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Minified Augmented Reality as a Terrestrial Analog for G-Transitions Effects in Lunar and Interplanetary Spaceflight

Authors

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Dynamic visual acuity (DVA) refers to the ability to visualize objects when the observer, object, or both are in motion. Maintaining optimum astronaut DVA is critical for human safety and effective mission performance during spaceflight. G-transitions occur while entering the gravitational field of a celestial body and results in rapid sensorimotor adaptation which can affect astronaut gaze control and impair DVA. The "Risk of Altered Sensorimotor/Vestibular Function" was identified by the National Aeronautics and Space Administration (NASA) as a potentially significant risk which requires mitigation for future lunar or Mars missions (NASA HRP, 2022). Altered sensorimotor and vestibular function can manifest as disorientation, motion sickness, motor control deficits which can impair spacecraft control and extravehicular activities (NASA HRP, 2022). These impairments are particularly concerning as they occur while entering or exiting gravitational fields, a time considered as the most critical phase of spaceflight (Waisberg et al., 2022a).

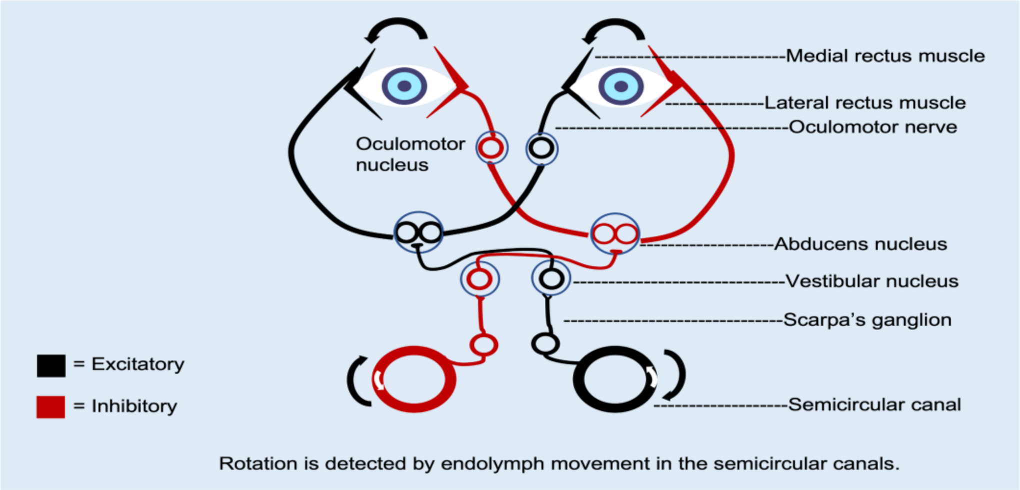
Following long-duration spaceflight (LDSF), returning astronauts have had significant DVA impairments of 0.75 eye chart lines on average, with some astronauts performing similarly to those with terrestrial vestibular impairments (Peters et al., 2011). These measurements were taken 24 hours after landing, which is likely a significant underestimate of the actual level of DVA impairment that occurs in the minutes to hours following G-transition events. There are currently no DVA assessments in space and vestibular adaptation remains incompletely understood in LDSF. To mitigate this condition, our group is developing a head-mounted, multimodal visual assessment system, that can monitor ocular structural and functional changes during long-term spaceflight (Ong, Tavakkoli, Zaman, et al., 2022; Ong, Zaman, Waisberg, et al., 2022; Ong, Zaman, Kamran, et al., 2022). Future terrestrial uses of this head-mounted visual assessment include screening for preventable blindness in developing countries (Waisberg, Ong, Paladugu, Zaman, et al., 2022; Waisberg, Ong, Paladugu, Kamran, Zaman, Tavakkoli, et al., 2022).

As a component of this visual assessment framework, we developed the first reported method to assess DVA in extended reality (Waisberg, Ong, Zaman, et al., 2022; Waisberg et al., 2022b).

DVA is dependent of on a multitude of factors, which includes: visual motion processing, the vestibulo-ocular reflex (VOR), catch-up saccades and static visual acuity (Ramaioli et al., 2019). The VOR plays an important role while the head is in motion to stabilize gaze (Figure 1). Gaze is stabilized when head movement occurs in any axis (vertical, horizontal, torsional) by a rotation of the eyes in the opposing direction (Crawford & Vilis, 1991). However in space, the ocular counter-rolling reflex which rotates the eyes in the opposite direction when the head is titled, is absent and is markedly reduced after spaceflight (Clément et al., 2020).

Figure 1

Diagram of the Vestibulo-Ocular System, which is acts as a Gaze-Stabilizing Reflex by Generating Compensatory eye Movements in Opposition to Head Movements

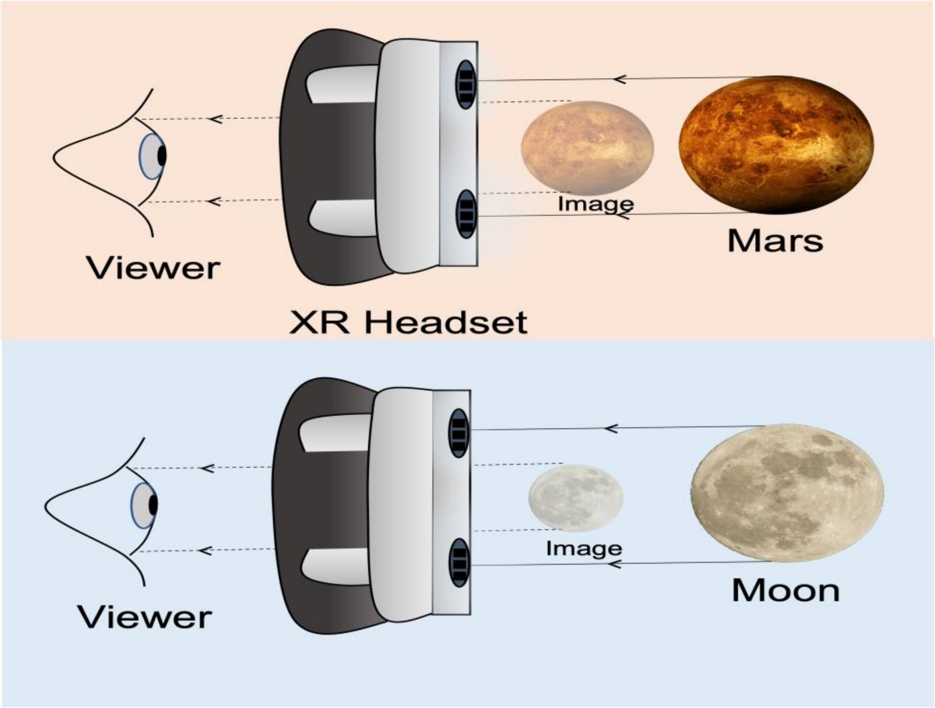


Rotation is detected by endolymph movement in the semicircular canals.

To our knowledge, this is the first application of minified augmented reality as a tool to simulate decreased DVA from G-transition effects. Developing an effective method to simulate a decrease in DVA is essential to help prepare astronauts for the future space missions. Previous research on this subject used 0.5x minifying lenses to simulate the adapting vestibulo-ocular state of a returning astronaut (Rosenberg et al., 2017). In Figure 2 (below), we demonstrate how our framework produces a minified image, and how the level of minimization can be customized to match the expected level of vestibulo-ocular dysfunction that will occur during a specific G-transition. We describe our methods for minimizing augmented reality and evaluate if this is a promising training method for astronauts that will undergo g-transitions.

Figure 2

Schematic of the Augmented Reality Head-Mounted Display and the Minifying Effect. Note that the Level of Minimization can be Increased to Match the Expected Level of Vestibulo-Ocular Dysfunction Expected During a G-Transition



Vestibulo-Ocular Gain

VOR gain refers to eye movement relative to head movement. VOR gain should ideally be equal to 1, with variations from this value resulting in balancing and postural issues, oscillopsia and a lack of visual stability (Sehizzadeh, 2005). Minifying lenses have been previously reported to cause a decreased VOR gain and a lens with minifying power of 6% has associated VOR gain decrease of 6% (Sehizzadeh, 2005). The effects of vestibulo-ocular training on VOR gain are shown in Figure 3. Vestibulo-ocular adaptation occurs to adapt to a new gain, and this process is a form of motor learning involving a combination of both visual and vestibular inputs (Carcaud et al., 2017; Sehizzadeh, 2005). The mechanism behind this process is shown in detail in Figure 4.

Figure 3

When an Object is Minified, Retinal Slip and Oscillopsia may Occur When the Head or the Object is Displaced. This is a Result of Visual-Vestibular Conflict, Produced When the eye Velocity and Head Velocity are Incongruent. In the Setting of Minified Augmented Reality, the eye Velocity will Decrease in Comparison to the Head Velocity (VOR gain decreases). In contrast, VOR Gain Would Increase if the Augmented Reality was Magnified

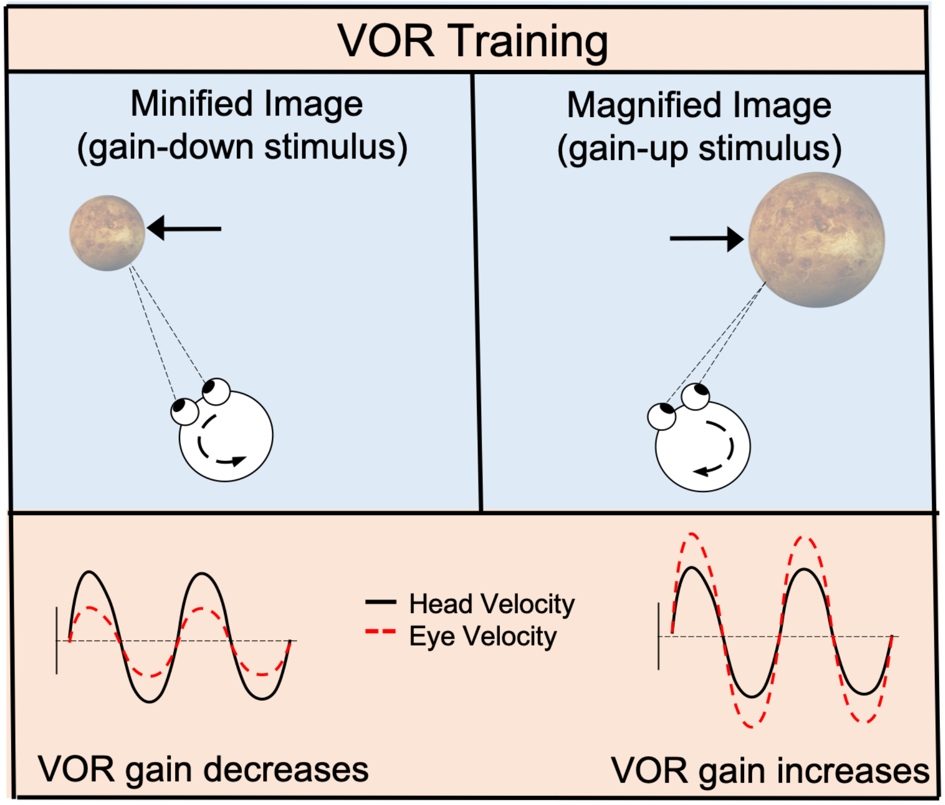
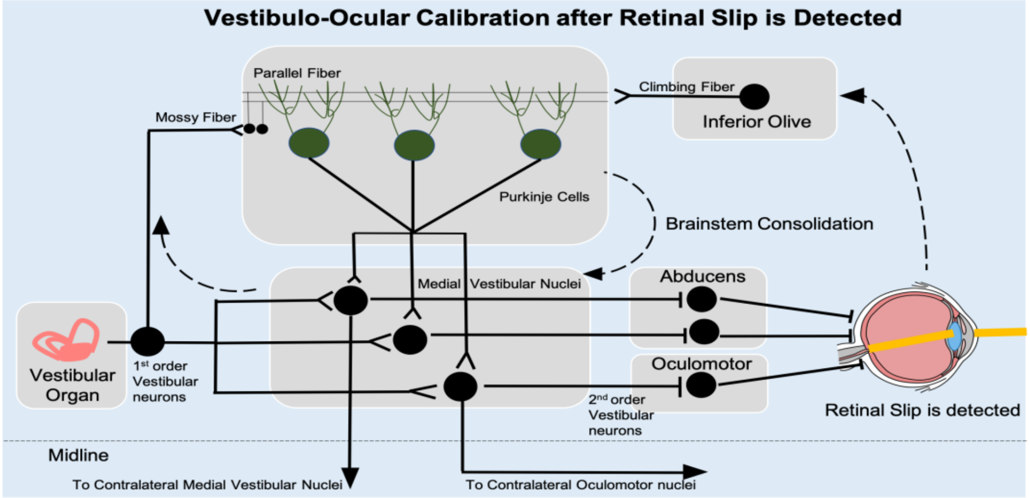


Figure 4

Schematic of the Vestibulo-Ocular Calibration Process. After Retinal Slip is Detected, the Signal Travels to the Inferior Olivary Nucleus, the Vestibulo-Cerebellum, and to the Vestibular Nucleus Which Then Alters the Response to Vestibular Input. Vestbulo-Ocular Re-calibration is a Gradual and Adaptive Process.



Methods

Hardware

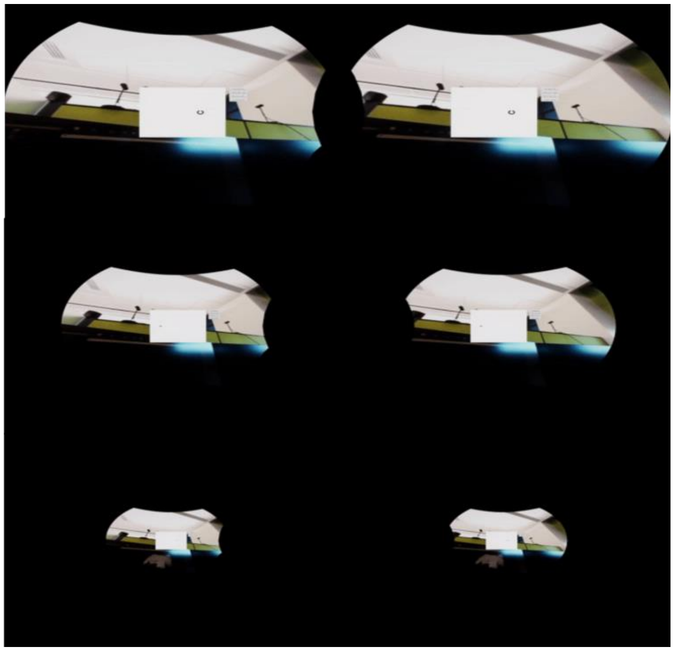
The HTC Vive Pro head-mounted display (HMD) was used to implement the minified augmented reality lenses. The HMD has two 3.5-inch diagonal dual active-matrix light emitting diodes (AMOLED) screens with a resolution of 615 pixels per inch, and 90 Hz refresh rate. The minified augmented reality effect was built using Unreal Engine 4 (version 4.27; Tavakkoli, 2018) and the augmented reality experience was established with SteamVR (Steam, 2023). The minifying effect was adjusted to 4 different levels: 30% smaller, 50% smaller, 70% smaller and 80% smaller; and DVA was individually measured at each level of minimization. Although minifying lenses have previously been used in studies to help induce a state of vestibulo-ocular dysfunction, this has previously never been tested in an augmented reality setting.

Assessment Design

The study protocol received University of Nevada Institutional Review Board (IRB) approval and conformed with the Declaration of Helsinki. Informed consent was received from all subjects prior to participation. Healthy subjects in our study wore minifying lenses to simulate the decreased DVA associated with g-transitions. We tested the impacts of minifying lenses on DVA in a stepwise manner, gradually increasing the level of minimization (Figure 5). DVA was measured binocularly with a head-mounted augmented reality HMD and Landolt C optotypes. The orientation of the gap in the "C" optotype may be in eight different directions, and the observer must visualize the correct location of the gap and respond appropriately using numpad keys. If the response is correct, the optotype size is then decreased in a logarithmic manner. Alternatively, the optotype size will increase if an incorrect response is chosen. To reduce the risks of potential confounding variables, the tests were performed in the same session, on the same day.

Figure 5

Modeled Approach to Detect Changes in DVA in Healthy Individuals on Earth, Simulate Decreased DVA, and Assessment with the Stroboscopic Augmented Reality (Top). Integration of Approach for Astronauts Undergoing Gravitational Transitions for Future Interplanetary Spaceflight



Results

Demographics

A total of 5 participants were enrolled in our trial. Background history was taken to ensure patients had no factors (such as vestibular disorders, vertigo, ocular history, etc.) that would impact DVA measurements. Participant demographics are presented in Table 1. There was a 4:1 male to female ratio.

Table 1

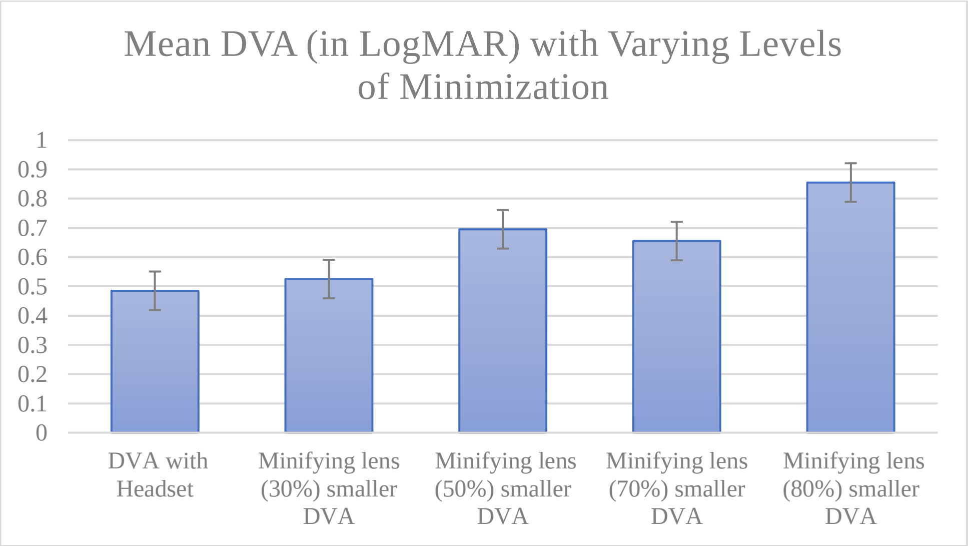
Participant Demographics

Characteristic	Participant
Age (years)	26.4 ± 1.5
Gender Male Female	 4 1
Ocular History	None
Best Correctable Visual Acuity	20/20
History of Seizures or Vertigo	None
Previous Balancing or Neurological Disorders	None

DVA of the participants was measured in augmented reality in LogMAR with varying levels of minimization (Figure 6). Data was plotted graphically in Figure 6 using Excel version 16.44 (Microsoft). Levels of minimization varied from none, 30%, 50%, 70%, and 80% and the associated mean DVA was 0.485, 0.525, 0.695, 0.655 and 0.855 respectively. Mean DVA tended to decrease as the levels of minimization increased. A mean decrease in DVA (0.370 LogMAR) was noted with the 80% minifying effect, indicating that minified augmented reality can successfully decrease DVA and be used to simulate G-transitions terrestrially.

Figure 6

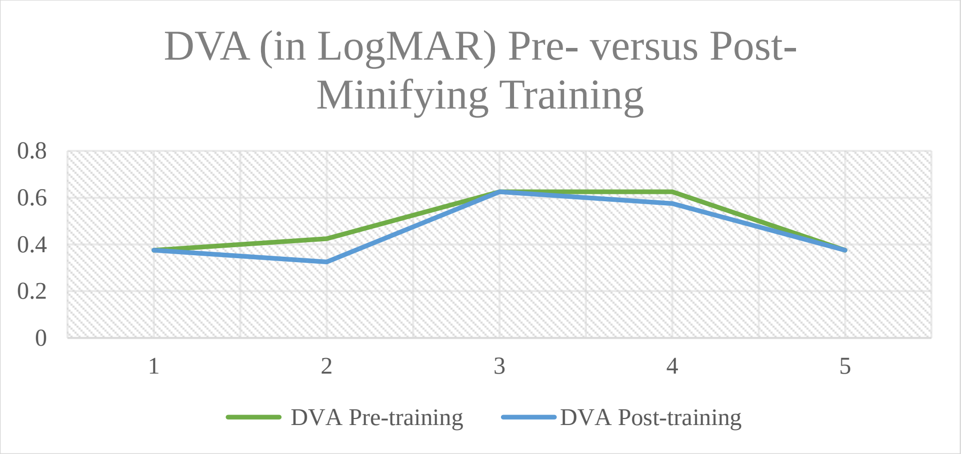
DVA with Different Levels of Minimization. As the Level of Minimization Increases, the DVA Also Tends to Decrease (n=5).



DVA in augmented reality was measured prior to training, and after training (Figure 7). Pre-training DVA of the participants was 0.375, 0.425, 0.625, 0.625, 0.375, while post-training DVA was 0.375, 0.325, 0.625, 0.575, 0.375 respectively. Following the minifying protocol, the mean DVA of the participants tended to increase, with a mean increase of 0.030 LogMAR. This increase in DVA indicates that minifying training can be a potential countermeasure to improve DVA during G-transitions.

Figure 7

DVA was Measured Pre- and Post-minifying Training and was Shown to Increase Following Minifying Training (n=5)



Discussion

A planned journey to Mars (anticipated in 2034) is expected to last 1.5 years. Significant sensorimotor and vestibulo-ocular adaptations will occur during this prolonged exposure to a microgravity environment, leading to an increased physiological response when landing on Mars and when returning to Earth. For this reason, NASA’s Human Research Program suggested that countermeasures be developed to mitigate these effects on astronauts for Lunar and Mars planetary flights (NASA HRP, 2022). We believe that our minified augmented reality will serve as a useful tool to help simulate the decreased DVA resulting from these g-transitions. In addition, astronauts are at risk for spaceflight associated neuro-ocular syndrome (SANS), which is a collection of neuro-ophthalmic imaging and clinical findings observed in astronauts following LDSF missions including optic disc edema, hyperopic shift, and choroidal folds (Ong, Tavakkoli, Strangman, et al., 2020). Therefore, preserving an astronaut’s functional vision is of utmost importance for future missions, such as the mission to Mars.

Current studies on minifying lenses are limited. The only previous study conducted with minifying lenses used 0.5x lenses to help simulate DVA decrements experienced by an astronaut returning to Earth (Rosenberg et al., 2017). This study was conducted on a group of 20 subjects, and found that DVA was decreased 31.5% while wearing the 0.5 minifying lenses, which is similar to the decrease seen in our study.

To our knowledge this paper was the first to show that minifying training can be used to increase DVA. The minifying training may perform akin to how high-altitude training increases endurance, where the increased difficulties facing DVA in minified augmented reality may drive visual-cognitive processes to improve. Astronauts training in minified augmented reality may be able to significantly increase mission performance, specifically during G-transitions. A primary limitation to this study was the small sample size of this early validation study. Although our study had a relatively small sample size of 5 participants, we plan to conduct larger studies in the near future examining the effects of minified augmented reality on DVA and on skill-specific tasks. Future studies will employ comparative statistics to assess for statistical significance, which was not performed in this paper to the nature of this early validation study. Future studies will also assess the effect of duration of minified augmented reality on DVA.

Currently stroboscopic visual training is the gold-standard method to increase DVA, and it has previously been used by companies such as Nike (Nike Inc. ©) to improve athletic performance (Holliday, 2013). Stroboscopic lighting produces discontinuous vision, which is believed to increase DVA through increased kinaesthetic awareness, and increased efficiency after receiving less visual samples (Wilkins et al., 2018). However stroboscopic visual training at higher frequencies may potentially cause seizures in individuals with photosensitive epilepsy, thus its usage with higher strobe frequencies is cautioned.

Beyond the use of minification for simulating decreased DVA in spaceflight, minified augmented reality has terrestrial implications for better understanding how vestibular disorders can impact vision. The development of a reliable method to simulate vestibular dysfunction, could allow vestibular dysfunction studies to be performed on normal, healthy subjects which would help reduce the recruitment challenges for these studies. In addition to this, having the ability to decrease DVA in studies without affecting other variables can potentially lead to a better understanding of vestibulo-ocular dysfunction and vestibulo-ocular disorders.

Conclusions

This is the first proposed augmented reality application of minifying lenses as a possible method to simulate vestibulo-ocular impairments that occur during G-transitions. This was also the first paper showing that minified augmented reality training can increase DVA. With its intuitive ease of use, minified augmented reality can be key a component of future astronaut training programs. To fully investigate the ability of minified augmented reality as an astronaut training tool, we must first find: the level of minimization that will cause the same magnitude of visual impairments when landing on Mars or the Moon, determine the length of time required for individuals to adapt to the minified environment, and determine the effectiveness of minified augmented reality to further understand other vestibulo-ocular disorders. Minified augmented reality may have important terrestrial implications in pilot training, vestibulo-ocular rehabilitation and understanding patient perception of vestibular disease.

References

Carcaud, J., França de Barros, F., Idoux, E., Eugène, D., Reveret, L., Moore, L. E., Vidal, P., & Beraneck, M. (2017). Long-lasting visuo-vestibular mismatch in freely-behaving mice reduces the vestibulo-ocular reflex and leads to neural changes in the direct vestibular pathway. *eNeuro*, *4*(1). doi:10.1523/ENEURO.0290-16.2017

Clément, G. R., Boyle, R. D., George, K. A., Nelson, G. A., Reschke, M. F., Williams, T. J., & Paloskiet, W. H. (2020). Challenges to the central nervous system during human spaceflight missions to Mars. *Journal of Neurophysiology*, *123*(5), 2037-2063. doi:10.1152/jn.00476.2019

Crawford, J. D., & Vilis, T. (1991). Axes of eye rotation and Listing's law during rotations of the head. *J Neurophysiol*, *65*(3), 407-423. doi:10.1152/jn.1991.65.3.407

Holliday, J. (2013). *Effect of stroboscopic vision training on dynamic visual acuity scores: Nike Vapor Strobe® Eyewear*. Utah State University.

NASA HRP. (2022). *Risk of altered sensorimotor/vestibular function impacting critical mission tasks*. https://humanresearchroadmap.nasa.gov/risks/risk.aspx?i=88

Ong, J., Tavakkoli, A., Strangman, G., Zaman, N., Kamran, S. A., Zhang, Q., Ivkovic, V., & Lee, A. G. (2022). Neuro-ophthalmic imaging and visual assessment technology for spaceflight associated neuro-ocular syndrome (SANS). *Surv Ophthalmol*. doi:10.1016/j.survophthal.2022.04.004

Ong J, Tavakkoli, A., Zaman, N., Kamran, S. A., Waisberg, E., Gautam, N., & Lee, A. G. (2022). Terrestrial health applications of visual assessment technology and machine learning in spaceflight associated neuro-ocular syndrome. *npj Microgravity*, *8*(1), 37. doi:10.1038/s41526-022-00222-7

Ong, J., Zaman, N., Kamran, S. A., Waisberg, E., Tavakkoli, A., Lee, A., & Webster, M. (2022). A multi-modal visual assessment system for monitoring spaceflight associated neuro-ocular syndrome (SANS) during long duration spaceflight. *Journal of Vision*, *22*(3), 6. doi:10.1167/jov.22.3.6

Ong, J., Zaman, N., Waisberg, E., Kamran, S. A., Lee, A. G., & Tavakkoli, A. (2022). Head-mounted digital metamorphopsia suppression as a countermeasure for macular-related visual distortions for prolonged spaceflight missions and terrestrial health. *Wearable Technol*, *3*, e26. doi:10.1017/wtc.2022.21

Peters, B. T., Miller, C. A., Brady, R. A., Richards, J. T., Mulavara, A. P., & Bloomberg, J. J. (2011). Dynamic visual acuity during walking after long-duration spaceflight. *Aviat Space Environ Med*, *82*(4), 463-466. doi:10.3357/ASEM.2928.2011

Ramaioli, C., Cuturi, L. F., Ramat, S., Lehnen, N., MacNeilage, P. R. (2019). Vestibulo-ocular responses and dynamic visual acuity during horizontal rotation and translation. *Front Neurol, 10*, 321. doi:10.3389/fneur.2019.00321

Rosenberg, M. J. F., Kreutzberg, G. A., Peters, B. T., & Reschke, M. F. (2017). Stroboscopic goggles as a countermeasure for dynamic visual acuity and landing sickness in crewmembers returning from long-duration spaceflight. https://ntrs.nasa.gov/api/citations/20160013635/downloads/20160013635.pdf

Sehizadeh, M. (2005). *Monocular adaptation of vestibulo-ocular reflex (VOR)*. University of Waterloo.

Steam. (2023). *Steam VR*. Accessed August 30, 2022. https://store.steampowered.com/app/250820/SteamVR/

Tavakkoli A. (2018). *Game development and simulation with unreal technology* (2nd ed.). Taylor and Francis.

Waisberg, E., Ong, J., Paladugu, P., Kamran, S. A., Zaman, N., Tavakkoli, A., & Lee, A. G. (2022). Advances in machine learning to detect preventable causes of blindness. *Eye*. doi:10.1038/s41433-022-02354-2

Waisberg, E., Ong, J., Paladugu, P., Zaman, N., Kamran, S. A., Lee, A., & Tavakkoli, A. (2022). Optimizing screening for preventable blindness with head-mounted visual assessment technology. *Journal of Visual Impairment & Blindness*, *116*(4), 579-581. doi:10.1177/0145482X221124186

Waisberg, E., Ong, J., Paladugu, P., Kamran, S. A., Zaman, N., Lee, A. G., & Tavakkoli, A. (in progress). Dynamic visual acuity as a biometric for astronaut performance and safety. *Life Sciences in Space Research*, 37, 3-6. doi:10.1016/j.lssr.2023.01.002

Waisberg, E., Ong, J., Zaman, N., Kamran, S. A., Lee, A. G., & Tavakkoli, A. (2022a). Stroboscopic augmented reality as an approach to mitigate gravitational transition effects during interplanetary spaceflight. *International Journal of Aviation, Aeronautics, and Aerospace, 9*(4). https://commons.erau.edu/ijaaa/vol9/iss4/6

Waisberg, E., Ong, J., Zaman, N., Kamran, S. A., Lee, A. G., & Tavakkoli, A. (2022b). Head-mounted dynamic visual acuity for G-transition effects during interplanetary spaceflight: Technology development and results from an early validation study. *Aerosp Med Hum Perform*, *93*(11), 800-805. doi:10.3357/AMHP.6092.2022

Wilkins, L., & Nelson, C., Tweddle, S., (2018).Stroboscopic visual training: A pilot study with three elite youth football goalkeepers. *Journal of Cognitive Enhancement*, *2*(1), 3-11. doi:10.1007/s41465-017-0038-z