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DVA as a Diagnostic Test for Vestibulo-Ocular Reflex Function

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The vestibulo-ocular reflex (VOR) stabilizes vision on earth-fixed targets by eliciting eyes movements in response to changes in head position. How well the eyes perform this task can be functionally measured by the dynamic visual acuity (DVA) test. We designed a passive, horizontal DVA test to specifically study the acuity and reaction time when looking in different target locations. Visual acuity was compared among 12 subjects using a standard Landolt C wall chart, a computerized static (no rotation) acuity test and dynamic acuity test while oscillating at 0.8 Hz (±60°/s). In addition, five trials with yaw oscillation randomly presented a visual target in one of nine different locations with the size and presentation duration of the visual target varying across trials. The results showed a significant difference between the static and dynamic threshold acuities as well as a significant difference between the visual targets presented in the horizontal plane versus those in the vertical plane when comparing accuracy of vision and reaction time of the response. Visual acuity increased proportional to the size of the visual target and increased between 150 and 300 msec duration. We conclude that dynamic visual acuity varies with target location, with acuity optimized for targets in the plane of rotation. This DVA test could be used as a functional diagnostic test for visual-vestibular and neuro-cognitive impairments by assessing both accuracy and reaction time to acquire visual targets.

Nomenclature

VOR = vestibulo-ocular reflex
DVA = dynamic visual acuity
SCC = semicircular canals
VT = visual target

I. Introduction

The vestibulo-ocular reflex is an automatic response system that works to stabilize a person's field of vision when motion of the head is induced. The eyes will move in the opposite direction of any head movement so as to keep the visual field in focus. Getting a functional measure of this system at work has been the object of many studies. One of the most popular methods is using a dynamic visual acuity test which measures a person's visual acuity while they are moving. With increasing frequency and velocity of motion, vestibular input becomes important for maintaining acuity. We wanted to create a DVA test that would allow us to get a functional measure of the VOR

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so that we could one day use it as a diagnostic test for astronauts after long duration missions to look for vestibular dysfunctions.

In the horizontal plane, the VOR is a result of communication and signaling between the semicircular canals of the inner ear the ocular muscles of the eyes. These SCC have tiny hair cells inside of them that indicate angular displacement of the head. When the hair cells are displaced by endolymph fluid, they send a signal to the brain that the head is moving. The VOR occurs when these signals leave the brainstem and travel to the muscles of the eyes telling them to move in the opposite direction of the head. The VOR is only necessary for higher speeds of movement; anything below about 20per second is low enough that smooth pursuit of the eyes is capable of stabilizing the visual field.[1] For example, when at rest, the human body will still involuntarily sway and the head will move about in the yaw, pitch, and roll axes.[2] This swaying motion will generally not induce the VOR. But when walking at a normal gait, the head naturally bobs up and down at a frequency of about 2Hz. This will elicit the VOR and as a result one's vision is clear and stable when walking and running. It is important to note that both visual and vestibular inputs are required for proper gaze stabilization.[3]

There are many different ways to run a DVA test because of all the possible variables involved. We chose to do a computerized, passive, horizontal test because this method fit best with our goals of finding a functional measurement. A computerized DVA test creates the situation in which a visual target is displayed only when a certain velocity of head movement is reached. This is a good method to use because a person's use of visual pursuit or fixation is minimized.[1] A passive test creates an external force to move the head and body so that the person has no control of motion. This passive force results in unpredictable head movements which means a greater decrement in visual acuity than active movements would produce. This is most likely because centrally preprogrammed eye movements and/or efference copy, which would contribute to gaze stability during predictable head movements, would not be used effectively with unpredictable head movements.[1] Rotating in the horizontal plane was simply a matter of convenience, although studies have shown that computerized tests in the horizontal plane have high positive and negative predictive values.[1] No matter what variables you pick for a DVA test, there are a few standards you have to comply with to make sure you are measuring what you want. The passive motion created by the test must follow the characteristics of movements in which gaze stability work. This means that the passive movements must be of sufficient frequency and velocity to elicit the VOR. As long as these guidelines are met, the computerized DVA test can be used to assess the degree of functional deficit of the vestibular system.

Although we wanted an overall functional measurement, we specifically wanted to look at a person's visual acuity when looking outside of the plane of movement and subsequently the plane of the VOR response. If someone is moving in the horizontal plane and needs to look up, is it going to take him a long time to look there or is his acuity going to be worse or some combination of both? If the VOR is meant to stabilize vision in the plane of the movement, how does this affect vision when suddenly leaving that plane? Our hypothesis is that vision will be better and more quickly acquired in the horizontal plane than in the vertical.

II. Methods

A. Participants

The participants for this study were recruited by JSC's test subject facility on site. They were in general good health, not taking any medication, and had at least 20/20 vision with or without corrective lenses. There was one participant who did not meet the vision requirement, and although she completed the test her data was not used. There were 12 participants, 4 female and 8 male, who ranged in age from 23 to 52.

B. Procedure

To test the participant's dynamic visual acuity, we decided to create the passive head movements with an oscillating rotator (chair) in front of a computer screen where we would present the VT. The average distance between the participant's eyes and the screen was 130cm, and the computer screen itself was 56 X 36.5cm. All of the oscillations were kept at a frequency of 0.8Hz and averaged a peak velocity of 60 degrees per second. We chose this frequency because 0.8Hz is when visual pursuit starts to slip and the VOR has to take over, but it is not so fast that the gain is deviating from one.[2] The rotator and VT presentations were controlled from a computer and two separate software programs each with pre-programmed profiles that ran the movement of the chair and the presentation of the targets. The participants used a joystick to respond and this allowed us to measure reaction time along with their accuracy/acuity.

We conducted multiple control tests before the actual DVA test in order to get comparisons. The first measurement we took was a visual acuity threshold using a standard wall chart of Landolt C's. The participants

stood 10 feet away and read off the lowest line legible to them indicating the direction in which the C was open. The lowest line in which they got three out of five letters correct was considered their threshold. Once their threshold was established, the participants were buckled into the chair and we put them in goggles which could tract their eye movements as the chair oscillated. We did three tests with the goggles on: an eye calibration with LED lights set 10˚ apart, a VOR in complete darkness at 0.8Hz, and a VVOR at 0.8Hz with the same LED lights as the calibration. After these tests we removed the goggles for the DVA test and those participants who needed them put on their eyeglasses before this test.

We ran eight total DVA tasks, five of which were the main tests. The first three tasks were preliminary measurements for the purpose of comparisons. The first test was a joystick reaction time; since the participants used a joystick to indicate the orientation of the C on the computer screen we needed a baseline reaction time of simply moving the joystick in the direction of a light stimulus. The next task was a static acuity test meaning the participants sat still in the chair while a single C flashed in the center of the screen for 300ms and the C's got smaller as the participants got them correct. As soon as they got three out of five correct at a certain size, the C's would drop a size. As soon as they got three out of five incorrect, the C's went up one size. This allowed the computer software to hone in on their acuity threshold while in the chair so that we could compare with the wall chart. Then we ran this same test while the subjects were oscillating in the chair so that we could measure what we call their active yaw acuity.

The five main tasks that the participants completed were the same for all participants no matter what their specific thresholds were. The tasks consisted of identifying the orientation of the presented C while the chair was oscillating and the C's were flashing in one of nine different locations on the screen. So the participants had to find the C first and then indicate its orientation. The subjects were given instructions to be "as quick and accurate as possible." Between the five tests we varied the presentation time of the C as well as the size of the C. Within each test these parameters stayed the same. We designated a size to be the threshold and then changed the sizes based on this threshold. We set it at size one which is 20/20 on the Snellen scale. All of the participants scored a better acuity than 20/20 on both the wall chart and static acuity so we knew that we were not picking an impossible size. Based on this threshold, the five tests were set at 1) threshold size (20/20) presented for 300ms, 2) 20/30 for 300ms, 3) 20/30 for 150ms, 4) 20/30 for 450ms, and 5) 20/50 for 300ms. This allowed for two difficult tests, two fairly easy tests, and one middle range test. The order in which the tests were completed was randomized for the participants so as to normalize for fatigue and learning effects. After the testing was complete, the participants filled out a questionnaire checking on their feelings of well being, although the rotator was not particularly conducive of motion sickness.

III. Results

A. Threshold Acuities

The results from the three threshold acuity tests were rather informative. Figure 1 shows the graph of the average threshold for all three tests. The y-axis is in the LogMAR scale which is a conversion from the Snellen scale. Zero represents 20/20 vision and negative numbers represent better than 20/20. So the higher the negative score, the better the threshold. The "standing" test is the wall chart, the "static" test is the computer test while sitting still in the chair, and the "active" test is the same as above but while oscillating. There was a difference between the standing and static tests although not a significant one. Theoretically these should be the

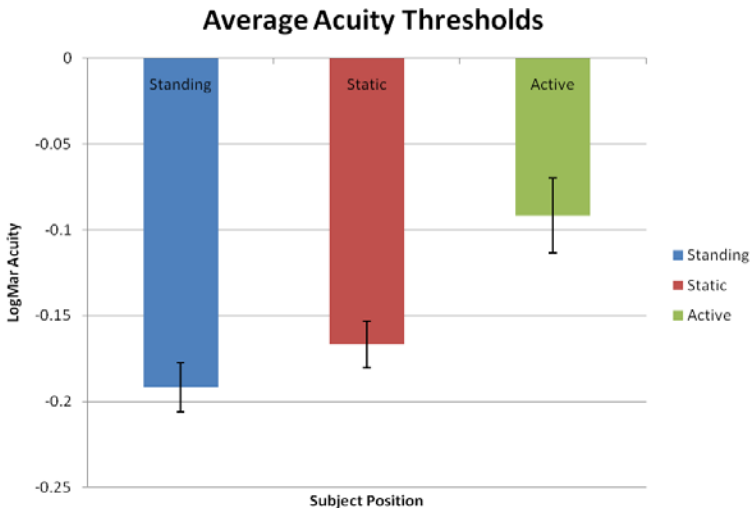

Figure 1. Average Threshold Acuities of Participants.
Error bars represent 1 standard error of the mean.

same values if our computerized test is accurate. There are two possible explanations for the difference; first of all the computer program did not use the smallest letter size that the wall chart did, and second the computer only displayed the letter for 300ms whereas the subjects could stare at the wall chart as long as they wanted. The difference between the static and active was expected and proved to be statistically significant. T- test $p < 0.01$. Since it was the same test, we know that the difference lies in the participants' acuities. Even though the vestibular system is aiding in eye stabilization and participants' vision is still good, a person's vision is just not as good when they are moving.

B. Reaction Time

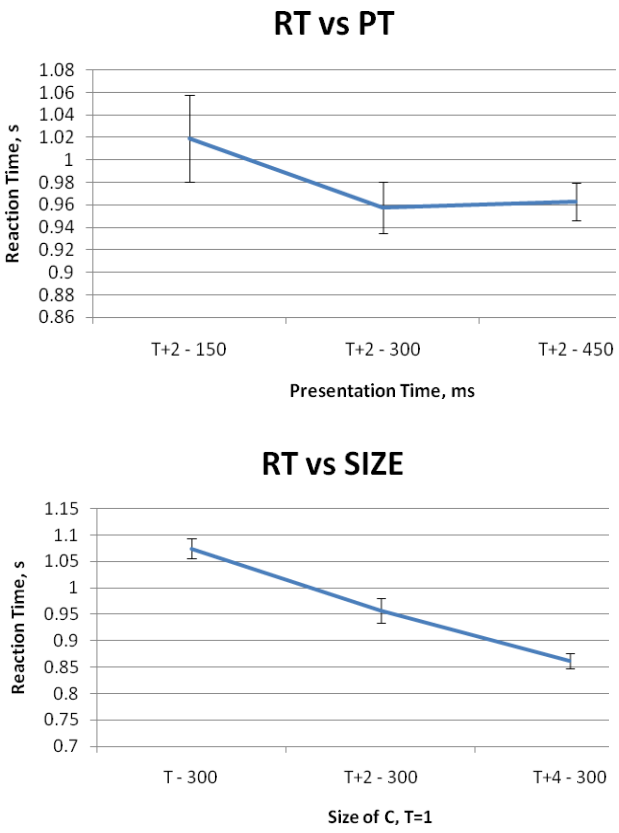

Figure 2. Participant's Reaction Time.
The top graph displays the RT versus the PT and the bottom graph displays the RT versus the size of the VT. The T+2 300 data point in both graphs is the same test. Error bars represent 1 standard error of the mean.

The passive design of the experiment allowed us to measure participants' reaction time of their response. This reaction is basically a sum total of three main components: the eye saccade to find the target, the cognitive thought to figure out the orientation of the letter, and the physical hand movement to operate the joystick. These are not three separate functions that take place in this exact order per se, but rather a combined effort of the brain. The average baseline reaction time test produced an average reaction time of 0.5952s which we know is the time it takes to make the eye saccade and the physical joystick response. Therefore the test reaction time minus this baseline reaction time is roughly the amount of time it takes to cognitively identify the orientation of the letter.

Figure 2 shows the graphs of the average reaction times for the five tests. The reaction time versus the size graph is exactly what we were expecting. As the size of the letter increased, the reaction time decreased which makes sense because if the participants can see the letter better they are going to take less time trying to identify it. The outcome of the reaction time versus presentation time was slightly less expected. We did not think it would level off so soon, let alone increase for the 450ms test. The 150ms test was very difficult and the participants probably took so long because they really had to concentrate on finding the letter and recognizing it. But once we presented the VT for 300ms there was enough time to find the "C" and make a response without needing to frantically search. We were expecting the same decrease when we presented the letter for 450ms but they actually took more time to respond on average. This may be because if they knew they had the time to find the "C" then they could focus more on being accurate as opposed to being faster.

C. Accuracy

The main measurement that tests visual acuity is the accuracy of the participants when doing the tasks. Their accuracy shows whether or not they can see well at a given size or presentation time. Figure 3 shows the average percent correct for each of the five tests. Both graphs show a general trend; as the letter size and presentation

increases so too does accuracy. If the participants can see the "C" better then they are going to perform better. Both graphs also show a general beginning of leveling off. The first slope is much steeper than the second slope on both graphs. This means that we are probably close to the peak accuracy and after that size or presentation time accuracy will not change much. When comparing the two easiest tests, everyone did well; the averages were both around 91%. But what is interesting is that participants who had a lower better threshold liked the 450ms test better and the participants who had a higher threshold liked the larger T+4 size test better. This may reflect that if someone has a low threshold and can see the smaller sizes, a large size is not necessarily going help him but a longer presentation time will help. And if someone has a higher threshold then a larger size letter is going to help him the most.

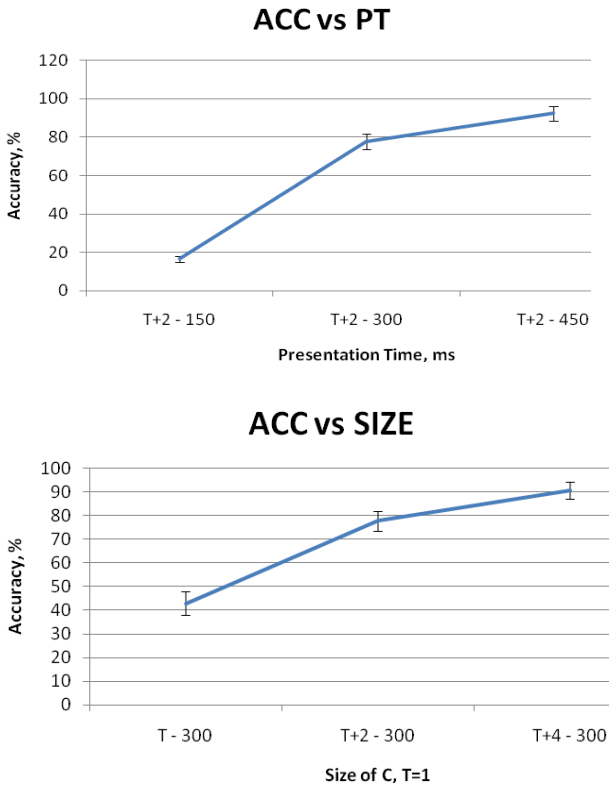

Figure 3. Participant's Accuracy.
The top graph displays the accuracy versus the PT and the bottom graph displays the accuracy versus the size of the VT. The T+2 300 data point in both graphs is the same test. Error bars represent 1 standard error of the mean.

D. Plane Comparisons

Of the nine locations on the screen where the "C" could possibly pop up, the left right and center positions were within the horizontal plane of rotation and therefore in the field of vision controlled by the VOR. So to compare these three locations with the other six, we averaged the reaction time and accuracy of each. This was done only for the T+2 300ms test because this was a good middle ground; no one scored 100% but everyone did better than 50%. Figure 4 shows the results in a bar graph. The "horizontal plane" is the left right and center average, and the "vertical plane" is the other six locations average. There was a significant difference of 12% between the accuracies of the two planes. (T-test $p<0.05$) There was also a difference between the reaction times, although not a significant one. Both of these results support our hypothesis though; when one has to look outside of the plane of motion to see a VT his accuracy can decrease significantly and

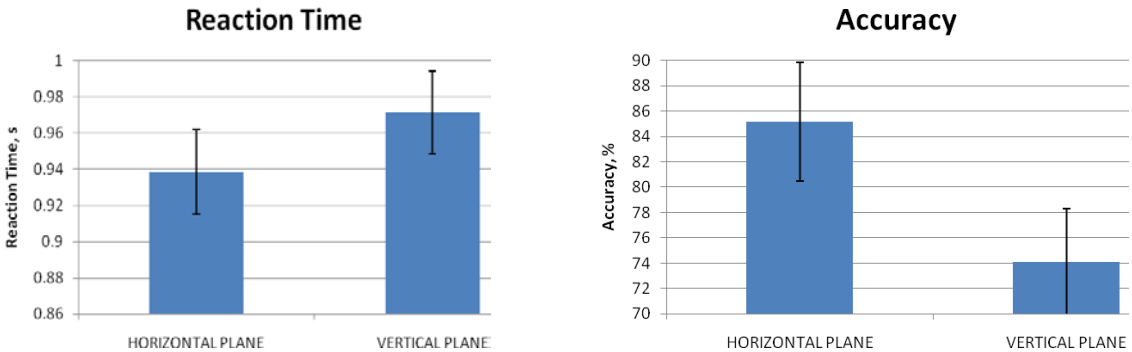

Figure 4. Plane Comparisons.
The top graph displays the RTs for the VT presented in the horizontal plane those outside the plane. The bottom graph displays the accuracy. Error bars represent 1 standard error of the mean.

his reaction time can increase. The VOR is definitely an aid in stabilizing vision, but does not work as well outside the plane of rotation.

IV. Conclusion

The results of this project are very promising. We have support that this is a successful functional measure of the VOR at work which also means that it could be used as a diagnostic test to search for visual-vestibular impairments. And our results of the plane comparisons can maybe be put to practical use. For example when building human operated machinery that will cause a lot of motion, it would be wise to put any instrumentation in the field of view of that motion so as to provide the easiest and fastest line of sight.

One thing to note about the passive test we chose is that there are pros and cons to using a passive test. It is very good because it frees the body from actively choosing and concentrating on movements which allows the use of a joystick and therefore the measurement of reaction time. However when oscillating in a chair, it is difficult to achieve the natural walking frequency of 2Hz that the body experiences every day. Like other variables, there is definitely a trade off.

Since this DVA task could be used as a functional measurement of vestibular action, then it can also prove to be an diagnostic measure of post-flight vestibular impairments for astronauts. After Shuttle flights and especially long duration Space Station flights, astronauts have a decreased vestibular function especially with regards to posture and balance. They also experience neuro-cognitive effects like disorientation and mental slowing. Both of these could affect the proper function of the VOR[4] and our DVA test would allow us to check for this. Looking at both reaction time and accuracy, we could check to see specifically where the problem is. Are they having trouble seeing and the problem is with the communication between the visual and vestibular systems, or are they seeing ok but at an overall slowed pace? Our test would be able to study this, and hopefully once we know the specific problem we could begin to look for a countermeasure or treatment for post-flight disorders.

Acknowledgments

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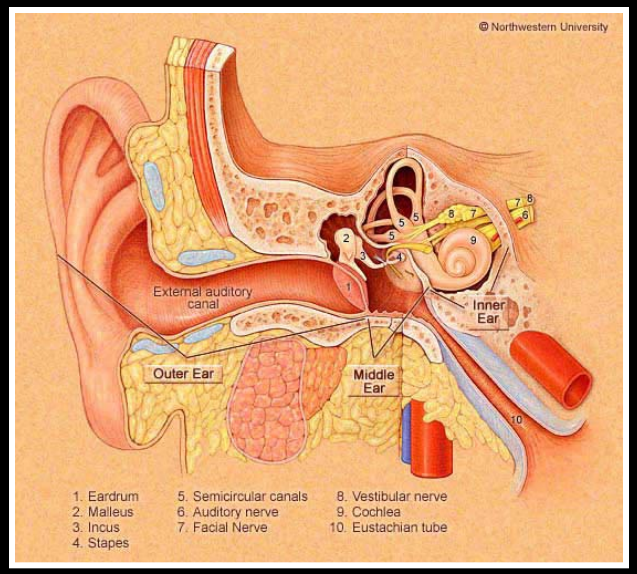
[4]Muth, E. R., "The Challenge of Uncoupled Motion: Duration of Cognitive and Physiological Aftereffects," *Human Factors,* Vol. 51, No. 5, 2009, pp. 752-761.

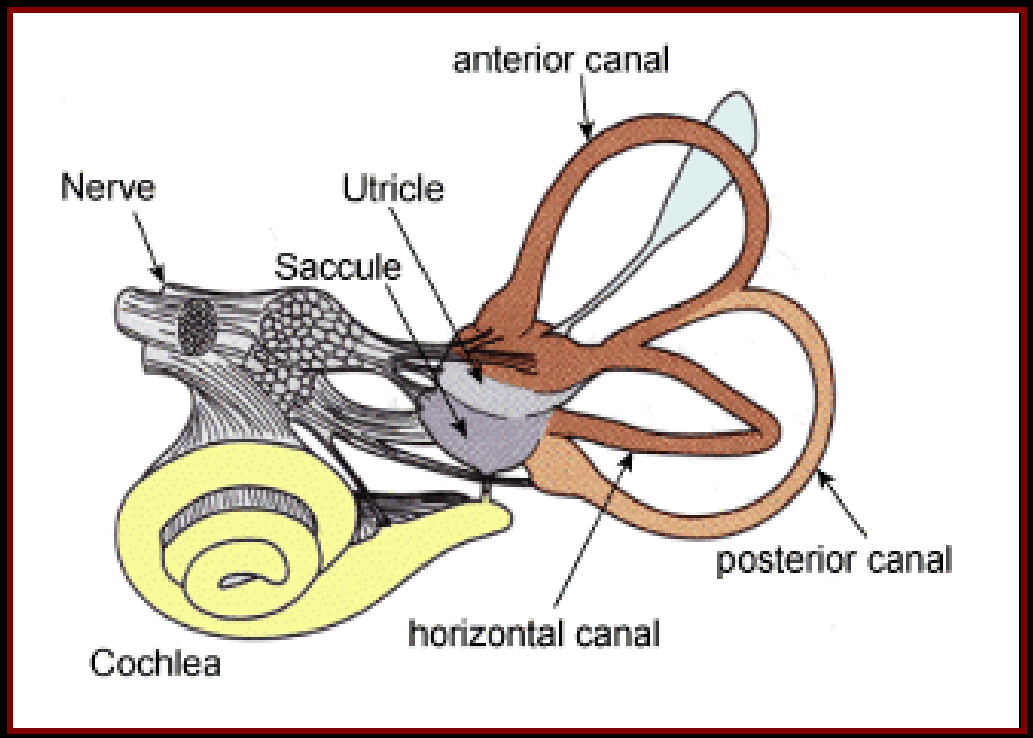
DVA as a Functional Diagnostic Test

The VOR and DVA

Anatomy

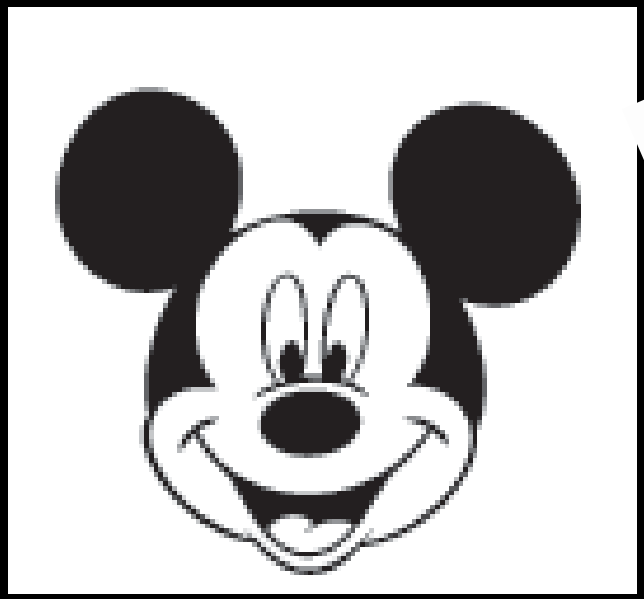
- Vestibular Apparatus
  - Semicircular Canals
  - Otoliths



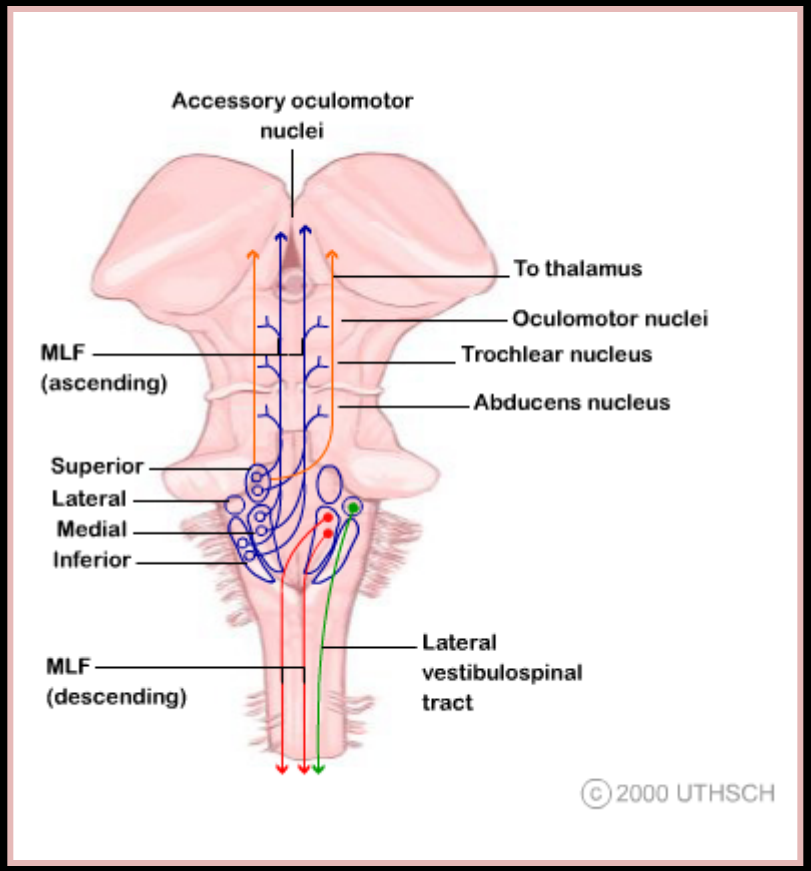


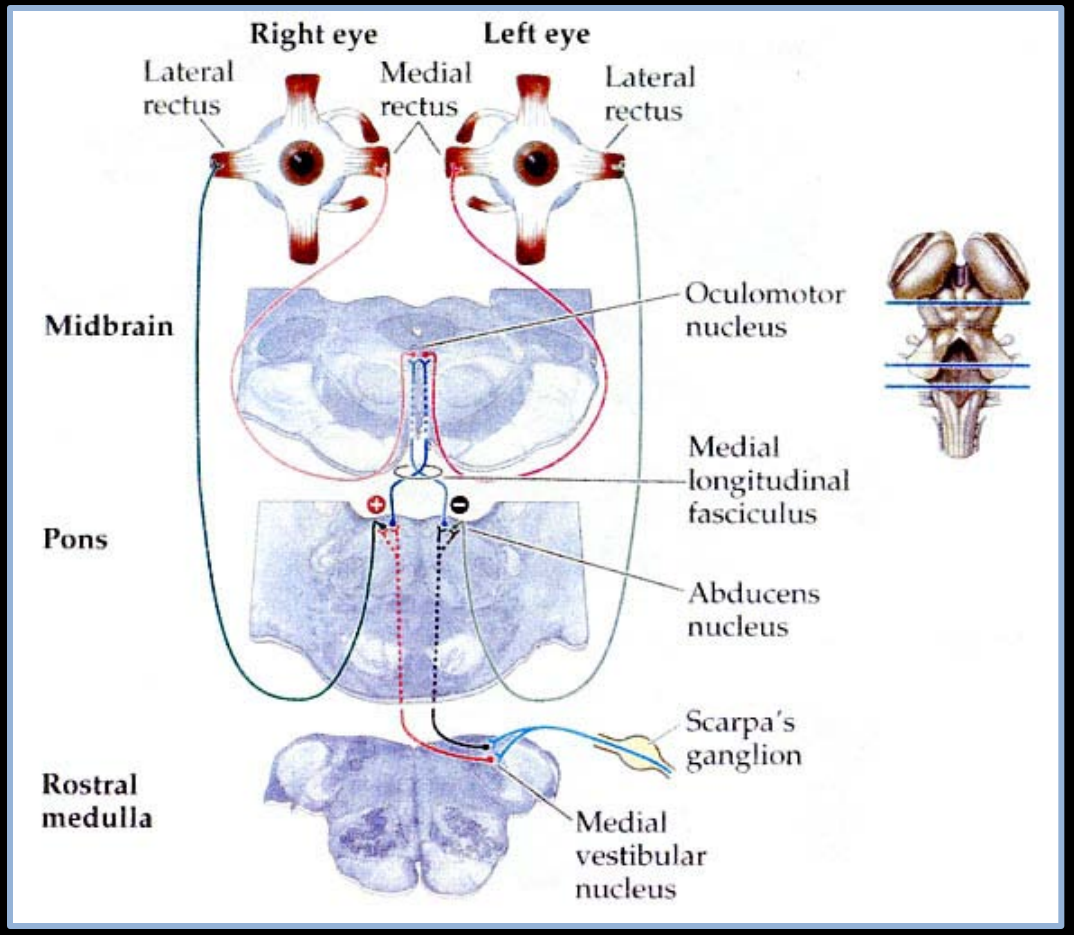
Background

- The Vestibulo-Ocular Reflex (VOR)
  - What, why, and how
  - Daily experiences



The VOR Pathway



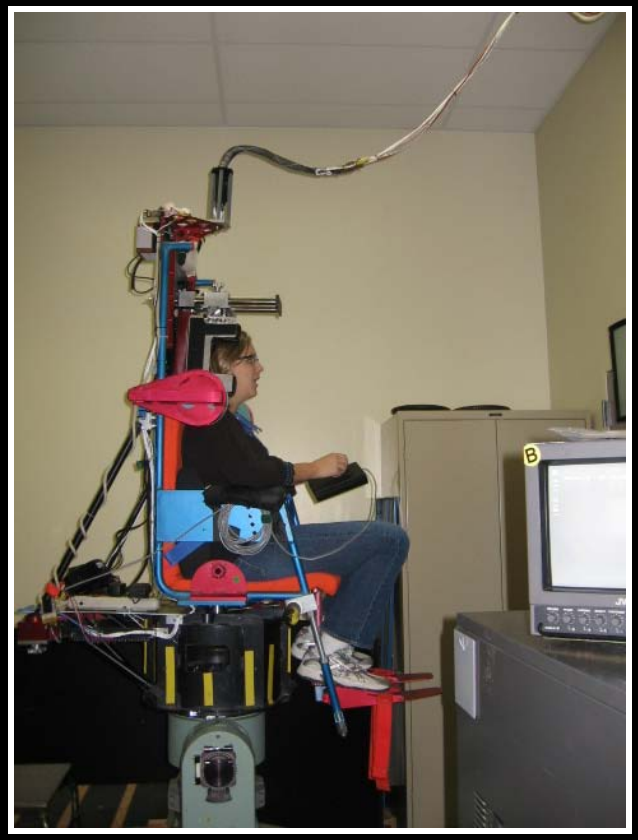


The Lack of a Vestibular System

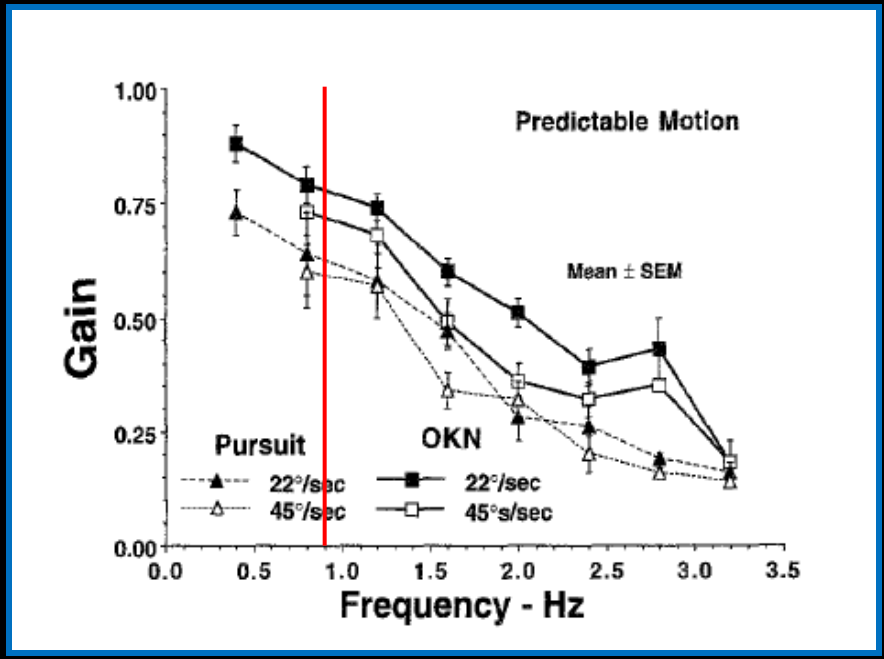
The Lack of a Vestibular System

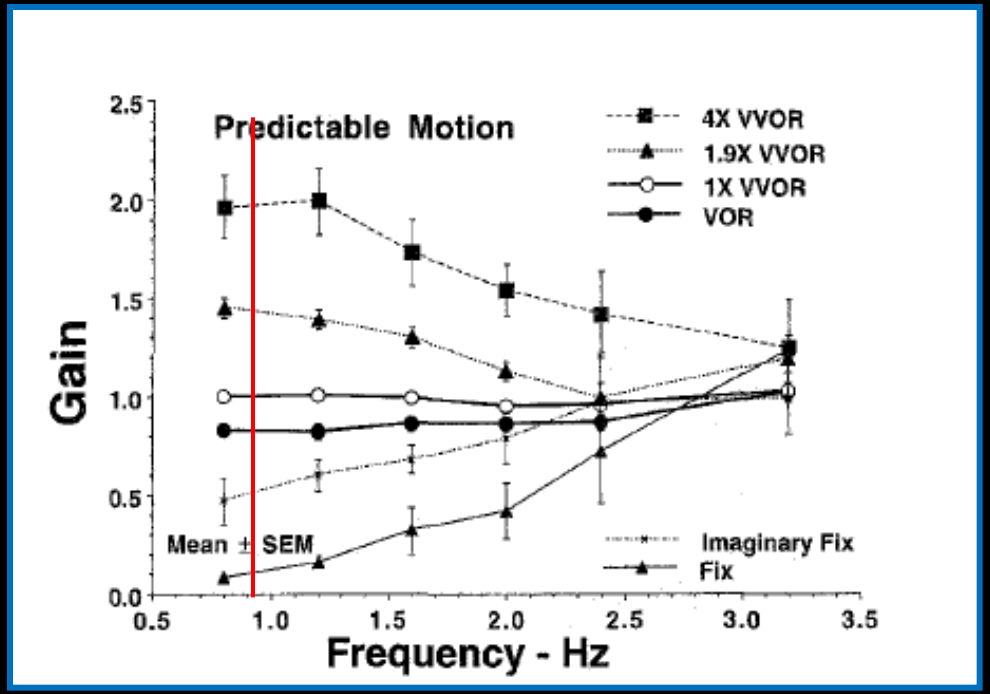
The DVA Test

- Computerized visual acuity test while moving
  - Sufficient frequency and velocity
  - Gain of 1



Reasoning behind 0.8Hz





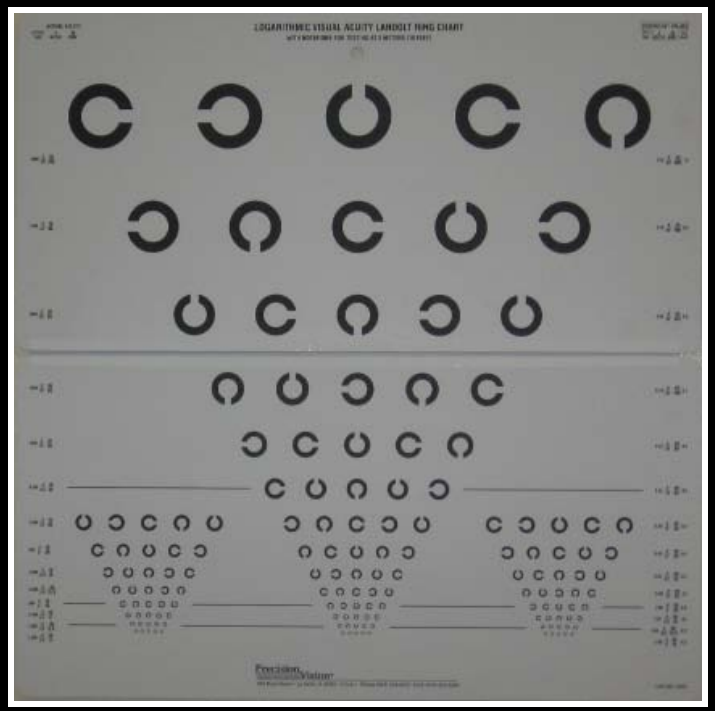
From Demer 1995

Our Ideas

- Functional measure
- Reaction time & Accuracy
- Hypothesis: Vision in plane of movement (horizontal) will be better and more quickly acquired than outside of plane (vertical)

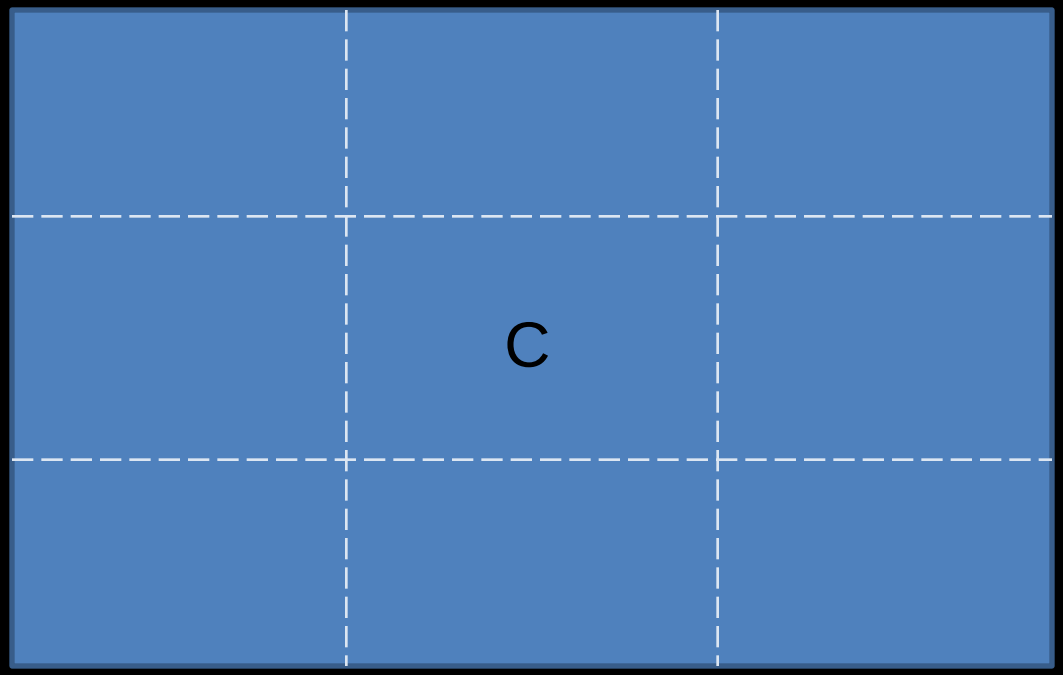
Methods

- Observe eye movements
- Measure baseline joystick reaction time
- Measure static acuity
  - Wall chart vs computer
- Measure dynamic acuity



Measuring DVA

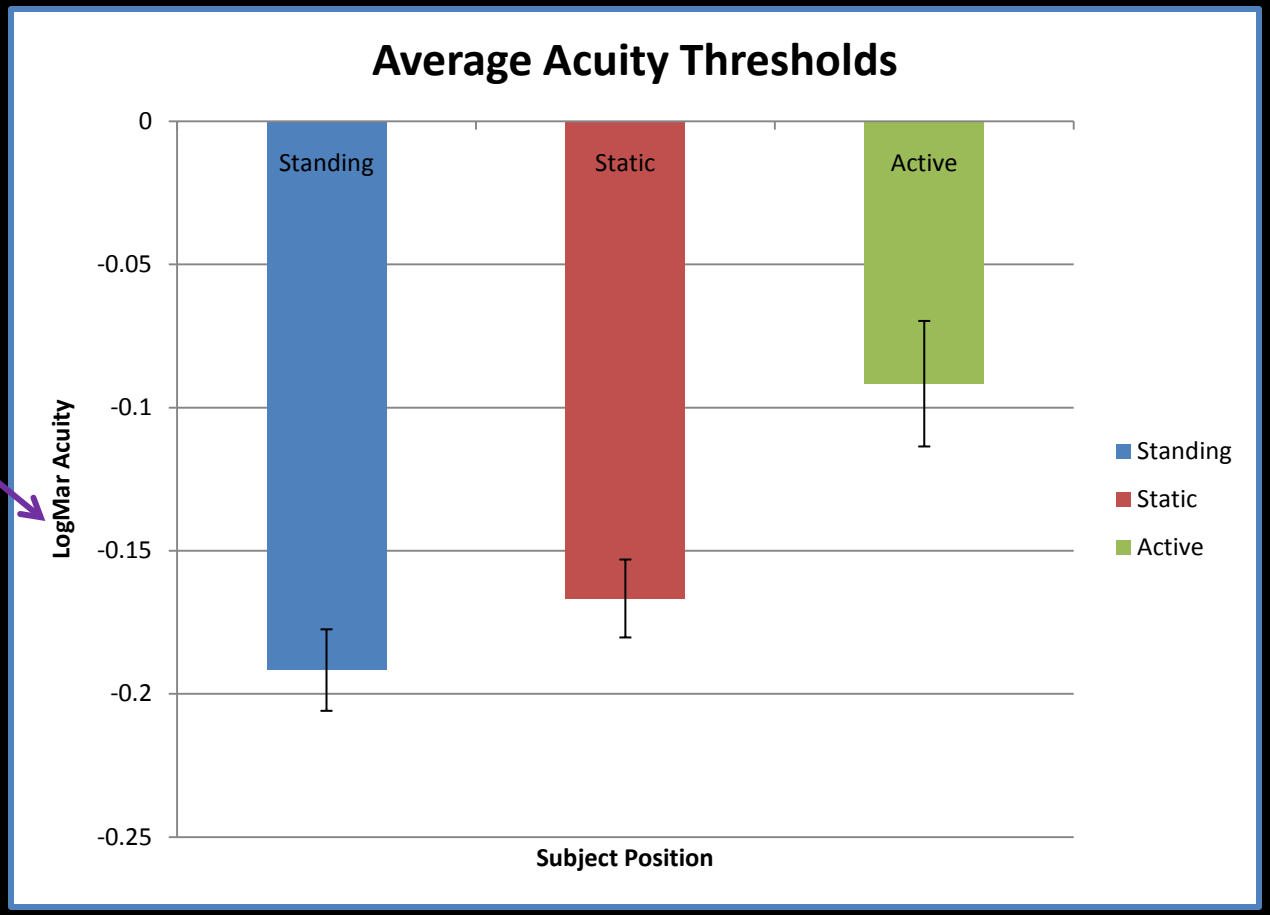
- Five Random Location Tasks
  - Vary Landolt C size as well as presentation time



View from the Chair

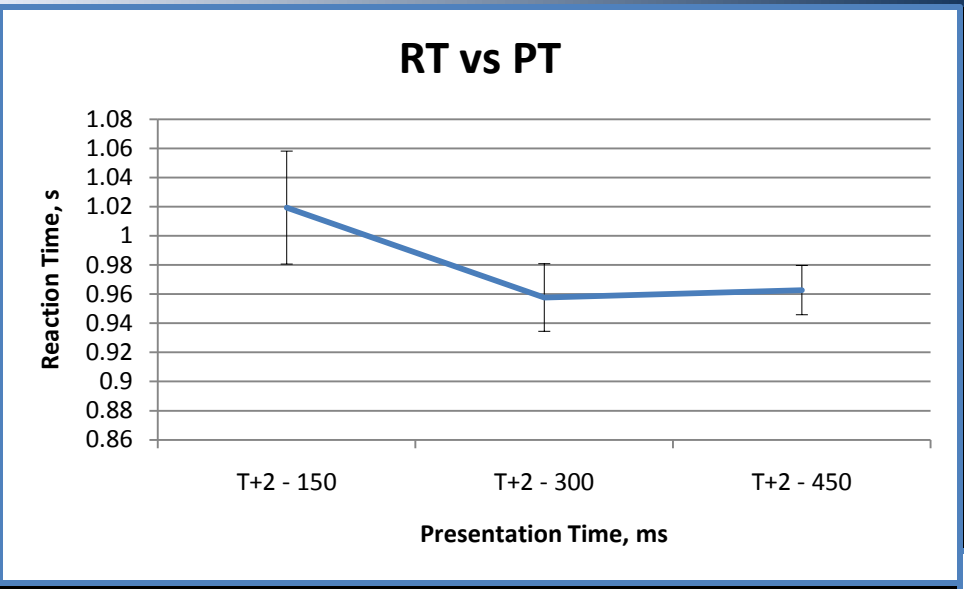
Results - Threshold Comparison

LogMar is the standard opthamology measurement



Error bars represent 1 standard error. N=11

Results – Reaction Time



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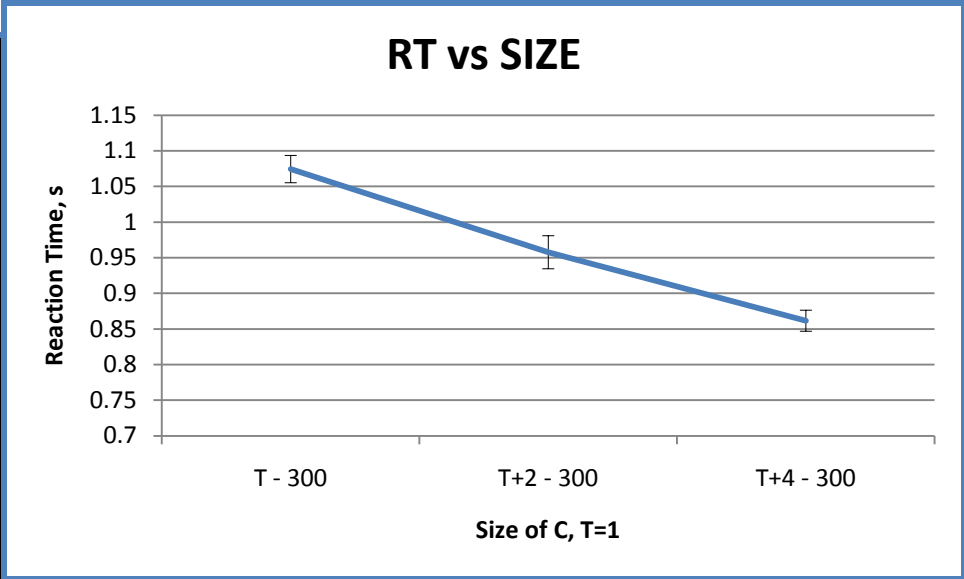

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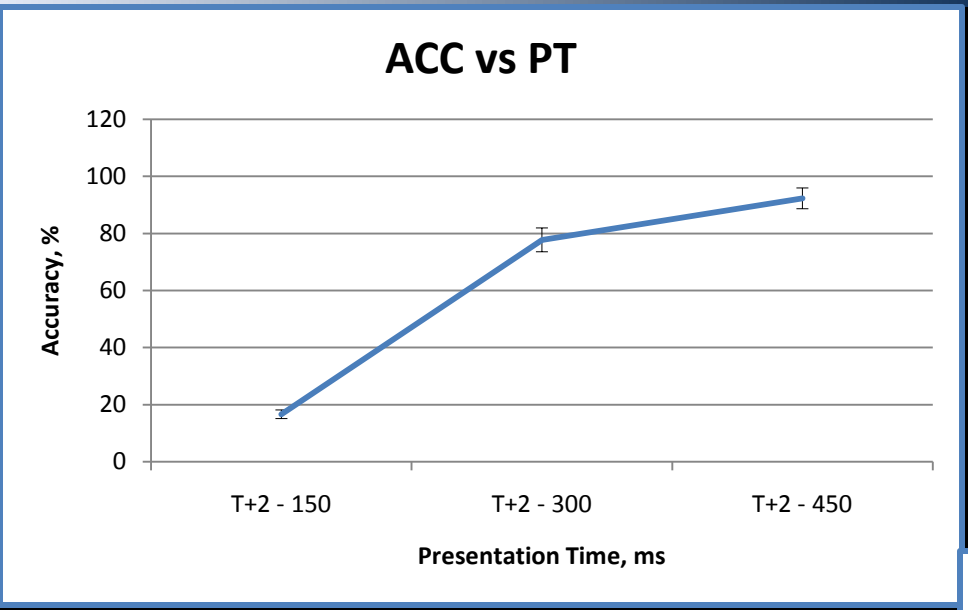
Results - Accuracy



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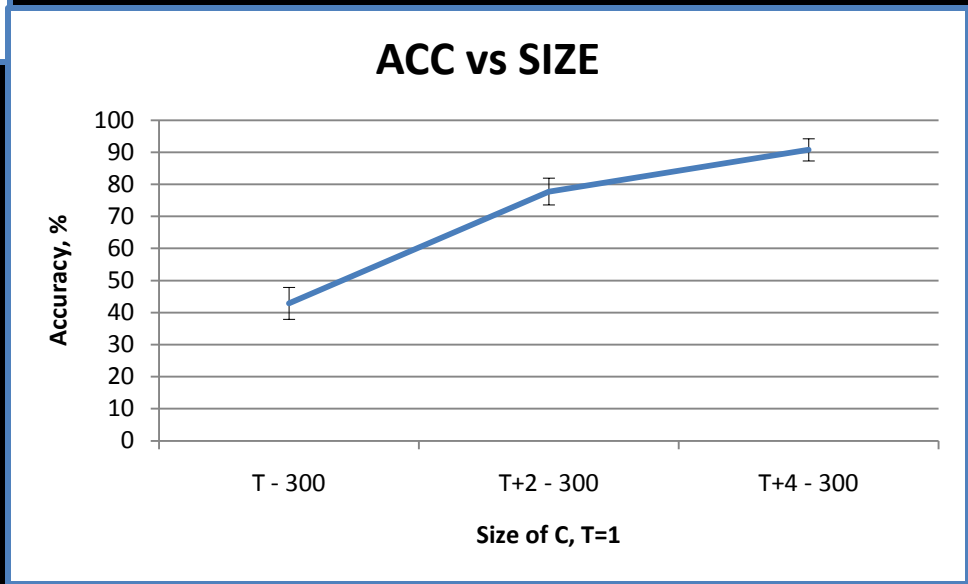
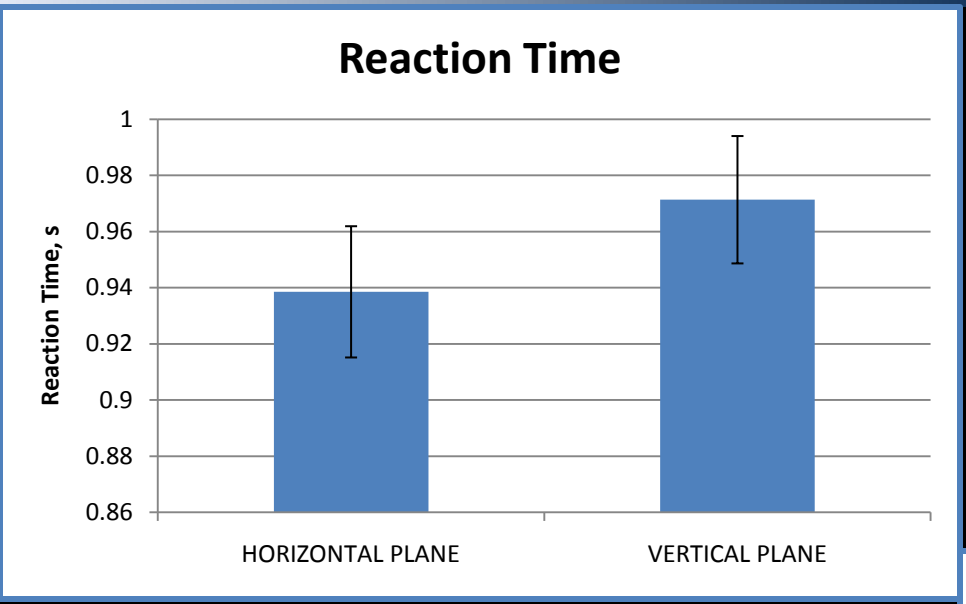


Results – Plane Comparison



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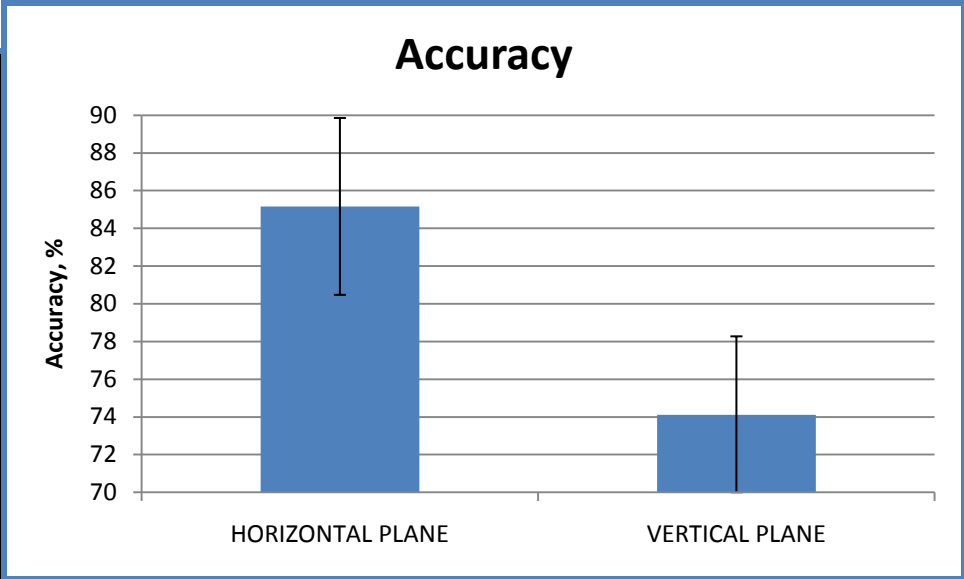

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Discussion

- So what does this mean?
- Pros and Cons (limitations) of passive
  - Hard to achieve natural freq (2Hz)
  - Easier to work with joystick to get RT
- How does this relate to the astronauts?
  - Now have a test to use for post-flight diagnosis of any impairments

Fun Times at JSC

Future…

- Another Internship?
- Off to Grad school
- Career Goals: NASA!
  - Astronaut Trainer, Biomedical Flight Controller, or Research Specialist

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- My Partner in Crime- Yiri de Dios
- My Software Programmer- Wally
- My Engineer- Robert
- My Program Coordinator- Veronica Seyl
- The Lab Group

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