# Introduction

Eye-gaze interaction with computerized systems holds a number of benefits. For instance, users’ hands are free to perform other tasks while interacting with the computer [1] and individuals with severe motor disabilities can communicate with their environment more easily [2, 3]. In addition, gaze interaction can be highly useful when screens are larger and when objects are in motion because time to move one's eyes between objects changes very little with distance [4] and tracking them when they are moving (as in video games) draws upon an inherent and especially adapt eye-brain mechanism [5, 6].

The interest in using gaze interfaces has led to empirical investigations of user-centered design questions. For instance, how should users select on-screen objects (e.g., icons) that they would like to interact with [7]? Wheth-er or not users should receive feedback on where they are looking [1] and what kind of feedback? [3, 8]. Findings have shown that when users selected objects for interaction by dwelling on them for a certain duration, selection times were faster than with the "traditional" mouse [3, 4]. Yet, other studies have demonstrated that when targets were smaller than 40 of visual angle, users had to confirm choices by key press or by moving their facial muscles to compete with the computer mouse in speed and in accuracy [9, 10]. Finally, Alonso, Causse [1] found that for targets smaller than 2.140, cursor feedback on where users were looking improved their accuracy in selecting these targets.

Interestingly, although pointing accuracy on smaller objects has been identified as key factor in the effective-ness of gaze interaction, the question of what eye points more accurately on targets has not been studied. This question may hold even greater importance in gaze interaction with moving targets that currently suffer from low success in target acquisition [10, 11). In the current study, we compared tracking accuracy between the “cyclope-an”, dominant and non-dominant eye.

## Missing of targets and the higher accuracy of the “cyclopean eye”

Cui and Hondzinski [12] conducted an experiment where they tested the gaze accuracy of participants. Partic-ipants viewed targets (i.e., weighted fishing anchors) suspended from the ceiling at three different heights while their binocular points of gaze were recorded at 60Hz. Errors were quantified as the absolute and angular distanc-es between targets and points of gaze of the right and of the left eye. Then, a third type of error was defined as the absolute and angular distances between targets and the average of the positions of the right and left eye. Findings showed that mean error of averaged positions were either smaller or not significantly different from the mean error of the right or of the left eye alone. Based on these findings, the conclusion from this study was that for a range of viewing conditions, averaged gaze positions would produce the most accurate results for viewing tasks.

From a broader theoretical perspective, Cui and Hondzinski [12] suggested that their findings resonate with the "cyclopean eye" theory that accounts for how people set their relative direction to objects in space. Accord-ing to this theory, people set their egocentric visual direction according to a line connecting the target and a point on an imaginary line between their eyes. In other words, when one assesses her relative positions to targets, it is a point between her eyes that designates her position. This point was metaphorically termed the "cyclopean eye" [13] and numerous studies have indeed demonstrated that individuals set “cyclopean” direction to objects in their field of view [e.g., 14, 15-17]. Cyclopean eye position, in turn, may be approximated by averaging left and right eye positions as in Cui and Hondzinski [12] study.

Although Cui and Hondzinski [12] did not account for why the right and left eye would miss targets in the first place, their findings do correspond with a well-documented phenomenon in optometry and the human vision and perception domains, termed “fixation disparity”. In fixation disparity, vergence eye movements fail to inter-sect both lines of sight on the intended targets and consequently, eyes do not land on the same spot, but rather fixate on slightly different locations from each other and from the intended targets [18, 19]. Hence, while right and left eyes may sometimes miss targets, the "cyclopean eye", who sets the direction to targets, may be the one that is placed on them more accurately. Cyclopean eye theory, therefore, resonates with that averaged gaze posi-tions, or cyclopean positions, may "land" closer to targets than single gaze positions. Still, another theory, that of eye dominance suggests that at least in some cases gaze positions of the dominant eye may land closer to targets.

# Experiment 1: Exploratory study

The purpose of the first experiment was to obtain first impression on what eye tracks a moving target more accurately before we test this question with gaze-interface tracking.

## Method

### Participants

27 undergraduate psychology and engineering students participated in the experiment in partial fulfillment of the requirements of a course in human factors engineering. Age ranged from 21 to 31 years (Mean=26, SD=2.7). 48% of the participants were males. We tested participants for normal binocular vision using Snellen test and for binocular stability using the “Parallel infinity balance test” (PTIB) [37].

Participants' ocular dominance was tested using the Dolman's Hole in the card/Peephole test [e.g., 24, 25, 26]. 19 of the 27 participants (70 %) were right-eyed. 24 of the 27 participants (89%) were right-handed. 6 of the 27 participants (22%) had an opposite eye-hand lateral dominance (i.e. right dominant eye with left dominant hand and vice versa). All mentioned proportions comply with the proportions reported in Bourassa, Mcmanus [27] meta-analysis.

### Task and procedure

Participants arrived at the lab for individual sessions that lasted approximately 20 minutes. Upon arrival, they were briefed about the procedure by the experimenter that encouraged participants to ask questions throughout and after the briefing. Participants signed the informed consent form only after the experimenter confirmed that they understood the procedure. Then, the experimenter tested participants for normal binocular vision and eye-dominance. The experiment was conducted in a sound-attenuated and darkened room. Participants sat in front of the display screen and the binocular eye tracker`s desktop camera (“Eyelink 1000” see apparatus).

Participants performed a free gaze-tracking task (see Figure 1). They were instructed to “track the moving tar-get with their eyes”. The moving target was a red circle, 80 pixels in diameter and 1.87° from a viewing distance of 65cm. Mean percent time on target of a similar size in a previous study we conducted with joystick tracking was approximately 55% [38] and we therefore anticipated that participants in the current study would be able to track the target with their eyes. We created six tracking conditions: 3 target velocities X 2 maneuvering types. Target velocities were: 1.7°/sec, 3.1°/sec and 4.5°/sec. Maneuvering types were straight lines and curved lines. Lowest and medium velocities were also adapted from Wagner, Sahar [38] and maneuvering types were chosen to create lower (straight lines) and higher (curved lines) degrees of difficulty [39].

Figure 1. The experimental task.

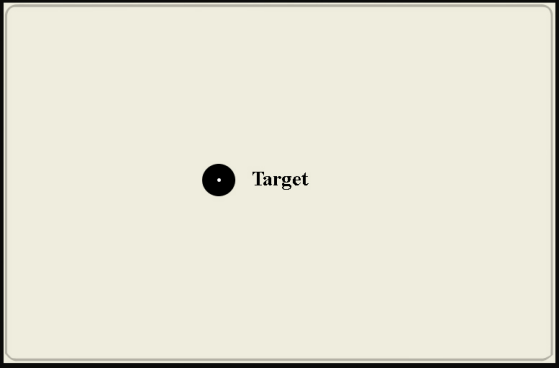


Table 1. The 6 tracking conditions within an experimental block according to 3 velocities X 2 maneuvering types

|  | | **Velocity** | | |
| --- | --- | --- | --- | --- |
| **Maneuver** | Slow  (1.7°/sec.) | | Medium  (3.1°/sec.) | Fast  (4.5°/sec.) | |
| Straight Lines | Slow & Straight | | Medium & Straight | Fast & Straight | |
| Curved Lines | Slow & Curved | | Medium & Curved | Fast & Curved | |

# References

Alonso R, Causse M, Vachon F, Parise R, Dehais F, Terrier P. Evaluation of head-free eye tracking as an input device for air traffic control. Ergonomics. 2013;56(2):246-55. DOI: https://doi.org/10.1080/00140139.2012.744473

Bates R, Donegan M, Istance HO, Hansen JP, Räihä K-J. Introducing COGAIN: communication by gaze interaction. Universal Access in the Information Society. 2007;6(2):159-66. DOI: https://doi.org/10.1007/s10209-007-0077-9

Majaranta P, MacKenzie IS, Aula A, Räihä K-J. Effects of feedback and dwell time on eye typing speed and accuracy. Universal Access in the Information Society. 2006;5(2):199-208. DOI: https://doi.org/10.1007/s10209-006-0034-z

Sibert LE, Jacob RJ, editors. Evaluation of eye gaze interaction. Human Factors in Computing Systems: CHI 2000 Conference Proceedings; 2000; Den Haag: the Netherlands: ACM Press.

Barnes GR. Cognitive processes involved in smooth pursuit eye movements. Brain and Cognition. 2008;68(3):309-26. DOI: https://doi.org/10.1016/j.bandc.2008.08.020

Krauzlis RJ. Recasting the smooth pursuit eye movement system. Journal of Neurophysiology. 2004;91(2):591-603. DOI: https://doi.org/10.1152/jn.00801.2003

Jochems N, Vetter S, Schlick C. A comparative study of information input devices for aging computer users. Behaviour & Information Technology. 2013;32(9):902-19. DOI: https://doi.org/10.1080/0144929X.2012.692100

Majaranta P, Isokoski P, Rantala J, Špakov O, Akkil D, Kangas J, et al. Haptic feedback in eye typing. Journal of Eye Movement Research. 2016;9(1). DOI: https://doi.org/10.16910/jemr.9.1.3

MacKenzie IS. Evaluating eye tracking systems for computer input. In: Majaranta P, Aoki H, Donegan M, Hansen D, Hansen J, Hyrskykari A, ed. Gaze Interaction and Applications of Eye Tracking: Advances in Assistive Technologies: Advances in Assistive Technologies. Hershey: IGI Global; 2011.

San Agustin J, Mateo JC, Hansen JP, Villanueva A. Evaluation of the potential of gaze input for game interaction. PsychNology Journal. 2009;7(2):213-36.

Smith JD, Graham T, editors. Use of eye movements for video game control. Proceedings of the SIGCHI international conference on Advances in computer entertainment technology; 2006; New York, UAS: ACM Press.

Cui Y, Hondzinski JM. Gaze tracking accuracy in humans: Two eyes are better than one. Neuroscience Letters. 2006;396(3):257-62. doi: 10.1016/j.neulet.2005.11.071.

Hering E. Spatial sense and movements of the eye. Oxford, UK: American Academy of Optometry

1. 1942.

Khokhotva M, Ono H, Mapp AP. The cyclopean eye is relevant for predicting visual direction. Vision Research. 2005;45(18):2339-45. doi: 10.1016/j.visres.2005.04.007.

Mapp AP, Ono H, Barbeito R. What does the dominant eye dominate? A brief and somewhat contentious review. Perception & Psychophysics. 2003;65(2):310-7. doi: 10.3758/BF03194802.

Ono H, Mapp AP, Howard IP. The cyclopean eye in vision: The new and old data continue to hit you right between the eyes. Vision Research. 2002;42(10):1307-24. doi: 10.1016/S0042-6989(01)00281-4.

Ono H, Wade NJ. Two historical strands in studying visual direction. Japanese Psychological Research. 2012;54(1):71-88. doi: 10.1111/j.1468-5884.2011.00506.x.

Howard I, Rogers B. Perceiving in depth, volume 2: Stereoscopic vision. Oxford, UK: Oxford University Press; 2012.

Stidwill D, Fletcher R. Normal binocular vision: Theory, investigation and practical aspects. West Sussex, UK: John Wiley & Sons; 2011.

Kepler J. Dioptrice. Augsburg: D. Francus; 1611.

Wade NJ, Ono H, Mapp AP. The lost direction in binocular vision: The neglected signs posted by Wells, Towne, and LeConte. Journal of the History of the Behavioral Sciences. 2006;42(1):61-86. doi: 10.1002/jhbs.20135.

Rubin ML, Walls GL. Fundamentals of visual science. Springfield: Thomas; 1969.

Walls GL. A theory of ocular dominance. Archives of Ophthalmology,. 1951;45(4):387-412.

Dolman P. The relation of the sighting eye to the measurement of heterophoria. A preliminary report. American Journal of Ophthalmology. 1920;3(4):258-61.

Ehrenstein WH, Arnold-Schulz-Gahmen BE, Jaschinski W. Eye preference within the context of binocular functions. Graefe's Archive for Clinical and Experimental Ophthalmology. 2005;243(9):926-32. doi: 10.1007/s00417-005-1128-7.

1. Li J, Lam CS, Yu M, Hess RF, Chan LY, Maehara G, et al. Quantifying sensory eye dominance in the normal visual system: A new technique and insights into variation across traditional tests. Investigative Ophthalmology & Visual Science. 2010;51(12):6875-81. doi: 10.1167/iovs.10-5549.
2. Bourassa D, Mcmanus I, Bryden M. Handedness and eye-dominance: A meta-analysis of their relationship. Laterality: Asymmetries of Body, Brain, and Cognition. 1996;1(1):5-34. doi: 10.1080/713754206.
3. Porac C, Coren S. Sighting dominance and egocentric localization. Vision Research. 1986;26(10):1709-13.
4. Khan AZ, Crawford JD. Ocular dominance reverses as a function of horizontal gaze angle. Vision Research. 2001;41(14):1743-8. doi: 10.1016/S0042-6989(01)00079-7.
5. Mapp AP, Ono H. Wondering about the wandering cyclopean eye. Vision Research. 1999;39(14):2381-6. doi: 10.1016/S0042-6989(98)00278-8.
6. Ono H, Barbeito R. The cyclopean eye vs. the sighting-dominant eye as the center of visual direction. Perception & Psychophysics. 1982;32(3):201-10.
7. Han Y, Seideman M, Lennerstrand G. Dynamics of accommodative vergence movements controlled by the dominant and non dominant eye. Acta Ophthalmologica Scandinavica. 1995;73(4):319-24. doi: 10.1111/j.1600-0420.1995.tb00034.x.
8. Van Leeuwen AF, Westen MJ, van der Steen J, de Faber J-TH, Collewijn H. Gaze-shift dynamics in subjects with and without symptoms of convergence insufficiency: influence of monocular preference and the effect of training. Vision Research. 1999;39(18):3095-107. doi: 10.1016/S0042-6989(99)00066-8.
9. Moiseeva V, Slavutskaya M, Shul'govskii V. The effects of visual stimulation of the dominant and non-dominant eyes on the latent period of saccades and the latency of the peak of rapid pre-saccade potentials. Neuroscience and Behavioral Physiology. 2000;30(4):379-82. doi: 10.1007/BF02463089.
10. Kawata H, Ohtsuka K. Dynamic asymmetries in convergence eye movements under natural viewing conditions. Japanese Journal of Ophthalmology. 2001;45(5):437-44. doi: 10.1016/S0021-5155(01)00405-1.
11. Vidal M, Bulling A, Gellersen H, editors. Pursuits: spontaneous interaction with displays based on smooth pursuit eye movement and moving targets. Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing; 2013; New York: USA: ACM Press.
12. Shapiro IJ. Parallel-testing infinity balance. Instrument and technique for the parallel testing of binocular vision. Optometry & Vision Science. 1995;72(12):916-23.
13. Wagner M, Sahar Y, Elbaum T, Botzer A, Berliner E. Grip Force as a Measure of Stress in Aviation. The International Journal of Aviation Psychology. 2015;25(3-4):157-70. doi: 10.1080/10508414.2015.1162632.
14. Wickens C, Hollands J. Engineering psychology and human performance. 2000. New York, NY: HarperCollins; 2000.
15. Stampe DM. Heuristic filtering and reliable calibration methods for video-based pupil-tracking systems. Behavior Research Methods, Instruments, & Computers. 1993;25(2):137-42. doi: 10.3758/BF03204486.
16. Nuthmann A, Kliegl R. An examination of binocular reading fixations based on sentence corpus data. Journal of Vision. 2009;9(5):1–28. doi: 10.1167/9.5.31.
17. Paterson KB, Jordan TR, Kurtev S. Binocular fixation disparity in single word displays. Journal of Experimental Psychology: Human Perception and Performance. 2009;35(6):1961. doi: 10.1037/a0016889.