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Addressing Empty Space Myopia to Enable Deep Space Travel with Extended Reality Auditory Biofeedback

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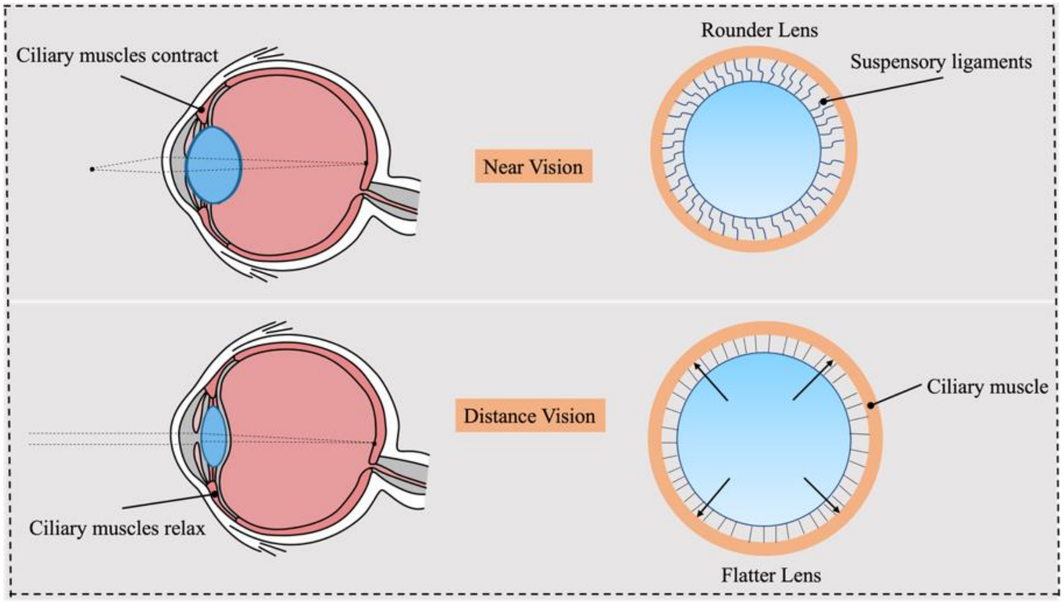
Visual accommodation refers to one's ability to adapt vision to varying distances. Empty space myopia is a phenomenon that has been observed in pilots when flying out in the open skies at high altitudes when there is no specific object to focus on in an empty sky, and the eye chooses to focus only a few meters ahead rather than at infinity (Brown, 1957). The focal point then constantly changes, and visual acuity is decreased significantly leading to issues with detecting incoming objects of interest and difficulty with determination of the size of these objects (Brown, 1957). During long-duration spaceflight (LDSF) astronauts are at risk of developing empty space myopia because of the vast darkness of space, which lacks nearby objects to focus on for the majority of the time. The occurrence of empty space myopia could lead astronauts to have a slower recognition time to recognize space debris, satellites, and incoming celestial bodies, posing significant dangers to the space crew. An additional hazard encountered when looking at a featureless dark sky is that saccadic eye movement occurs. Saccadic eye movement has been shown to leave significant gaps in distance vision as well as significantly decrease visual acuity (Schallhorn, 1990).

The accommodation response (also known as the near triad) is a three-part reflex involving convergence (the inward rotation of eyes), miosis (pupillary constriction) and accommodation (ciliary muscle contraction leading to lens thickening) (Fisch, 2015). The inward rotation of the eyes (convergence) involves impulses from the oculomotor nuclei leading to medial recti muscle contraction, turning the eyes inward. Pupillary constriction involves both the parasympathetic and sympathetic nervous systems which act on the sphincter pupillae muscles. The increased convexity of the lens is controlled by the Edinger-Westphal nucleus and is further explained in Figure 1.

Figure 1

Schematic of Ciliary Muscle Action in the Accommodation Reflex

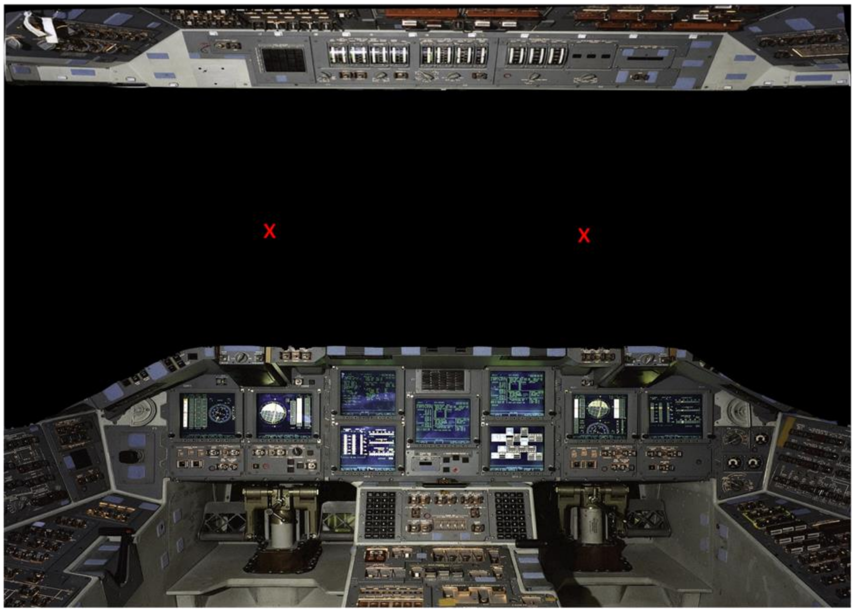


Note. For near vision, the ciliary muscle contracts, which relaxes the suspensory ligaments (zonules), allowing the lens to become rounder, increasing its focal power. Distance vision involves relaxation of the ciliary muscle, which tightens the zonules, causing a flattening of the lens.

This work is a component of our NASA-funded endeavour to monitor and uphold astronaut vision during LDSF (Ong, Tavakkoli, et al., 2022; Ong, Zaman, Kamran, et al., 2022). Currently spaceflight associated neuro-ocular syndrome (SANS) is considered to be the greatest ocular risk during long-duration spaceflight, and its pathophysiology is not yet fully understood (Masalkhi et al., 2023a; Soares et al., 2024; Waisberg, Ong, Masalkhi, Mao, et al., 2024; Waisberg, Ong, Masalkhi, & Lee, 2023). Other components of our related research include developing visual assessments that can be performed in space, as well as developing countermeasures to improve astronaut vision (Ong, Zaman, Waisberg, et al.,2022; Waisberg, Ong, Zaman, et al., 2022), and detecting structural vision changes (Kamran et al., 2024; Masalkhi et al, 2023b; Ong, Waisberg, Masalkhi, Kamran, et al., 2023; Waisberg, Ong, Kamran, et al., 2023).

To combat empty space myopia in pilots, current recommendations are to establish a long-range focal point by focusing on terrain near the horizon, flying outside of smoke or hazy conditions, and focusing on aircraft wing tips in conditions of low visibility to provide additional visual stimulation (Skybrary. (n.d.). However, these tips do not translate well for space travellers in LDSF. One previous suggested countermeasure for this phenomenon in space was to use optical projections outside of the spacecraft windows, to provide astronauts with an opportunity to vary their focal length and focus close to infinity (Skyline, (1963). This would allow astronauts to be prepared for distance vision to ensure anything incoming towards the spacecraft can be focused on, and identified, immediately.

Figure 2
Darkness During Long-Duration Spaceflight



Note. An astronaut during long-duration spaceflight will encounter vast regions of darkness while looking outside of the spacecraft. The astronaut's vision will then focus only a few meters ahead, impairing distance vision. In addition, judging the size and distance of nearby objects such as the "red X" markings becomes challenging with no reference objects for scale.

Research to combat empty space myopia led to the creation of the first automatic optometer (autorefractor) to objectively measure the refractive power of the eye (Cornsweet & Crane, 1970). A follow-up study by Cornsweet and Crane (1973) was consistent with these results. Subjects were given binaural headphones, with the pitch of one ear being controlled by an autorefractor output (the subject's accommodation level), and the other ear by a knob given to the observer. The subjects were instructed to turn the knob and to change their visual accommodation to attempt to match both of the pitches. After a training period of 3 hours, all of the subjects were able to volitionally change their visual accommodation to match the tones (Cornsweet & Crane, 1973). These results are also interesting as they demonstrate that controlling visual accommodation through artificial feedback requires significantly more time than when the feedback is natural (such as a visual blur). Following this, experiments at NASA Ames Research Laboratory by Randle (1988) found that through training, it was possible to gain volitional control of accommodation.

Benefits of Extended Reality

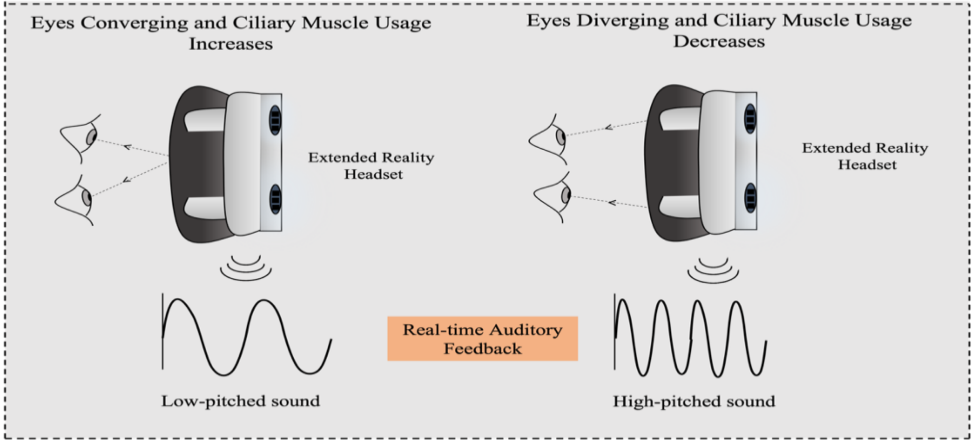
The advent of extended reality technology has revolutionized how vision can be accessed (Sarker, 2023; Woodland et al., 2023; Zaman, 2023.) Particularly when applying this technology to empty space myopia, there are various strengths to help uphold astronaut accommodation. Extended reality allows for users to continue viewing the external environment through an LED screen. This will be a critical aspect as astronauts can continue to work on tasks onboard the spacecraft while training their accommodation. Eye-tracking technology was used to determine how an individual navigates the simulated aerospace environment and determine which aspects they are focusing on. Foveated rendering was used to reduce the necessary rendering workload.

Extended Reality Biofeedback Design

Our extended reality framework was built in UnrealEngine 4.24 (Epic Games, MD, USA). The UnrealEngine plugin "SRanipal" was used to assess the accuracy of eye tracking. The HTC Vive Pro Eye system (615 pixels per inch, 110° field of view) was used to experience the extended reality content. With eye tracking technology, differing auditory feedback was provided based on the location of gaze focus (Figure 3). We also developed an extended reality flight simulator, to provide a realistic simulation of the experience of a pilot (Figure 4). The red dot shows the location of gaze focus, and additional auditory feedback is provided when gaze is focused on a nearby plane.

Figure 3

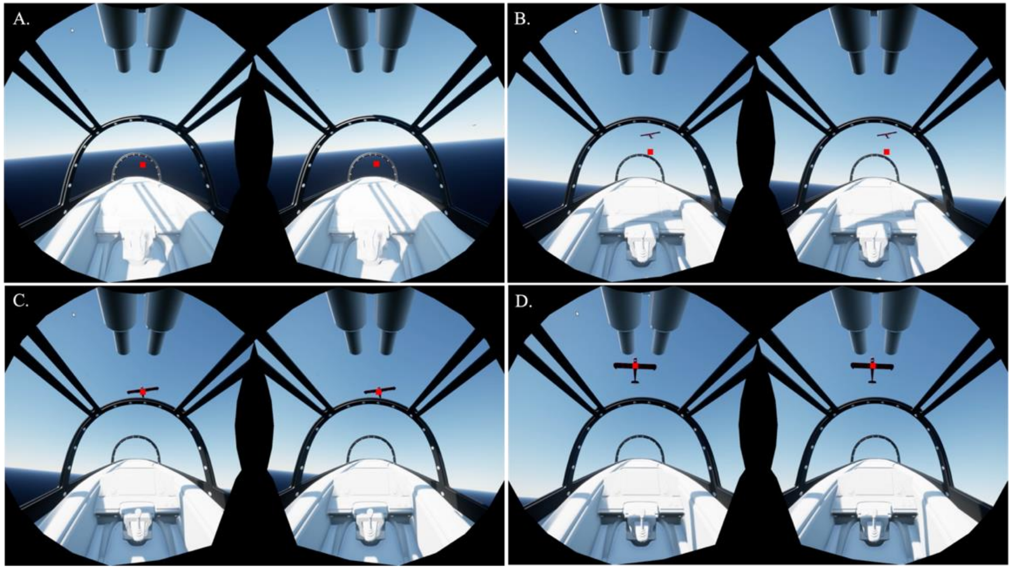
Schematic of our Extended Reality Framework



Note. Eye detection is used to track eye convergence and eye divergence and real-time auditory feedback is played in real time.

Figure 4

Virtual Reality Simulation of a Dynamic Aerospace Environment



Note. The red dot is generated based off eye tracking technology and shows where the participant gaze is focused. **4A.** When gazing into a featureless sky, the focal point is only a few meters ahead (empty space myopia is induced). **4B.** Detection of an approaching airplane is delayed due to this state of empty space myopia. **4C.** Participant gaze is focused on the plane. With no other features in the sky, the direction that the plane is travelling is not yet determined. 4D. Gaze continues to follow the plane, the path of the approaching plane has been determined.

Conclusions

In this paper, we discussed the effects of empty field myopia in space and reported on the novel development of extended reality with auditory biofeedback as a potential astronaut training tool. This area of research remains promising, and further validation studies are required to determine the effectiveness of extended reality-based auditory feedback training to address empty space myopia. Our hope is that this technology development with extended reality for human health in space can be built upon by researchers and engineers who are applying extended reality to uphold astronaut performance and safety.

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