NS201: SENSATION AND PERCEPTION

PSYCHOMETRIC THRESHOLD FOR MOTION DETECTION: CENTRAL VS PERIPHERAL VISION

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Note: All of the code and output is on this GitHub Repository as well as a zip file. A Video of the experiment is in the same folder, which explains things better than I can with Words.

ABSTRACT

Motion detection is a very important part of our visual processing system. Moving objects generally stand-out, even in the peripheral vision. Here, I try to find out how well we can detect absolute object motion against a featureless background. *(Generally, we use the local surrounding regions to determine motion, but we can also detect absolute motion by its change in visual angle on our eye).* I do this for objects moving both in our central and peripheral vision and see if there's any difference, in the threshold between the two.

To achieve the same, I used an adaptive staircase method to adjust the strength of motion. *(A not-so-wise decision in hindsight.). (In fact, one could also say that this experiment was also a verification of Murphy's Law)*

METHODS

PSYCHOPHYSICAL EXPERIMENT:

(The experiment was designed using PsychoPy 2022.1.4 on Python 3.8.13; code for the same is attached with the submission)

The basic task is as follows: A white square appears on the screen. It moves **left, right or not at all**. The subjects have to respond with the direction they saw the square moving. There are two parts in the experiment, where the moving object is in the center and in the periphery of the visual field. More details of the experiment are shown below.

On-Center: Each Trial is composed of the follows:

- **FIXATION:** A red cross fixation cross is shown
- **STIMULUS PRESENTATION:** The white square then appears and moves **.**
- A yellow circle appears as a **response queue**. The participant has to respond with a keypress indicating whether the stimulus was moving left right or not at all.

*(The keypresses are recorded for the entire stimulus duration and response duration**). All shapes are shown in the center of the screen.***

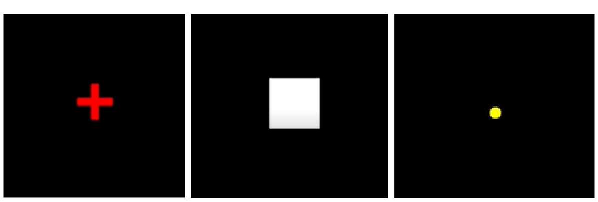


FIG: Fixation vs Stimlus vs response period.

Off-Center:
Here, the fixation cross has to be present for the entire duration of the stimulus presnetation to make sure the subjects gaze doesn't move to the moving square.

In addition, during trials it was observed that if the square suddenly appeared during the stimlus period, the *flash would inadvertandly draw the gaze of the subject to the square*, destorying the enitre purpouse of the experiment. Therefore slight modifcations were made to the protocol. Each Trial is composed of the follows:

- **FIXATION:** A red cross fixation cross is shown (*50 pixels below and to the left of the top right corner of the screen*). The white square is also present, although it isn't moving
- **STIMULUS PRESENTATION:** The red cross turns blue, and the white square starts moving.
- **RESPONSE TIME:** The cross disappears, and a yellow circle appears in the same position as the cross as a response queue.

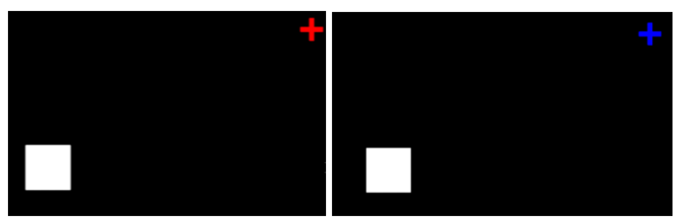


FIG: fixation period(left) vs stimulus motion period (right)

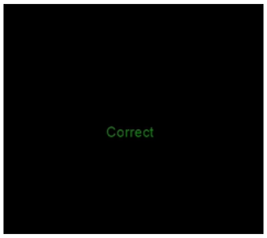
Stimuli were presented in blocks of 3

Time Intervals: For both on- center and off-center stimulus:

Fixation Period	2s
Stimlus Presentation	1s
Response period	1s
Inter-Trial Interval	1s
Inter-Block Interval	5s

In both cases, the **cross was 50px*50px**, the **square 100px*100px**, and **the circle had a diameter of 10px.**

The training rounds were identical, except that, after each trial the participants were given **feedback (5s)** on whether their choice was correct or incorrect



Videos of the trials are attached with the submission

BLOCK DESIGN, TRIALS AND VELOCITY ADJUSTMENT:

For both off-center and on-center experiments, 16 blocks of 3 stimuli were shown.

In each of the 3 trials in one block, the square randomly moves leftward or rightward with speed v, or not move at all. The Nonmoving stimuli occurred with **probability 5/9 at most once per one block**, while the rightward and leftward stimuli occurred equally frequently without any constraints. Each bock had a **5s Inter-Block-interval between it.**

The speed was updated between each block as follows. If a participant got **3/3 or 2/3** responses **right** in one block, the speed decreased by $\Delta^{-} = \mathbf{0.002}$. Otherwise, if the participant got it right **1/3 or 0/3 times** in one block, then the speed increased by $\Delta^{+} = \mathbf{0.003}$. *(The paper [2] strongly advised against setting $\Delta^{+} = \Delta^{-}$)*

Besides, the subjects were also trained with 4 training blocks for on-center stimulus and 2 training blocks for off-center stimulus.

To summarize, the subjects performed the following:

- 4 blocks of the on-center training task.
- 16 blocks of the on-center task.
- 2 blocks of the off-center training task.
- 16 blocks of the off-center task.

In that order.

The convergence value was the mean of (average of the last 4 trials) and the minimum value in each trial (There are much better metrics, but due to a lack of trials this was chosen)

DEVICE AND OTHER PHYSICAL SPECIFICATIONS:

All the participants sat a distance **0.86m** from the monitor (as measured from the fixation cross). The monitor height, and horizontal position were adjusted so that the fixation cross was at the same height as the subjects' eyes, and at the **center of their visual field**.

The 6-bit display Monitor had a resolution of 1366×768 pixels, with a refresh rate of 60Hz. The Monitor was a 14-inch monitor (i.e., $30.99\text{cm}\ \text{X}17.43\text{cm}$ in sane units).

Data was collected from **11 subjects** and analyzed. *(Read: 10 friends were bribed with chocolates to be subjects).*

THE MODEL:

The subject's response was assumed to be a sigmoid-like response. Details are as follow:

The subject has a certain probability of detecting motion for various speeds. This can be represented by the **psychometric function** $\boldsymbol{\psi_i}$, $\mathbb{R}^{+} \rightarrow [0,1]$, which maps a speed to the probability of detecting it correctly. The subject's response is stochastic following this function modulated by some random noise.

This function needs to **be monotonically increasing, with value 0 at 0(*)**. Since, there are 3 alternatives, the subject can randomly guess the answer 1/3 times. Therefore, for **very small speeds this value should be 1/3**. In this case the exact function is assumed to be sigmoidal,

$$\psi(x) = \begin{cases} \alpha + \beta * \dfrac{1}{1 + e^{-\frac{(x-a)}{b}}} & : x > 0 \\ 0 & : x = 0 \end{cases}$$

Here, a, and b describe **the mean and spread** of the sigmoid, while α *and* β are parameters chosen s.t, $\lim_{x \to 0} \psi(x) = \frac{1}{3}$ *and* $\lim_{x \to \infty} \psi(x) = 1$

The assumption is that this staircase process converges to some speed, s for each subject, s.t $\psi_i(s) = \boldsymbol{p}$, for all subjects. (**p** is the same for all subjects) (i.e. the procedure converges to a particular speed, which that person has a probability **p** of detecting)

(*) ADDITIONAL NOTE: *One might assume that the probability of detecting* ***a non-moving square to be moving or not*** *depends on the speed of the current block. (i.e., if the subject sees the square moving at a very high speed, he will not misclassify nonmoving squares, but in a block where the squares move very slowly, he misclassifies non-moving squares more). But this apparent in the data. Zero-speed squares being misclassified did not have high correlation with the speed of the block.*
This might be because in both experiments, the subject sees a non-moving cross/ square right before the block moves. This resets any bias they might have due to the squares they've previously seen moving in the same block.

The value of p depends on the criterion used for updating the speed. For the criteria, I have used, A certain paper report the convergence value to be $\boldsymbol{p = 0.5}$ *[1]*

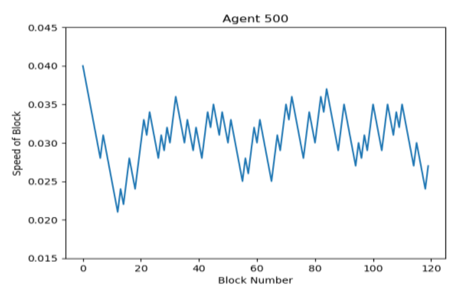
However, that is a 2-Alternative forced choice Experiment. Even though this **experiment can be reduced to a 2 AFC**, **the baseline probability (by random guessing) is different**. Therefore, the actual value would be different. I find the exact value using simulation *(because math is hard)*

SIMULATING RESPONSES

Responses were simulated for Mote-Carlo like random agents to check the convergence of the methods used.

Each agent had a response curve $\psi(s)$, which denotes the probability of it detecting motion at speed, s. It would respond to the stimuli according to this function, but with various levels of noise ([0.01,0.02,0.05,0.1]). The parameters a and b were varied in the ranges (0.02,0.04) and (0.05,2).

These agents performed the same experiment, following the same rules for updation of velocity, but with 120 blocks. One such run is shown below



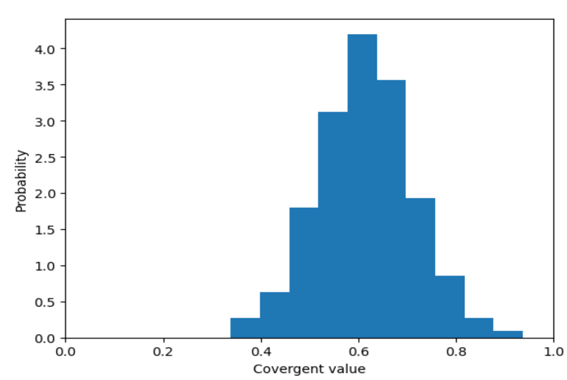
The converging probability -value is determined by averaging the speed of the last 20 blocks and finding $\psi(s_{20})$.

RESULTS

SIMULATION:

As a sanity check, since we know that the 2-AFC is supposed to converge to 0.5, I modify the sigmoid s.t. ψ starts from 0.5(random probability). This converges to 0.5 as expected.

The agents all converged to values **centered around 0.61**. `(mean median and standard deviation of 0.614 0.617 0.098)`

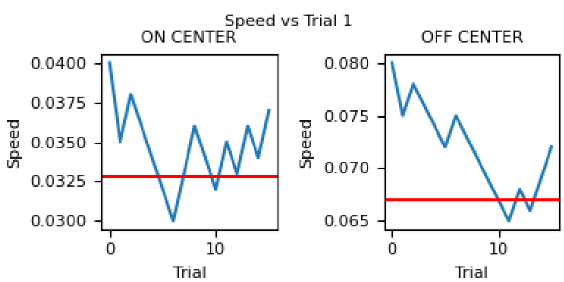


Therefore, I will from now on assume the responses of participants to converge to $\boldsymbol{p = 0.61}$ and proceed to the actual data. This number makes sense because its in between the update criteria for increasing and decreasing speed. (i.e., between 0.33 and 0.67)

MEASURING THE THRESHOLD:

Since an **adaptive method has been used, and the number of trials less, plotting the exact psychometric isn't really that informative.** What can be determined though, is the threshold value to which the speeds converged.

The threshold has *arbitrarily* been calculated as the **average of the minimum speed trial and that of the last 4 trials**. The threshold as well as trial speeds has been shown representatively for one participant below.



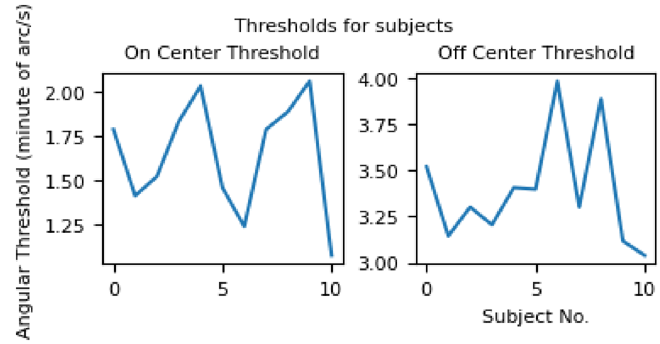
The average value of this threshold in terms of the speed of the block are

$\boldsymbol{v^{0.61}_{\text{oncenter}} = 0.030 \pm 0.006}$ *and* $\boldsymbol{v^{0.61}_{\text{off-center}} = 0.064 \pm 0.006}$

What makes more sense is to correct for viewing distance, and angle (for off center).

$$\theta = \tan^{-1}\left(\frac{x}{D_{monitor}}\right)$$

The angular velocity thresholds in terms of the angle projected on the eye for the subjects can be calculated as $\left(\omega_{min} = \frac{v_{min}}{D_{Monitor}} * \left(\frac{1}{1+\tan^2\theta}\right)\right)$. The same is plotted below:



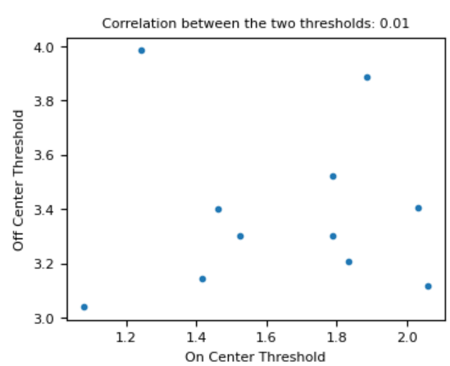
The Average thresholds are $\boldsymbol{\omega^{0.61}_{\text{on center}} = 1.64 \pm 0.31}$ *and* $\boldsymbol{\omega^{0.61}_{\text{off-center}} = 3.39 \pm 0.29}$**.** These are the thresholds such that the stimulus is detected only 61% of the time.

The value of on-center ω= is similar to the value reported by other studies [3].

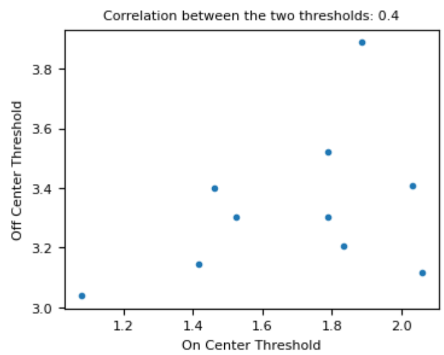
As seen above, the thresholds vary quite a bit. What would be interesting is to find out whether these differences are due to poorer resolutions of the visual map (i.e., in measuring position itself), or in measuring velocity in MT.

CORRELATION BETWEEN ON-CENTER AND OFF-CENTER THRESHOLDS AND A CURIOUS CASE OF ASTIGMATISM:

What was interesting was that there was seemingly low correlation between the off-center and off-Center thresholds.



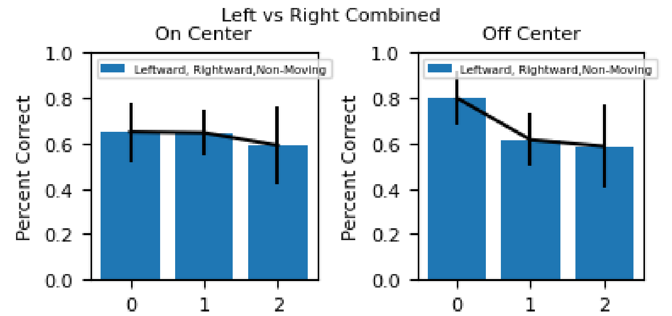
This correlation seems off mainly due to one point (1.2,4). On further probing it was realized that this subject had **Astigmatism** and hadn't corrected his lens in 5 years**,** which could potentially be the reason for the same. (*Therefore, there's a large difference between the on-center and off-center motion detection). After removing this point, the correlation seemed better*



This makes more sense; one would expect subjects with better motion perception on-center to have better off-center motion perception as well.

LEFT VS RIGHT DETECTION

Here I plot the percentage detection rates for left-moving, right-moving and non-moving stimuli.



In the On-Center case, the values are more or less the same. But, for off-center, it is noticed that it's significantly much easier to move leftward motion than rightward motion.

This bias exists because of the experimental design, where the fixation cross was in the top-right portion of the screen, while the square was on the center.

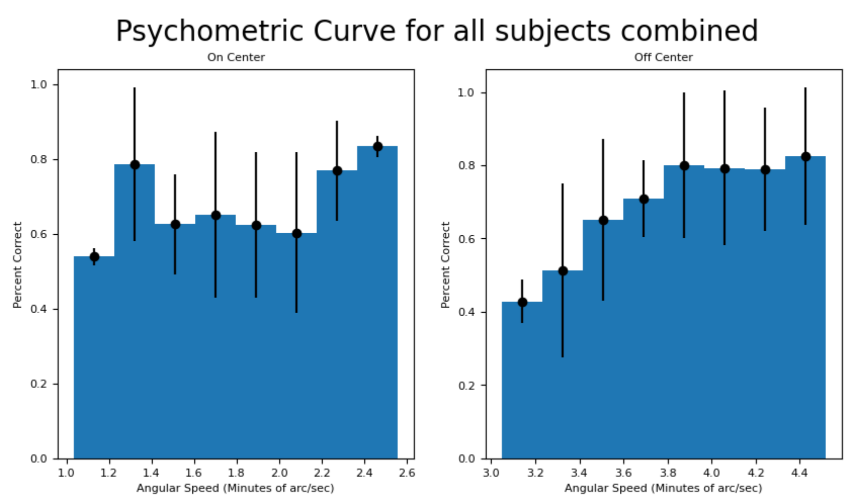
PSYCHOMETRIC CURVE

Below is the psychometric curve of the percentage correct responses for different speeds

(The responses had to binned to get enough trials).

The Curves have a lot of noise *(as shown by the error bars)* because at some velocities had very few trials. But an **increasing trend can still be noticed**.

(The threshold values determined have accuracies of roughly 0.5-0.6, so it checks out)



DISCUSSION

From the data it is reasonable to conclude that the **threshold for on-center velocity detection is lower than the off-center velocity detection**. This is also apparent from the psychometric curve, the probability of detecting Angular speeds drops to around 0.4 near lower values of the off-center response, which is higher than the maximum value in on-center responses.

b) Why is there noise in your data? What are the possible sources?

The decision-making process of a subject is stochastic. Therefore, for the same velocity, the subject might respond differently. This stochasticity can be averaged out with a lot of trails. A lot of noise in this data boils down to the fact that each velocity value has so few trials. Therefore, the percentage correct values can only be multiples of the same.
Also due to time constraints, the subjects are bound to make some wrong choices.
The low number of trials also affect the convergence of speed which gives some noise.

c) Would your result be different if you run the same subject twice? Why?

No, it would mostly remain the same. Since the velocities are random, it's impossible for a subject to report motion without perceiving it. In addition, the subjects had sufficient training rounds to get used to the study design.

d) Would your result be different if you changed some incidental details of your stimuli (e.g. if you are testing line length, does its brightness matter)? Will the threshold increase or decrease?

I assume that it would change with the size with the central square. It might follow Weber's law. The actual shape might also affect the results, with sharp edges making it easier to motion. Similarly for lower contrast squares.

One factor which does play a very important role is the **time for which motion is shown**. If motion is shown for longer, it would become easier to perceive, maybe solely from the change in displacement, rather than the velocity.
For the off-center experiment, the position of the cross will affect the results. It would be interesting to measure this threshold for different parts in the visual field.

e) Can you include yourself as a subject in this experiment? Why?

Yes, I can include myself as a subject in this study. Since the speeds are random, there's really no way I can guess. In fact, just to test this, I took the test myself and the results were pretty similar to the rest of the subjects.

CRITICISM

Since, it's been my first time, there's a bunch of things with my study design and analysis that don't really hold up to rigor. Given some more time, I would've probably addressed them. A few others were mistakes that I could've corrected but realized very late into the experiment. Here are some of them:

- The criterion set for updating the velocity, i.e., $\Delta^+ \ and\ \Delta^-$ were chosen in an ad-hoc fashion, without really considering how well it help in convergence. In addition, I've not worked out the math for finding the convergent value ($probability\ p,\ \ such\ that, the\ speed\ converges\ to\ v = \psi^{-1}(p)$), the simulation results may or may not be correct.
- The method for finding the convergent value was not rigorous, there was a clear need for much more trials for better convergence. *The study was already around 15-20 minutes so, more trials couldn't be done.*
- While calculating the angular velocity from the linear velocity, the relation $\theta = \tan^{-1}\left(\frac{x}{D_{monitor}}\right)$ was used. The square moves only along the x-axis, while x is along the line joining the fixation point and the square. Therefore, in the off-center case, the calculation for ω is a little more complicated. The actual value won't be that different, and, will be higher than the current value. Therefore, the result that threshold $\omega_{on\_center} < \omega_{off_{center}}$ is still true.
- Of course, many things about the set-up could be more rigorous. The display refresh rate was only 60Hz, which might make the block not move at tiny velocities (but in my tests, speeds less than half the minimum detected speed produced visible movement). This might still make the movement choppy and less smooth, which might affect results. Also, the subjects would often move their heads changing the position often. While doing the off-center task, the subjects could also change their gaze to the center of the screen. Ideally We would need to constrain the patients head to avoid these problems.
- Another Internal error in the code: The block's position changes every frame by addition. This is fairly constant at 60Hz throughout the execution of the program but can vary minorly if there are heavy tasks running in the background. This is also susceptible to floating point errors. Therefore, I should've ideally updated the positions as $pos = v * currrent\ time$.

CITATIONS

1. Transformed Up-down Methods in Psychoacoustics (stanford.edu)
2. Forced-choice staircases with fixed step sizes: asymptotic and small-sample properties - ScienceDirect
3. The minimum temporal thresholds for motion detection of grating patterns - PubMed (nih.gov)