BME 301A Quantitative Physiology

Physical Lab #2: The Electrooculogram (EOG)

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David Young

Lab Partners: Jodi Small, Jordan Nick

Introduction:

Measuring biomedical signals accurately is a keystone of engineering as it relates to medicine. Attempting to measure signals without previous experience, and without expectations regarding data, would likely yield meaningless results. Consequently, little would be learned. Therefore, when learning to measure biomedical signals, one should start with a well-documented signal for which there exist expected results. For this Physical Laboratory, such a signal (to be measured and analyzed) is the electrooculogram (EOG). The EOG is a measure of angular displacement of the eyeball acquired by sensing changes in the orientation of the electric dipole which results from the front of the eye being positive relative to the back of the eye. The signal that results is very well documented, simplistic and time dependent. It is also easy to access using basic skin electrodes. The goal of this paper, by analyzing the EOG results under different experimental conditions, is to identify various movement behaviors of the eye (including saccadic, smooth pursuit, vergence, VOR, and OKN movements). Even though the measurements are pertaining to action and movement of the eye itself and not the muscles which influence it, ideally I will still be able to make some conclusions about the abilities of the brain and controlling muscles to create different movement behaviors. I also aim to identify and speculate the boundaries or limits of those behaviors.

To provide some basic background, I will attempt a synopsis of the eye behaviors relative to this paper. Saccades are rapid eye movements which move the eye to various fixed points. I hope to show that saccadic movement can be the result of reflex or conscious thought. Smooth pursuit is the behavior of the eye to stably track a moving object upon which vision is fixed. Although one can choose the object to fixate upon, people should not have the ability to consciously replicate smooth pursuit behavior without tracking some movement. Vergence is the adjustment of the angle between the eyes to focus on an object at different distances away from the eyes. Conscious manipulation of this behavior should lie somewhere between saccadic and smooth pursuit control. Vestibulo-ocular reflex (VOR) is the behavior of the eye to maintain fixation on a point even when the head is rotated. This function is generated by a fluid gyro mechanism in the head which indicates movement to the brain. Optokinetic Nystagmus (OKN) is a behavior involving a mix of saccadic like rapid eye movements alternating with slow smoother eye movements. OKN occurs when the head is stationary and the eye tracks large moving fields.

Materials:

1. AD Instruments Powerlab and LabChart.
2. BioAmp Flat Electrode Wires
3. Handheld Pushbutton
4. Protractor
5. Shielded Bio Amp Cable
6. BioAmp disposable recording electrodes
7. Electrode Gel
8. 9pinD to 9pin DIN adapter

Methods:

During Procedure 1 LabChart software was calibrated to receive the EOG and pushbutton signals as well as read out a derivative of the EOG signal. 3 electrodes were placed on the subject's head (1 on the left temple, 1 above the left eye, and one on the right temple) and it was verified that data was being properly collected by the software.

During Procedure 2, data of saccadic eye movement was recorded. The subject looked back and forth between two fixed points, starting slow and working up to as fast as the eye would move. These measurements were conducted for horizontal saccade ranges of 5, 11, 23 and 45 degrees. Lastly saccadic movement was recorded under a few different conditions including while reading text, while the eyes were closed, and with the subject attempting to make especially slow saccades.

During Procedure 3, data of smooth pursuit behavior was recorded. Using a metronome at 40, 80, 120 and 160 bpm, the subject tracked the moving head. This way it was possible to quantify the frequency of the pursuit. Smooth pursuit speed tests were also recorded. This was accomplished by having the subject track a finger moved at relatively even speed increases (judged by a lab partner), until the subject could no longer smoothly pursue the finger. Lastly the subject attempted to make smooth pursuit eye movement in the absence of a track-able object. The subject could not do this however, as was expected.

During Procedure 4, experiments were conducted to test the reaction time of the subject using the button to denote commands to look a certain direction, and readouts from the Software to find the duration between command and movement. A few saccadic experiments were conducted, including giving one command to look right or alternating commands to look in 4 directions (up, down, left and right). Smooth pursuit response tests were also conducted, where the subject would fixate upon the finger of a lab partner and would attempt to pursue it as soon as it began to move. Unfortunately our group missed one of the experiments (the 2 direction experiment) needed for a few of the graphs. Therefore we opted to utilize a different group's data for all graphs and analysis pertaining to reaction times, since using data from reactions of 2 different subjects would be inconsistent. (See References #2)

During Procedure 5, vergence eye movement was recorded. The subject alternated between looking at a pencil 25cm from the eyes and looking at a point 6m away.

During Procedure 6, recordings of VOR and OKN behaviors were documented. For the VOR recordings the subject's head was rotated rapidly ~80 degrees one way and then back to center continuing the other way ~80 degrees, and repeated. During this action the subject attempted to maintain fixation on a given point a meter to 2 meters away. The experiment was repeated while the subject performed basic mental arithmetic, counting backwards from 20 by 3. And then again with the fixation point being a finger placed inches from the face. For the OKN experiments the subject's head was held fixed and a newspaper, with dense text, was moved left to right about 6inches from the face.

Results:

A sample of the raw eye position data recorded during the initial testing of procedure 1 can be seen in Figure 1. The graph shows the basics of the EOG signal, where amplitude (in mV) is graphed over time. These results were simple and as expected. One can clearly note the direction of the eye movement from the direction of amplitude change.

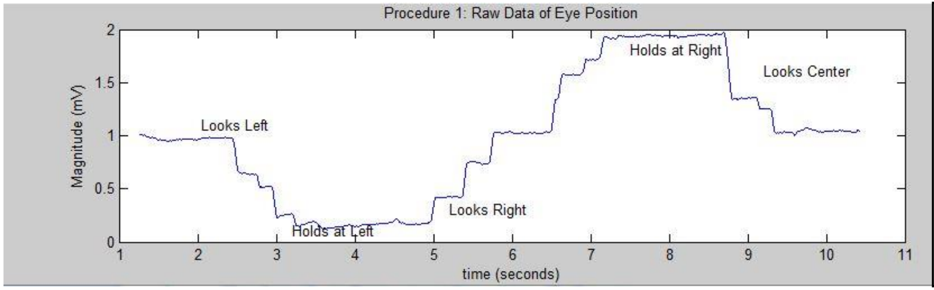


Figure 1: Raw data of eye position recorded during procedure 1. Looking left is represented graphically by a downward change in amplitude. Conversely, looking right is represented by an upward change I amplitude.

To plot peak velocity as a function of saccade amplitude, a calibration curve was required to convert voltage units to degrees. The data and curve used to obtain a conversion formula, along with the formula itself are shown in Figure 2. The plot of peak velocity (in degrees/s) as a function of saccade amplitude is shown in Figure 3. The 4 vertices in Figure 3 represent the peak velocities of 5, 11, 23 and 45 degree saccades. The results were as expected, indicating a plateau effect with peak velocity.

Voltage Difference (mV)	Angle (Degrees)
0.456	45
0.37	23
0.2125	11
0.11	5

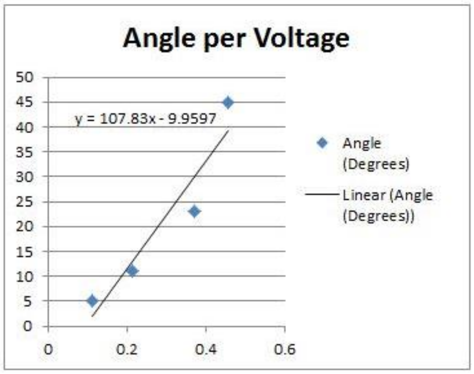


Figure 2: Data, calibration curve and conversion formula used to convert amplitudes (and amplitudes/time) from voltages to degrees.

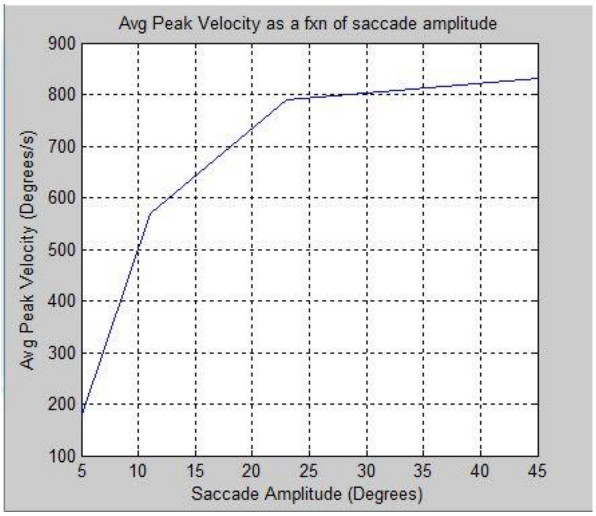


Figure 3: Average peak velocity as a fxn of saccade amplitude for 5, 11, 23, and 45 degree saccades. Data recorded during procedure 2.

Procedure 2 also included the recording of saccades under different conditions. Figure 4 overlays normal 45 degree saccades, from procedure 2, with saccades made while the subject's eyes were closed. Although the subject attempted to match the amplitudes, the closed eye saccades are not as accurate in amplitude, nor as clearly formed as their normal counterparts.

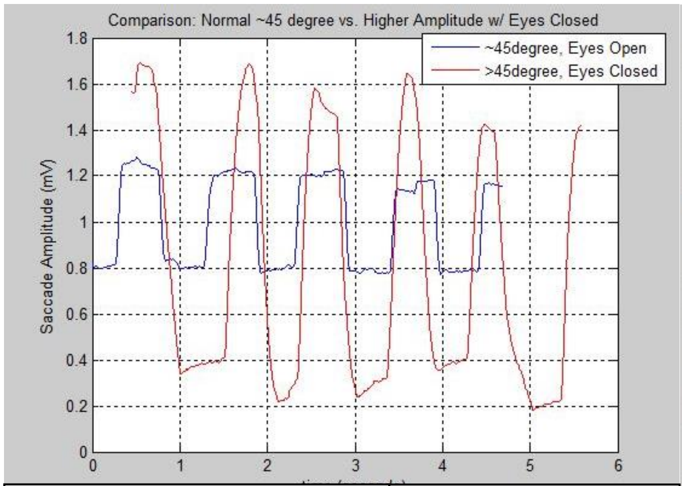


Figure 4 (Above): Overlay of Procedure 2 Saccades under different conditions. Blue represents saccades made under normal conditions. Red represents saccades made with the eyes closed.

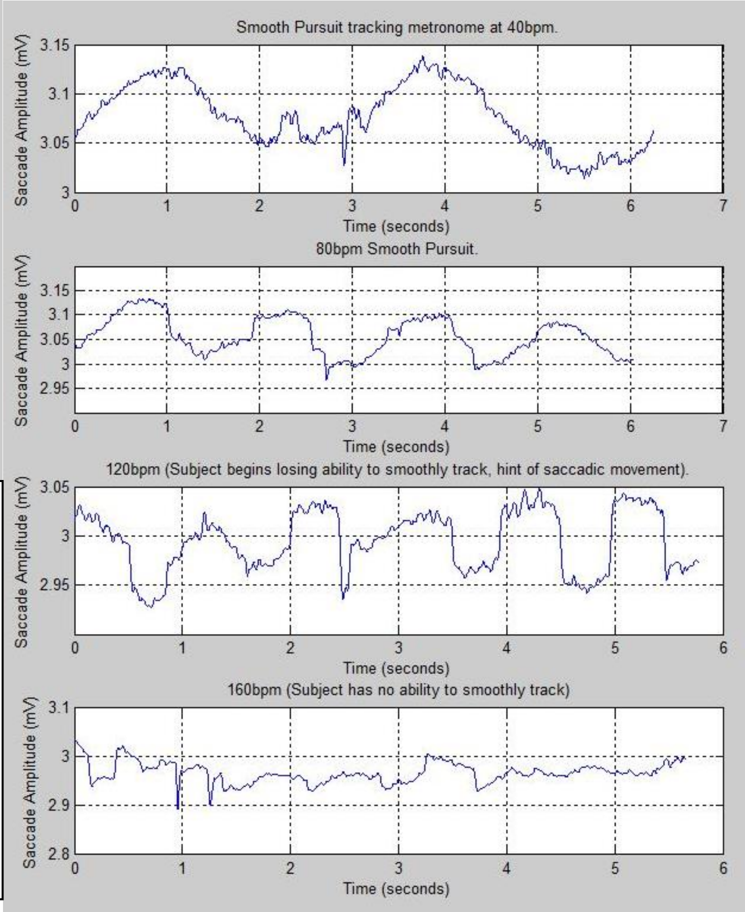


Figure 5 (Right): Procedure 3 results. Smooth Pursuit eye behavior while tracking a metronome tip at 40, 80, 120 and 160bpm. Subject begins deviating from complete smooth pursuit behavior at 80bpm. 120bpm trial was a mix of smooth pursuit and saccadic elements, and in the 160bpm trial the subject had no ability to smoothly pursue the metronome.

The results of the smooth pursuit trails conducted during procedure 3 can be seen in Figure 5. Each graph corresponds with a speed (in beats per minute) of the metronome the subject attempted to track. As the speed increased, the subject began to lose the ability to smoothly pursue the metronome until the subject could not manage any semblance of synchronized smooth pursuit behavior (See Figure description and Discussion for more specifics).

The procedure 4 reaction time experiment data provided here originates from a different group's experiment. The graphs and analysis are original to this paper, but the data is not. Figure 6 shows the reaction times associated with the rightward (only) movements in one-, two- and four-direction trials as well as the reaction times of saccade and smooth pursuit behaviors from the 2nd part of Procedure 4. The smooth pursuit reaction times seemed to be, on average, 39% faster than the saccadic reaction times. See Discussion for analysis.

Rightward Only Test Type	Avg. Reaction Time
1 Direction Saccade:	0.213
2 Direction Saccade:	0.345
4 Direction Saccade:	0.448

Reaction Time Test	Avg. Reaction Time
Saccadic:	0.177
Smooth Pursuit:	0.248

Figure 6: Procedure 4 data borrowed from another group.

Reaction times associated with 1,2 and 4 direction saccadic trials. Reaction times associated with saccadic vs. smooth pursuit behaviors.

A graph of the vergence data, collected during procedure 5, is shown in Figure 7. In this experiment focus was switched from a fixed point at 25cm to a fixed point at 6m.

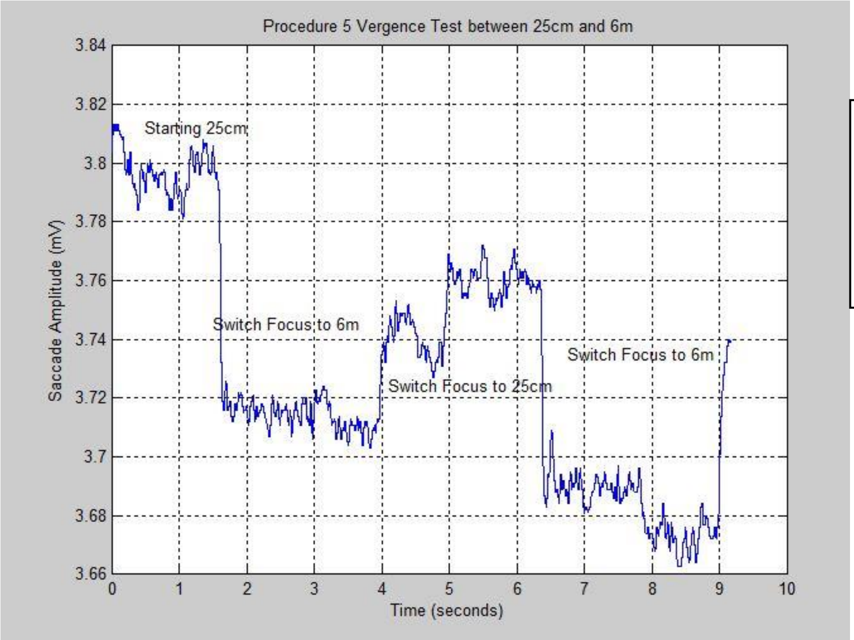
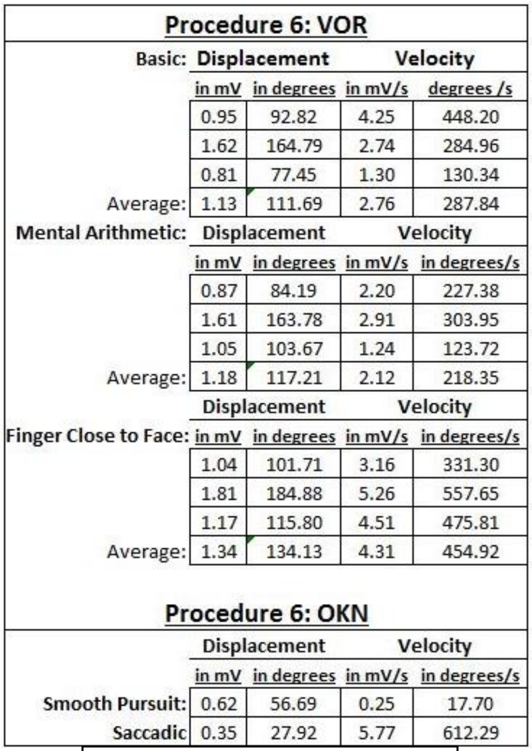


Figure 7: Procedure 5 data for Vergence tests. Subject alternated focus between a point 25cm from the eyes and a point 6m from the eyes.

Displacement and velocity data, along with their averages, for the procedure 6 VOR experiments, can be seen in Figure 8. This includes data for the control experiments where the subject attempted to fixate on a finger held 6 inches from the face, as well as fixating upon the 2m distanced point but while performing basic mental arithmetic. Qualitatively, all the experiments yielded very similar results;

however the latter experiment yielded a slightly smoother eye movement, with less instantaneous changes in position, while the closer fixation point experiment yielded a more defined and harsh beginning and end to each change in movement. These trends can be noted in Figure 9.



Procedure 6: VOR				
Basic:	Displacement		Velocity	
	in mV	in degrees	in mV/s	degrees /s
	0.95	92.82	4.25	448.20
	1.62	164.79	2.74	284.96
	0.81	77.45	1.30	130.34
Average:	1.13	111.69	2.76	287.84
Mental Arithmetic:	Displacement		Velocity	
	in mV	in degrees	in mV/s	in degrees/s
	0.87	84.19	2.20	227.38
	1.61	163.78	2.91	303.95
	1.05	103.67	1.24	123.72
Average:	1.18	117.21	2.12	218.35
	Displacement		Velocity	
Finger Close to Face:	in mV	in degrees	in mV/s	in degrees/s
	1.04	101.71	3.16	331.30
	1.81	184.88	5.26	557.65
	1.17	115.80	4.51	475.81
Average:	1.34	134.13	4.31	454.92
Procedure 6: OKN				
	Displacement		Velocity	
	in mV	in degrees	in mV/s	in degrees/s
Smooth Pursuit:	0.62	56.69	0.25	17.70
Saccadic	0.35	27.92	5.77	612.29

Figure 8: Procedure 6 data for both VOR and OKN displacements and velocities.

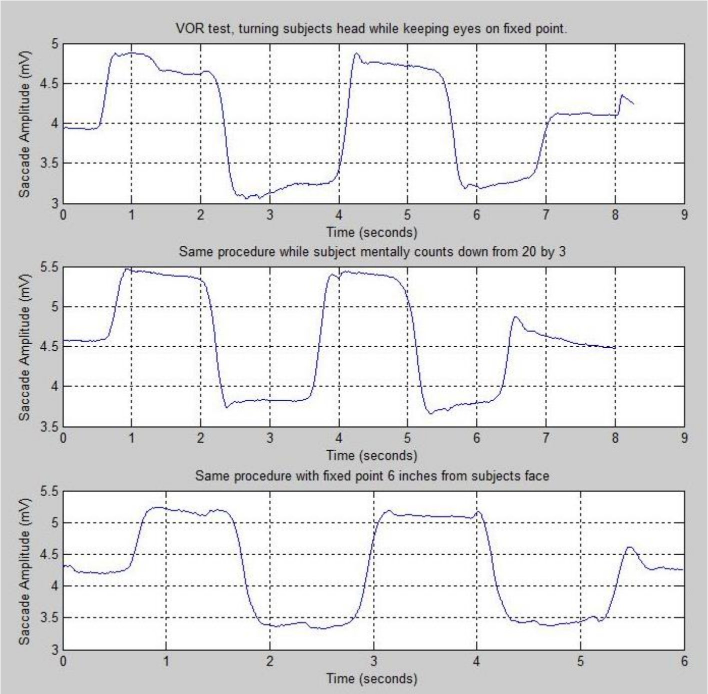
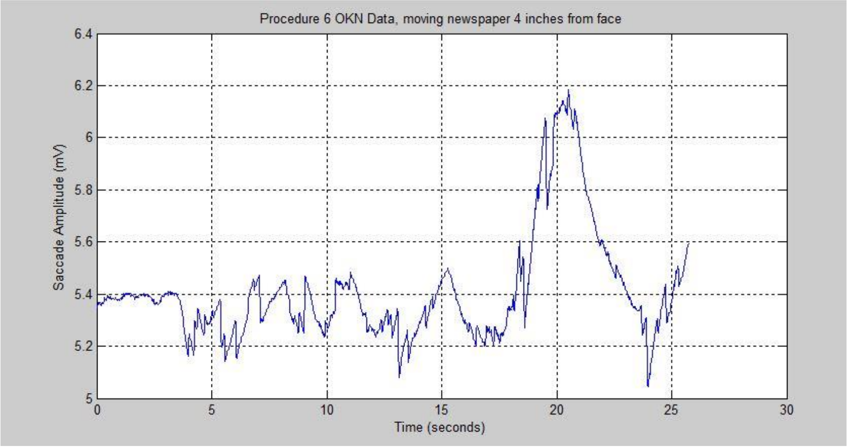


Figure 9: Procedure 6 VOR data under 3 different conditions. The first a normal VOR experiment with a fixation point 2m from the eyes, then an identical experiment but with the subject performing mental arithmetic, and lastly the same procedure but with a fixation point at 6inches..

Figure 10 shows a graph of the OKN data. There is a clear mix of saccadic and smooth pursuit behaviors. Samples of displacement and velocity for both behaviors can be seen in Figure 8. For a control test we held the same newspaper stationary, 6inches in front of the subject's face while they stared at the center.

Figure 10: Procedure 6 OKN experiment results. There exists a clear combination of both saccadic and smooth pursuit behaviors.



Discussion:

The time from beginning of a right saccade to beginning of the next right saccade including the left saccade in-between was 0.84 seconds. Therefore, the minimum saccadic frequency was 1/0.84=1.25. The dominant frequency was 1.94Hz. This makes sense because the minimum saccadic frequency of 1.25 should be less than the dominant frequency, but relatively close as the saccades were all attempting the same speed. Alternatively, the fastest time duration of a saccade measured from beginning of the right saccade to the beginning of the left saccade was .28 seconds. Looking at the FFT of such a saccade, at about 11 Hz the small blips in amplitude were discount-ably small relative to the rest of the wave. As sine waves add to make an actual square wave, I would expect to see blips in amplitude at many harmonics out past the dominant. Eventually the addition of more harmonics doesn't discernibly contribute to a visual difference in the square wave form. At about 33 Hz was the highest frequency spike in the FFT that I could see. This indicated that if one were to construct the waveform only using sinusoids with frequencies below 33 Hz, the construction would be fairly accurate to the complete waveform.

The graph in Figure 3 shows that as saccade amplitude increases, so does the average peak velocity. However this values increases at a decreasing rate. By plotting more data points, I suspect one would see a curved function with a clear plateau. I think as the saccade amplitude increases, the average peak velocity approaches an asymptotic maximum that is most likely a function of viscosity and muscle properties among other dampers. This is similar to a terminal velocity in free fall being limited by drag. The function of a maximum seems valid in that if velocity were to increase at the same slope over increasing amplitude, then a very large angle jump will yield a very high velocity such that stopping at the desired angle/point would be difficult due to a need for large deceleration in a very short distance. I suspect nature has perfect a balance between speed and control.

Smooth pursuit behavior seemed to follow the same pattern, but the difference between a smooth sloped line and a stepping function (to the same amplitude value) with minor jumps can begin to blur when the individual saccade steps are small enough relative to the large saccade in question. For example, when the subject read text off a page, there were miniature saccades for jumps between letter and words, but a grand movement from one side of a line to the next. Without looking closely enough at an exploded graph, this would look like smooth pursuit until one sees the individual steps involved in forming the overall sloped line. Additionally the saccades made with closed eyes (See Figure 4) resulted in some strange patterns. Although the overall template of rises and falls was the same, the rises were similar to smooth pursuit and peaks were always very rounded (but pointy, and not step like at all). The troughs were sloped but clearly saccadic, just without holding constant for long.

All the smooth pursuits seemed to be comprised of miniature saccadic like movement, if one zooms in close enough. This function becomes more exaggerated as the frequency of the smooth pursuit increases. At a certain point the saccadic element of the graph overpowers the smooth pursuit element. When the subject tracked a 40bpm (.67Hz) metronome, the smooth pursuit sloped elements of the graph clearly dominated. When that speed jumped to 80bpm (1.33Hz), the peaks of that sloped graphs were a little less smooth and held a little more constant while at peak or trough. When the speed jumped to 120bpm(2Hz) the saccadic elements began to overpower the sloped smooth pursuit elements, and I am comfortable saying the subject began to lose the ability to track a moving object with smooth pursuit eye movements. By 160bpm (2.67Hz), the subject had lost all ability to smoothly pursue the metronome. The eye movement was erratic and lacked coherent components of saccadic or smooth pursuit behavior. In all smooth pursuit trails, when increasing the speed of the pursuit, a point was reached where smooth pursuit was not possible. Lastly, the subject did not feel they could make smooth eye movements without saccadic jumps when staring at a blank wall.

For the reaction time results, a clear trend presented itself. If there were more choices in direction to choose from, there was an increase in reaction time. This is most likely a mental effect, as the subject was often confused and looked the wrong way or paused to think of which direction was commanded. Also within each trial the subject's reaction time tended to improve, showing it was a trainable skill and not restricted in its entirety by the eye.

Reaction time, under similar experimental conditions, was greater in smooth pursuit by about 39% than in its saccadic counterpart trial. This is expected. I would think that without the mental requirement to pick a direction to twitch an eye, but instead simply following the moving point the subject can already see, that the reaction time would be very low for the smooth pursuit and higher for the saccadic. Again this is all mental. The physical limitations of reaction time to move an eye, once the muscles receive the input to move from the brain, should be identical, but the reaction time until the brain outputs that signal is different.

During our vergence tests we had two separate points in 3dimensional space for the subject to look at that both resided upon the same line stemming from between the users eyes. The first point was 25cm away, the second was 6m away. We had the subject switch instantly. This is different than having them track a point that smoothly moves closer or farther away. Because of this, I expected to see saccadic movement when jumping back and forth between points. I saw this in our results. Each jump from close to far was saccadic in form.

The VOR results were very consistent. Even with the added experimenting all the trails showed movement that was mostly saccadic in form, but with far smoother transitions than in the saccadic trials from early procedures. The movement was very smooth, surprisingly so. This may be the result of fixating on a point, rather than searching for it during a saccade. The corners of the plateau are also very rounded. In all VOR trials, rotation of the head was ~75-80 degrees.

I would be very interested in experimenting with VOR behavior under virtual reality conditions. Using an immersive device such as the Oculus Rift, which provides a 3D 180 degree visual field, if one were to simulate the rotation of the subject's head by shifting the visual field presented on the screens (instead of actually rotating the head) and asked the subject to track a point that stayed fixed in the virtual world, would the eye movement be the same? I suspect that it would be similar in form but more delayed, as the internal fluid gyro of the head would not instantaneously note the acceleration. Instead the brain would have to process the movement from the visual field and react.

The OKN results were actually very close to what I expected. I expected to see a very erratic, saccadic behavior filled graph with a few bits of concentrated smooth pursuit behavior mixed in. This is exactly what I saw. The smooth pursuit elements were most likely where the eye managed to catch a word or two from the newspaper and track it until losing the pursuit and saccading around more in between. The velocities of the saccadic vs. the smooth pursuit behaviors during the OKN trials were orders of magnitude different. The saccadic behavior was about 3458% larger. (See Figure 8) I'd expect this because the smooth pursuit is following the speed of the moving text on the paper and is therefore limited in velocity accordingly; however the saccadic behavior is free to move as fast as the eye can achieve.

To conclude, the movement of the eye is a dynamic process the body manages to control with a staggering amount of precision. Although this paper did not touch upon the mechanisms by which the eye is actually controlled, the behaviors recorded here can outline the function and abilities of such mechanisms. The behavior of the eye is responsive to conscious command and to reflex in various ways depending on the type of movement. Saccadic movement can be the result of conscious thought or a reflex. Smooth pursuit lies at the opposite end of the spectrum, as it is nearly impossible to replicate smooth pursuit in the absence of a traceable object. Vergence lies somewhere in between the latter two. An individual can consciously adjust the angle between their eyes (crossing the eyes), but will also reflexively track a point moving closer or farther away from the eyes. OKN is less definable as a task to try and replicate, and VOR seems to be little affected by mental distraction.   The behaviors of the eye range, in control, from conscious to subconscious, but that range allows an individual to accomplish a large variety of tasks.

References:

1. Enderle, John D., and Joseph D. Bronzino. *Introduction to Biomedical Engineering*. Amsterdam: Elsvier/ Academic, 2012. Print.
2. Procedure 4 Data from a fellow group comprised of Brett Baker, Danielle Chirumbole and Emily Kenny.

Unofficial Sources:

- Physical Lab Manual for Quantitative Physiology
- Computational Lab Manual for Quantitative Physiology
- Module 2 Lecture Slides
- Blackboard Discussions
- Discussants: Lauren Bedell, Maeve Woeltje, Jodi Small, Paras Vora, Matt Everett