Middle Ground – Field of View for Future Helmet Mounted Displays

Siddharth Shyamsundar

BAE Systems Operations Limited, United Kingdom

SUMMARY

Drawing on research spanning multiple decades, different platforms and use cases, this literature review provides an in-depth overview of Field of View (FOV) in fixed wing military aviation Helmet Mounted Displays (HMDs), focusing on its human factors (HF) and performance implications. Expanding on the capabilities of human vision, it highlights how FOV and human vision are interlinked and why the current fixed wing HMD FOV standard is inadequate, failing to leverage the far-reaching capabilities of the human eye. This paper delves into both the preeminent FOV perspectives – the “as small as possible” and the “bigger the better” approaches, and identifies a “middle ground” of horizontal FOVs between 60° and 90°, where the benefits of wide FOV HMDs are at their most advantageous. Using this as a starting point, this study calls for the development of a wide FOV HMD for fixed wing military aircraft to include empirical HF research using appropriate use cases while accounting for platform and sensor capabilities and mission sets.

KEYWORDS

Helmet Mounted Displays, Field of View, Pilot Performance

Introduction

In military aviation, a key function of augmented reality (AR) devices like helmet mounted displays (HMDs) is to overlay virtual information over the real world. Virtual symbology and imagery showing flight parameters and sensor information are displayed on a see-through visor. The pilot can attend to this information while still looking into the outside world through the visor.

For an HMD, the field of view (FOV) refers to the maximum angular size that the virtual image can occupy on the visor (Melzer, 2017). Virtual information is presented within this FOV, beyond which the pilot sees just the outside world, but with no virtual content overlaid on it. FOV is sometimes defined horizontally (HFOV), vertically (VFOV), circularly or diagonally (Melzer, 2017). In modern day military aviation HMDs, the FOV occupies only a limited proportion of the entire visor. This is due to technological constraints associated with conventional optics, whereby increasing FOV results in higher mass, lower resolution and challenging optical requirements for image processing. However, techniques using binocular overlap, optical tiling and dichoptic area of interest can address this issue (Browne et al., 2011; Hoppe & Melzer, 1999; Melzer, 1998, 2017).

The Human Eye and FOV

FOVs of fixed wing military aviation HMDs haven’t significantly increased over time. Even on cutting edge, modern 4th and 5th generation aircraft like the Eurofighter Typhoon and the Lockheed Martin F-35, the HMD’s HFOVs are capped at 40° (BAE Systems, 2023; Collins Aerospace, 2023).

In comparison to the FOV of the human eye, an HMD's FOV highlights how little of the human visual system is currently being leveraged. Research indicates that the human eye's FOV ranges from 180° x 125° to over 210° x 150° (Arthur, 2000; Canon, 1986; Trepkowski et al., 2019). Human binocular vision covers 114° to 120° of horizontal vision and 50° above and 75° below the vertical axis of our line of sight (Deering 1998; Howard and Rogers, 1995). Clearly, with current capability on fixed wing fighters, only about a fifth of the human visual field is being augmented.

It is also essential to consider eye movements. Research reports that when looking straight ahead, 95% of all eye movements are within +/- 20° of the centre (Foulsham et al., 2011; Stahl, 1999; Tobii, 2021). When attending to a stimulus, the eyes will move first, followed by the head. Typically, viewing anything beyond 20° involves some head movement. However, in military aviation, head movement may be difficult or even dangerous. A recent NATO (2020) study found that a major proportion of fixed wing aviators suffered from neck pain and injuries, exacerbated partly by the use of HMDs in high-G_z manoeuvres. With head and helmet mass multiplying with the G_z, head/neck movement could potentially cause or worsen neck injuries. Consequently, rather than moving their heads, pilots use eye movements more frequently and to greater extremes than the average individual. A wide FOV HMD can leverage such eye movements and reduce neck strain by presenting more information across a larger area, allowing pilots to attend to it without moving their head or neck (aided by the use of an eye tracker serving as an effective human machine interface). A higher level of eye movement, however, could cause increased eye strain (Melzer, 2017), potentially resulting in increased workload, reduced performance and higher risk to ocular health.

Within the FOV of the human eye, there are differences in sensitivity and acuity, affecting how much and how well we see at different angles. Central vision consists of the fovea (up to 5.2°), parafovea (5° – 9°) and perifovia (9° – 17°), all collectively referred to as the macula. Beyond this, areas of the eye contribute to peripheral vision, composed of the near-, mid- and far – peripheral zones (Wandell, 1995). Deering (1998) suggests that text recognition can extend to 20° of vision, symbol recognition to 40°, colour detection to 60°, and motion to over 120°. Lou et al. (2012) indicated that peripheral vision is more sensitive to shape and colour discrimination, especially for green and brown. Motion detection and velocity discrimination are as precise in the periphery as they are in central vision, both helping to direct the eye in search tasks (McKee & Nakayama, 1984; Torralba et al., 2006). Current HMDs, with a maximum HFOV of 40°, exploit very little of the peripheral visual system, limiting opportunities for enhanced search, track and motion detection.

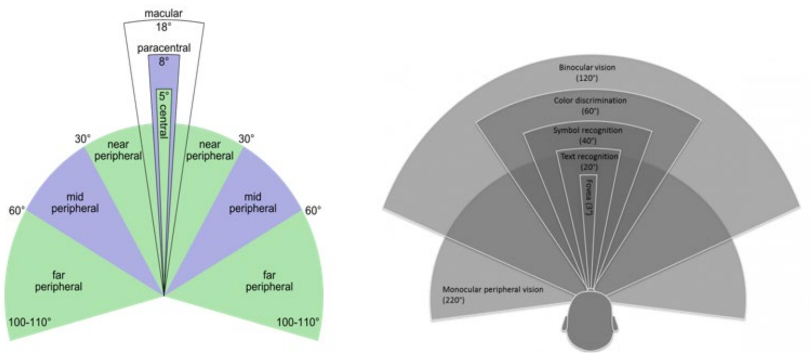

Figure 1: Regions of Human Vision and their abilities (Deering, 1998)

The eye has two visual modes. The focal mode uses the macula and answers the "what". The ambient mode uses peripheral vision with some overlap with the macula, and is aimed at answering the "where". Working with the vestibular system, the ambient mode aids spatial orientation and is sensitive to movement and flicker (Leibowitz et al., 1985; Wickens, 2002). The ambient mode is thought to be "pre-attentive" or automated, requiring negligible cognitive resources. Using an HMD with an FOV wide enough to engage this mode can improve situational awareness (SA) and prevent attentional tunnelling without increasing workload (Melzer, 2017; Uhlarik & Comerford, 2002).

Along with the proprioceptive (awareness of the body's movement and position) and vestibular systems, visual cues play a very vital role in posture, balance, orientation and detection of self-motion. In fact, visual cues can sometimes override conflicting inputs from the other two systems (Allison et al., 1999; Hansson et al., 2010; Streepey et al., 2007; Warren and Kurtz, 1992). However, visual cues are limited by the size of the HMD, especially when using synthetic vision systems, and their limited presence in narrow FOV fixed wing HMDs could cause illusions and spatial disorientation (Melzer, 2017). A wide FOV HMD can help provide more visual cues to pilots, enhancing SA, reducing spatial disorientation and improving performance and safety.

FOV in Military Aviation HMDs and Pilot Performance

"The Bigger, the Better" approach

This approach calls for the widest possible FOV for an HMD. Studies endorsing this highlight how narrow FOVs negatively impact spatial orientation, navigation, heading perception, distance estimation and flying performance across several scenarios (Alfano & Michel, 1990; Arthur, 2000; Dolezal, 1982; Covelli et al., 2010; Richman et al., 1998; Rogers et al., 2001). Wells et al. (1989) assessed the impact of FOV on locating targets in a simulated air-to-air exercise, concluding that narrower FOVs severely constrained task performance. A study by Brickner and Foyle (1990) presented a sensor image of a simulated slalom course for helicopter pilots to fly through. The sensor image was presented in three FOVs – 25° x 19°, 40° x 30° and 55° x 41°, with navigational and flying accuracy being significantly higher in the widest FOV. Pilots using narrow FOV helmets exhibit increased head movement and velocity, significantly exacerbating workload and increasing the risk of injury (Covelli et al., 2010; Rogers et al., 2001; Verturino and Wells, 1990).

Wider FOV HMDs can improve SA, enable faster target search and acquisition, reduce clutter and provide more area for added information (Piantanida et al., 1992; Rogers & Asbury, 1999; Rogers et al., 1996). With better organisation of data and reduced information density in the central area, wider FOV HMDs provide more user comfort (Chevaldonne et al., 2006; Kishishita et al., 2014) and could reduce eye strain. FOVs up to 114° and 160° have been shown to aid pilot performance in tasks involving bomb delivery and descending turns (Dixon et al., 1989; Kraft et al., 1982). FOVs up to 140° provide more visual cues, improve balance and stability, increase presence and immersion and reduce spatial disorientation. Wider FOVs also aid performance in piloting tasks that rely on visual information to gauge distance and motion, like low level flying (Duh et al., 2001; Foyle et al., 1992; Li et al., 2016; Lin et al., 2002; Melzer, 2017). In fact, pilots themselves assert that bigger is better! Blundell and Harris (2023) found that participants believed a wider FOV could improve performance, safety and operational, tactical and spatial SA. They highlighted the value of video imagery and peripheral cueing, both of which could be better leveraged in wide FOV HMDs.

The "As Small as Possible" approach

However, some studies suggest that wide FOV HMDs may not be as impactful. On comparing FOVs of 35°, 54°, 81° and 100°, Kishishita et al. (2014) found that FOV size had very limited impact on response times and mental workload. Regardless of FOV size, pilots using an HMD resort to head movements, called the Opto Kinetic Collic Reflex (OKCR), to align the horizon to their fovea. With head movement still present in form of the OKCR, a wide FOV HMD may not limit head/neck movements to the extent that it is advantageous (Gallimore et al., 1998).

Studies report that narrow FOVs may not impair distance judgement and that wider FOVs could increase the risk of simulator sickness, especially due to latency (Duh et al., 2001; Knapp & Loomis, 2004; Lin et al., 2002). Melzer (2017) makes a case for narrow FOVs, asserting that existing HMDs with FOVs of up to 40° (HFOV or circular) have a proven track record of enhancing pilot performance. Wider FOVs can result in increased HMD mass, which has already contributed to the increasing prevalence of neck injuries among pilots (NATO, 2020). Several studies argue that the added weight, resolution and usability penalties of wide FOV HMDs may negate any advantages they offer (Arthur et al., 2014; Blundell & Harris, 2023; Tran et al., 2018).

Finding the Middle Ground

A cluster of impactful research points towards some middle ground in FOV size and HMD development for fixed wing aircraft. Studies simulating air to air manoeuvring, combat and low level flying report that the improvements wider FOVs bring to flying performance, search and acquisition, discovery rates and workload are observed till 60° - 80° HFOV, after which they tail off and diminish (Chevaldonne et al., 2006; Kasper et al., 1997; Kishishita et al., 2014; Wells et al., 1989). Using FOVs ranging from 20° x 13.5° to 160° x 108°, Covelli et al. (2010) reported that the reductions in head movement were only observed up till the 80° x 54° FOV, beyond which, no significant effects were seen. Wells et al. (1988) found that while target acquisition and response times improved with wider FOVs, there were negligible improvements beyond 90° x 60°.

These results point towards a “middle ground” for fixed wing military HMDs of 60° – 90° HFOV, within which the tactical, operational and human factors (HF) advantages offered by a wider FOV are at their greatest. Beyond this, users can expect to see diminishing benefits or no benefits at all.

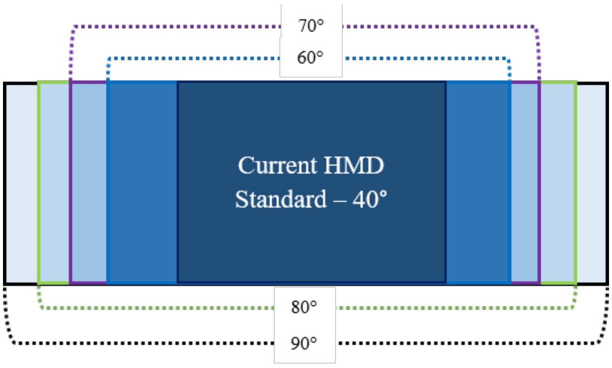

Figure 2: Different HFOVs in the recommended middle ground. The VFOV is held constant at 30°

The Way Forward – HMDs of the Future

Today, HMDs provide a competitive advantage to fixed wing military aviators. However, they only leverage a limited part of human vision, with technological constraints restricting their FOV.

There is overwhelming evidence demonstrating that wide FOV HMDs could increase SA, reduce workload, improve flying performance, help leverage enhanced and synthetic vision systems and provide better user comfort and information management. While some literature does point to limited effects, the majority of it cannot unequivocally assert that the current fixed wing HMD standard is adequate. While reporting the OKCR, Gallimore et al. (1998) also found that head yaw reduced with increasing FOV. While applauding the efficacy of current HMDs, Melzer (2017) admitted that the requirements of future warfare within dense and degraded theatres could call for a wider FOV. Technological advancements like waveguide displays, foveated rendering and dual display HMDs can help overcome issues with mass and resolution that currently restrict FOV size.

Based on an extensive literature review, this paper suggests that it might no longer be a question about the smallest possible or largest attainable FOV. Instead, it posits that the optimum FOV for fixed wing military aircraft HMDs lies between 60° – 90° HFOV. With current capability at 40° HFOV, this represents a significant step change, and any further investigation into fixed wing HMD FOVs should:

- Utilise these findings as a starting point to expedite early research and consider FOVs within 60° – 90° HFOV, where the benefits of wide FOV are at their most advantageous.
- Design and run empirical HF assessments to study the impact of wide FOVs on key HF metrics like SA, workload, task performance, disorientation, and head and neck movement.
- Consider the sensor capabilities, operational requirements and tactical mission sets of the platform for which the HMD is being developed and integrate these into the assessments.
- Leverage the power of commercial off the shelf virtual and extended reality systems to test different FOV sizes and aspect ratios in a relatively easy, rapid and cost effective manner.
- Advocate judiciousness in displaying information across the visor, ensuring that a wide FOV is complemented by information management and an intelligent human machine interface to further minimise workload, drive SA and ensure operator efficacy.
- Approach the HMD from a system-of-systems perspective, noting that its primary role is safety and accounting for risks associated with increasing mass and any resultant injuries.

Conclusion

Fixed wing military aviators are required to perform visually demanding tasks in an information rich, sensor fused environment. The HMD is a key capability enhancer, providing pilots with a competitive advantage. However, it is clear that the current HMD FOV standard in inadequate.

Based on an extensive review of literature across multiple decades, platforms and use cases, this paper recommends that a “middle ground” for fixed wing military aviation HMD FOV development lies between 60° – 90° HFOV. It is here that the benefits of wider FOVs are at their greatest, enabling the pilot and extensively aiding operational and tactical flying. This is a departure from the “as small as possible” and “the bigger the better” perspectives that dominate this field of work.

Given the resource, cost and technological requirements to achieve step changes in FOV size, it is pertinent that further empirical research is conducted to provide a more specific FOV requirement. While determining the FOV for future fixed wing HMDs, it is vital to consider key HF issues around SA, workload, head movement and task performance. It is these, along with a platform’s mission set and sensor capabilities that are at the core of determining optimal HMD FOV.

References

Alfano, P. L., & Michel, G. F. (1990). Restricting the field of view: Perceptual and Performance effects. *Perceptual and Motor Skills*, *70*(1), 35–45. https://doi.org/10.2466/pms.1990.70.1.35

Allison, R. S., Howard, I. P., & Zacher, J. E. (1999). Effect of field size, head motion, and rotational velocity on roll vection and illusory self-tilt in a tumbling room. *Perception*, 28(3), 299–306.

Arthur, J. J., Prinzel, L. J., Barnes, J. R., Williams, S. P., Jones, D. R., Harrison, S. J., & Bailey, R. E. (2014). Performance comparison between a head-worn display system and a head-up display for low visibility commercial operations. *SPIE Proceedings.*

Arthur, K. (2000). Effects of field of view on performance with head-mounted displays. University of North Carolina at Chapel Hill.

BAE Systems. (2023). Striker® II Digital Helmet-Mounted Display. https://www.baesystems.com/en-uk/product/striker-ii-digital-helmet-mounted-display

Blundell, J., & Harris, D. (2023). Designing augmented reality for future commercial aviation: A user-requirement analysis with commercial aviation pilots. *Virtual Reality*.

Brickner, M. S., & Foyle, D. C. (1990). Field of view effects on a simulated flight task with head-down and head-up sensor imagery displays. *Proceedings of the Human Factors Society Annual Meeting*, 34(19), 1567–1571. https://doi.org/10.1177/154193129003401931

Browne, M. P., Moffitt, K., Hopper, D. G., & Fath, B. (2011). Preliminary experimental results from a Dichoptic Vision System (DiVS). *SPIE Proceedings*.

Cannon, M. W. (1986). Recent advances in understanding peripheral vision. *Proceedings of the Human Factors Society Annual Meeting*, 30(6), 601–603.

Chevaldonné, M. (2006). Field-of-view tests for a virtual cockpit application. *Journal of Electronic Imaging*, 15(2), 020501. https://doi.org/10.1117/1.2189211

Collins Aerospace. (2023). F-35 Gen III helmet mounted display system. https://www.collinsaerospace.com/what-we-do/industries/military-and-defense/displays-and-controls/airborne/helmet-mounted-displays/f-35-gen-iii-helmet-mounted-display-system

Covelli, J. M., Rolland, J. P., Proctor, M., Kincaid, J. P., & Hancock, P. A. (2010). Field of view effects on pilot performance in Flight. *The International Journal of Aviation Psychology*, 20(2), 197–219. https://doi.org/10.1080/10508411003617888

Deering, M. (1998). The Limits of Human Vision. *2nd International Immersive Projection Technology Workshop.*

Dixon, K.W., Martin, E.L., & Krueger, G. M. (1989). The effect of stationary and head-driven field of view sizes on pop-up weapons delivery. *Proceedings of the 11th Interservice/Industry Training Systems Conference*, 137-140

Dolezal, H. (1982). Living in a world transformed: perceptual and performatory adaptation to visual distortion. New York, NY: Academic Press.

Duh, H. B.-L., Lin, J. W., Kenyon, R. V., Parker, D. E., & Furness, T. A. (2001). Effects of field of view on balance in an immersive environment. *Proceedings IEEE Virtual Reality 2001.*

Foulsham, T., Walker, E., & Kingstone, A. (2011). The where, what and when of gaze allocation in the lab and the natural environment. *Vision Research*, 51(17), 1920–1931.

Foyle, D., Kaiser, M., & Johnson, W. W. (1992). Visual cues in low-level flight: Implications for pilotage, training, simulation, and enhanced/synthetic vision systems. *American Helicopter Society 48th Annual Forum,* 1, 253–260.

Gallimore, J. J., Brannon, N. G., & Patterson, F. R. (1998). The effects of field-of-view on pilot head movement during low level flight. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 42(1), 6–10. https://doi.org/10.1177/154193129804200103

Hansson, E. E., Beckman, A., & Håkansson, A. (2010). Effect of vision, proprioception, and the position of the vestibular organ on postural sway. *Acta Oto-Laryngologica*, 130(12)

Hoppe, M., & Melzer, J. E. (1999). Optical tiling for wide-field-of-view head-mounted displays. *SPIE Proceedings*. https://doi.org/10.1117/12.368204

Howard, I. P., & Rogers, B. J. (1995). Binocular vision and stereopsis. Oxford university press.

Kasper, E. F., Haworth, L. A., Szoboszlay, Z. P., King, R. D., & Halmos, Z. L. (1997). Effects of in-flight field of view restriction on rotorcraft pilot head movement. *SPIE Proceedings.*

Kishishita, N., Kiyokawa, K., Orlosky, J., Mashita, T., Takemura, H., & Kruijff, E. (2014). Analysing the effects of a wide field of view augmented reality display on search performance in divided attention tasks. *2014 IEEE International Symposium on Mixed and Augmented Reality (ISMAR).* https://doi.org/10.1109/ismar.2014.6948425

Knapp, J. M., & Loomis, J. M. (2004). Limited field of view of head-mounted displays is not the cause of distance underestimation in virtual environments. *Presence: Teleoperators and Virtual Environments*, 13(5), 572–577. https://doi.org/10.1162/1054746042545238

Kraft, C. L., Anderson, C. D., & Elworth, C. L. (1982). Peripheral cues and color in visual simulation. *Proceedings of the Human Factors Society Annual Meeting,* 26(10), 906–910.

Leibowitz, H. W., Shupert, C. L., & Post, R. B. (1985). Two modes of visual processing: Implications for spatial orientation. *Emergent Techniques for Assessment of Visual Performance*

Li, B., Nordman, A., Walker, J., & Kuhl, S. A. (2016). The effects of artificially reduced field of view and peripheral frame stimulation on distance judgments in hmds. *Proceedings of the ACM Symposium on Applied Perception*. https://doi.org/10.1145/2931002.2931013

Lin, J. J.-W., Duh, H. B. L., Parker, D. E., Abi-Rached, H., & Furness, T. A. (2002). Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. *Proceedings IEEE Virtual Reality 2002*. https://doi.org/10.1109/vr.2002.996519

Lou, C. I., Migotina, D., Rodrigues, J. P., Semedo, J., Wan, F., Mak, P. U., Mak, P. I., Vai, M. I., Melicio, F., Pereira, J. G., & Rosa, A. (2012). Object recognition test in peripheral vision: A study on the influence of object color, pattern and shape. *Brain Informatics*, 18–26.

Mckee, S. P., & Nakayama, K. (1984). The detection of motion in the peripheral visual field. *Vision Research*, 24(1), 25–32. https://doi.org/10.1016/0042-6989(84)90140-8

Melzer, J. (2017). How much is enough? The human factors of field of view in head-mounted displays. *SPIE Proceedings*. https://doi.org/10.1117/12.2263334

Melzer, J. E. (1998). Overcoming the field-of-view/resolution invariant in head-mounted displays. *SPIE Proceedings*. https://doi.org/10.1117/12.317441

NATO. (2020). Aircrew Neck Pain Prevention and Management.

Piantanida, T. P., Boman, D. K., Larimer, J. O., Gille, J., & Reed, C. (1992). Studies of the field-of-view/resolution tradeoff in virtual-reality systems. *SPIE Proceedings.*

Richman, J. B., Stanfield, J., & Dyre, B. P. (1998). Small fields of view interfere with perception of heading during active control but not passive viewing. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 42(22), 1545–1549.

Rogers, S. P., & Asbury, C. N. (1999). Development of a flight simulator and an intelligent symbology management system for helmet mounted displays in rotorcraft. *Anacapa Sciences.*

Rogers, S. P., Asbury, C. N., & Haworth, L. A. (2001). Evaluations of new symbology for wide-field-of-view HMDs. *SPIE Proceedings*. https://doi.org/10.1117/12.437997

Rogers, S. P., Spiker, V. A., & Asbury, C. N. (1996). Development of an intelligent symbology management system for HMDs in rotorcraft. *Anacapa Sciences, Inc.*

Stahl, J. S. (1999). Amplitude of human head movements associated with horizontal saccades. *Experimental Brain Research*, 126(1), 41–54. https://doi.org/10.1007/s002210050715

Streepey, J. W., Kenyon, R. V., & Keshner, E. A. (2007). Field of view and base of support width influence postural responses to visual stimuli during quiet stance. *Gait & Posture*, 25(1)

Tobi. (2021). Visual angles. Tobi. https://vr.tobii.com/sdk/learn/eye-behavior/visual-angles/

Torralba, A., Oliva, A., Castelhano, M. S., & Henderson, J. M. (2006). Contextual guidance of eye movements and attention in real-world scenes: The role of global features in Object Search. *Psychological Review*, 113(4), 766–786. https://doi.org/10.1037/0033-295x.113.4.766

Tran, T. H., Behrend, F., Funning, N., & Arango, A. (2018). Single pilot operations with ar-glasses using Microsoft hololens. *2018 IEEE/AIAA 37th Digital Avionics Systems Conference*

Trepkowski, C., Eibich, D., Maiero, J., Marquardt, A., Kruijff, E., & Feiner, S. (2019). The effect of narrow field of view and information density on visual search performance in augmented reality. *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR*).

Uhlarik, J., & Comerford, D. A. (2002). A review of situation awareness literature relevant to pilot surveillance functions. *PsycEXTRA Dataset*. https://doi.org/10.1037/e426142004-001

Venturino, M., & Wells, M. J. (1990). Head movements as a function of field-of-view size on a helmet-mounted display. *Proceedings of the Human Factors Society Annual Meeting, 34(19),* 1572–1576. https://doi.org/10.1177/154193129003401932

Wandell, B. A. (1995). Foundations of Vision. Sinauer Associates.

Warren, W. H., & Kurtz, K. J. (1992). The role of Central and peripheral vision in perceiving the direction of self-motion. *Perception & Psychophysics*, 51(5), 443–454.

Wells, M. J., Osgood, R. K., & Venturino, M. (1988). Using target replacement performance to measure spatial awareness in a helmet-mounted simulator. *Proceedings of the Human Factors Society Annual Meeting*, 32(19), 1429–1433. https://doi.org/10.1177/154193128803201926

Wells, M. J., Venturino, M., & Osgood, R. K. (1989). The effect of field-of-view size on performance at a simple simulated air-to-air mission. *Helmet-Mounted Displays.*

Wickens, C. D. (2002). Multiple Resources and performance prediction. *Theoretical Issues in Ergonomics Science*, 3(2), 159–177. https://doi.org/10.1080/14639220210123806