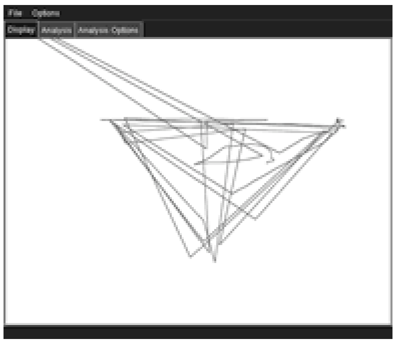
Subjects 1, 4, and 5 were found to be the standards of the experiment because of the similarity of the patterns of their scanpaths. Although a few variations occur, the scanpaths for this trial seemed to have a straightforward triangular pattern as shown in Figure 4. The target square has a finite number of patterns or directions that it can take. This, in part, explains why the scanpaths would be similar when the subjects follow the target square correctly and smoothly. The eye data points for the three subjects mostly lie in the same general area, in relation to their x- and y-coordinates. Blinking was kept to a minimal in all three subjects. This is important in keeping track of the target's position.



(A)



(B)



(C)

Figure 4. Scanpaths for Subjects 1 (A), 4 (B), and 5 (C) for the trial with the three red squares (trial A).

Below is a chart of the information gathered from the analysis program provided by the instructor.

	Subject 1	**Subject 5**
Sampling time(s)	20.67	20.44
Sampling rate(Hz)	15.5297	18.2975
Fixation points	283	285
Fixation groups	4	7
Mean group fixation duration(ms)	4965	2338.57

Because the scanpath patterns, amounts of blinks, and the eye data were similar, these three subjects have become standard references for our analysis. Although Subject 5 is classified as a standard or average scanpath pattern, there are variations in the scanpath that may raise some concern.

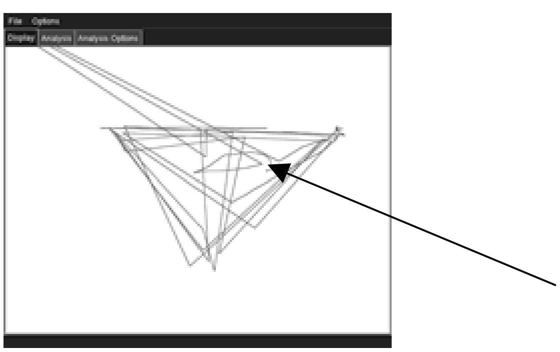


Figure 5. Subject 5's scanpath pattern

As pointed out in Figure 5, there is an area where the subject seemed to have lost concentration on the targeted square. One explanation could be that the subject blinked, losing sight of the position of the target square. Another explanation is that when the squares swapped from the leftmost position to the rightmost position or vice versa, the subject may have gotten confused as to which square to follow. Still another explanation is that when the subject lost contact of the targeted square, he may have guessed as to where it would be and began following that square. These reasons may explain why the subject incorrectly identified the position of the targeted square after the trial was completed.

Subject 3 provided the best data out of all the subjects. It is determined that the data gathered from subject 3 is near perfect based on number of blinks, scanpaths, and the correct answers given by the subject. First, the subject never blinked during any of her trials. Without any blinks occurring, and with correct calibration, the eye tracker never lost where the eye was looking on the screen. It therefore made it easier to use the data to determine whether or not the subject followed the target square the entire time or whether she looked at the other squares as they moved. After interpreting the data and displaying the scanpaths, it is easy to see the subject smoothly followed the target square. From the picture of the scanpath in Figure 6, we can see that the subject probably chose a single spot on the target square to follow and stuck with that spot. However, when the scanpaths dip down or make small loops, it is likely the subject glanced or followed one of the other squares as they moved. Finally, the correct answer the subject gave with the data collected and analyzed, we can determine that the subject knew where the target square was located the entire time during the trial.

This subject makes it obvious that it is not necessary to be looking at the target square the entire time to know where it is. It is also worth mentioning that it is easy for moving objects to draw the attention of subjects away from the object they are told to watch and follow.

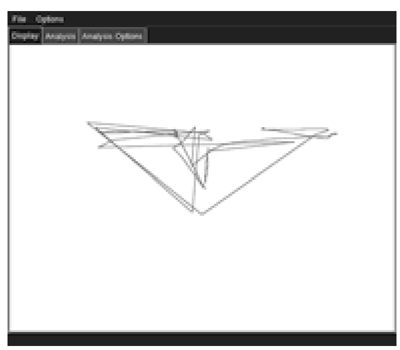


Figure 6. Subject 3's scanpath pattern

Subject 6's results are completely opposite to Subject 3's results. Subject 6 began following the target but soon lost track of its position. It seemed that he began guessing where the target was. When he chose a square to follow, he may have begun concentrating on different corners or edges of the square. The subject may have also begun to look at the trial as a "big picture" rather than concentrating on just one square. He may have found it easier to concentrate on the entire screen rather than the moving target. These reasons explain why the paths are sporadic yet still follow the same basic pattern for a standard scanpath for this experiment.

Although the subject correctly determined the position of the target, this may have been a guess since the scanpath is irregular compared to the standards as shown in Figure 7.

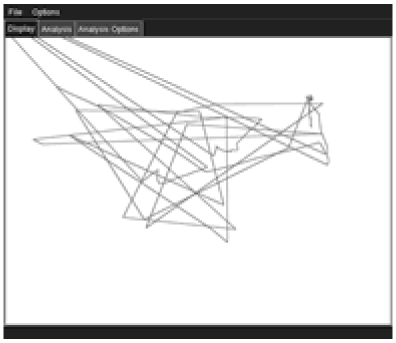


Figure 7. Subject 6's scanpath pattern

4 CONCLUSION

There is no evidence that shows sex (male/female), culture, or vision acuity differences had an effect on the results. The majority of the results show that color and shape enhance our ability to follow a moving target in smooth pursuit. The target is easier to recognize and locate. Even if the subject lost track of the target, the subject easily located the target once again and began following its movement. This is why most subjects were able to locate the position of the target easily when told to follow a target of a different color or shape. This is consistent with previous observations and studies that color is an effective factor in visual search.

Attention also plays an important role in correctly identifying the position of the moving target at the end of each trial. Attention is dependent on the color and shape of the moving target. For example, subjects paid more attention in the trial with the three red squares than in the other trials. This is because the same color and shape made it more difficult for the subject to recognize the target's location and follow its movement. When the target was lost, the subject had no way to identify the position of the red square unless he guessed. The non-target squares seemed to act as "distractors", drawing the subject's attention away from the target square, while they were in motion. Similar to the observations made by Krauzlis et al., subjects tended to briefly follow the non-target squares when they were in motion and then quickly revert back to focusing on the target square when it began to move. Environmental distractions, such as outside noises or movements, also had an effect on the subject's attention level. The more attention the subjects seemed to give to the moving target, the more accurate the results were. It's also probable that if subjects are given more explicit instructions on following the target square, the accuracy and effectiveness could be altered, potentially increasing the smoothness in which a subject pursues the target object.

Finally, we found blinking to have an unexpected effect on the subjects' abilities to correctly identify the positions of the targets. As the number of blinks for a subject increased, the inaccuracy of their smooth pursuits also increased. Because the targets moved at a fairly swift pace, it is possible that the position of a moving target could be lost in an instant.

In summary, we find that in a game such as the shell game, where the shells are the same shape, size, and color, the best way to "beat" the game and correctly identify the position of the hidden ball (moving target) would be to pay close attention to the shell as it is moving and to keep blinking to a minimum.

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