Comprehensive Guidelines for Binocular Display Alignment

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A deep and comprehensive understanding of binocular alignment and viewing comfort is critical for developing meaningful specifications and standards for binocular displays. In this brief document, I address conditions representative of binocular displays and associated viewing environments. A research effort based on these ideas would fill in gaps of what alignment parameters are important, as well as correct misperceptions about specifying requirements for binocular alignment and viewing comfort.

Part I of this document describes the linkage of binocular alignment and viewing comfort of the user. Part II provides preliminary viewing-comfort data. My goal is to extend this approach into a formal investigation.

I. The Linkage of Binocular Alignment and Viewing Comfort

Viewing comfort is critical to the success of binocular display systems, and is closely linked to a well-aligned system. Misalignment and the resulting eyestrain and headaches have killed a number of commercial products and delayed several military systems. While we have fragmentary knowledge about what "well-aligned" is, we are not able to place binocular misalignment into any sort of context. We also have gaps in our knowledge concerning image divergence and focus that extend beyond optical infinity, the use of viewing comfort versus diplopia thresholds for designing equipment, and the effect of multiple misalignments.

Early studies (e.g., Duwaer & van den Bring, 1981; Gibson, 1980; Moffitt, 1997; Rash, 1999; Self, 1986; Warren, Genco & Connon, 1984) provide some useful guidelines, but are notably incomplete and use a variety of dependent measures that are difficult to compare. The recent work of Kooi & Lucassen (2001) represents promising methodology for answering critical binocular display questions. These researchers were able to quickly collect ratings of visual discomfort for a large number of display conditions, including several combinations of conditions. This methodology tied these ratings to a lower rating of one—representing an aligned and high-quality reference image. Only a small part of this study investigated binocular displays.

My approach takes a comprehensive look at binocular misalignment. This has the advantage of defining the scope of viewing comfort. One end of a scale of viewing comfort is likely tied to a distant nature scene—similar to Kooi's reference image—while the other end is (implicitly or explicitly) tied to some sort of malicious misalignment. This end-point misalignment is not necessarily a large value—it could be a relatively small amount of vertical offset that is just enough to make the eyes vertically diverge in a stressful effort to achieve image fusion.

I see a need for comprehensive guidelines for symbology imaged against a real-world scene. The most urgent need is for standards for military aviation—a distant scene as viewed through a canopy. A secondary application is the imaging of computer graphics against a nearby object or field—for use in surgical guidance and medical diagnosis.

The outcome of this research would answer the following types of questions:

1. What is the scope or scale of visual comfort for binocular imagery? Are there natural endpoints? How do multiple misalignments (including disparate left/right focus) combine to affect visual comfort? Would multiple dimensions add clarity to this problem?
2. How do binocular misalignments interact with the eyebox and IPD adjustability to affect viewing comfort?
3. Should binocular alignment beyond parallel eyes be specified? The alternative is a range starting at zero and ending at some amount of ocular convergence.
4. Should focus be specified as a tolerance (e.g., 0D plus and minus 1/4 D), or as a range starting at optical infinity and ending at some amount of near focus?
5. Is the perceived intermediate distance of symbology a fundamental limitation of viewing comfort? If so, then the best we can do is achieve some level of acceptable comfort.
6. Given that the misalignment of vergence and focus is inherent in stereo displays, is there also a fundamental limitation of viewing comfort? What is the viewing-comfort advantage versus perceptual disadvantage of limiting binocular disparity (i.e., microstereopsis)?

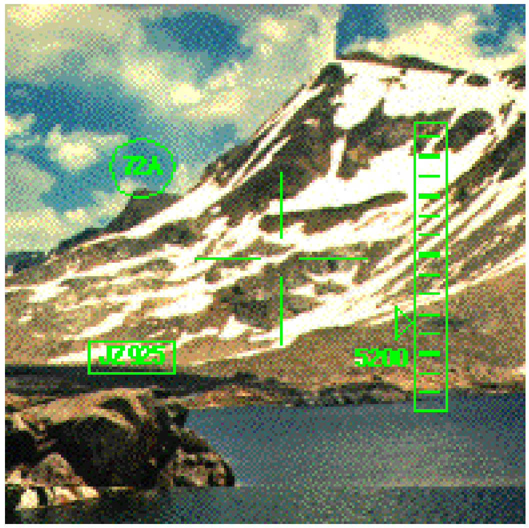
Answers to these questions will allow the designer of binocular imaging systems to prioritize alignment requirements, specify vergence and focus with confidence, and start with a realistic expectation of achievable viewing comfort. For the military, this knowledge can translate into the savings of millions of dollars. For industry, this can pave the way for product success. In addition, this knowledge can lessen the risk of health hazards and safety litigation.

II. Preliminary Data on Binocular Alignment and Viewing Comfort

Median data from three observers are presented from a preliminary investigation of visual comfort and binocular alignment. Observers briefly viewed binocular imagery and provided a rating of visual comfort on the following scale:

1	Not uncomfortable
2	A little uncomfortable
3	Somewhat uncomfortable
4	Very uncomfortable
5	Extremely uncomfortable

The baseline image was green symbology viewed against a colorful scenic background. This image in perfect alignment was explicitly linked to a rating of 1 – *Not uncomfortable to view*, and was briefly viewed between trials. The three observers were simply instructed to rate the comfort of viewing the image. There were no explicit instructions to “fixate” the background or symbology, and there was no task to perform.



After the initial aligned image, observers viewed a random sequence of misaligned images at the distance of optical infinity. This misalignment was either Local (the symbology but not the background was shifted) or Global (both the symbology and background were shifted). Misalignments included Horizontal (convergence or plus, divergence or negative), Vertical, Magnification difference, and Rotation difference (rotation was outwards). Several combinations of misalignments were tested. In addition, the aligned image was tested at several positive (closer than optical infinity) and negative (further than optical infinity) focus values with an image vergence corresponding to optical infinity or parallel lines-of-sight.

Notations for each set of conditions are:

H0 H+1 H+3 H+6 H+9 H+12	Relative horizontal misalignment of 0 to +12 min
H0 H-3 H-6 H-9 H-12	Relative horizontal misalignment of 0 to -12 min
V0 V3 V6 V9 V12	Relative vertical misalignment of 0 to 12 min
M0 M1 M2 M3	Relative magnification of 0 to 3%
R0 R1 R2 R3	Relative rotation of 0 to 3 deg
H0 H+60 H+120 global	Global horizontal misalignment of 0 to +120 min
H0 H-60 H-120 global	Global horizontal misalignment of 0 to –120 min
V0 V15 V30 V45 V60 global	Global vertical misalignment of 0 to 60 min
M0 M1 M2 M3 global	Global magnification of 0 to 3%
R0 R1 R2 R3 global	Global rotation of 0 to 3 deg
-1/2 –1/4 0 +1/4 +1/2 D	Global focus of –1/2 to +1/2 diopter

These preliminary data are presented as grouped median ratings with commentary:

Rating of 1: Not uncomfortable to view

H0	V0	M0	R0	0D	Local	Perfect alignment baseline
H+1	V0	M0	R0	0D	Local	Gibson's (1980) preferred value
H+6	V0	M0	R0	0D	Local	35 meters
H-3	V0	M0	R0	0D	Local	
H0	V3	M0	R0	0D	Local	
H-60	V0	M0	R0	0D	Global	20x H-3 local
H0	V15	M0	R0	0D	Global	5x V3 local
H0	V0	M1	R0	0D	Global	
H0	V0	M0	R0	+1/4D	Global	Tolerance for small amount of close focus

Rating of 2: A little uncomfortable to view

H+3	V0	M0	R0	0D	Local	
H+9	V0	M0	R0	0D	Local	
H+12	V0	M0	R0	0D	Local	Tolerance for close symbology, 17 meters
H-6	V0	M0	R0	0D	Local	
H0	V0	M1	R0	0D	Local	
H0	V0	M2	R0	0D	Local	
H+60	V0	M0	R0	0D	Global	Greater tolerance for convergent global
H0	V30	M0	R0	0D	Global	
H0	V0	M2	R0	0D	Global	
H0	V0	M0	R0	+1/2D	Global	

Rating of 3: Somewhat uncomfortable to view

H0	V6	M0	R0	0D	Local	
H+3	V6	M0	R0	0D	Local	
H0	V0	M3	R0	0D	Local	
H0	V0	M0	R1	0D	Local	
H+120	V0	M0	R0	0D	Global	
H-120	V0	M0	R0	0D	Global	
H0	V0	M3	R0	0D	Global	
H0	V0	M0	R2	0D	Global	
H0	V0	M0	R3	0D	Global	Greater tolerance for global R
H0	V0	M0	R0	-1/4D	Global	

Rating of 4: Very uncomfortable to view

H-9	V0	M0	R0	0D	Local	
H0	V9	M0	R0	0D	Local	
H0	V12	M0	R0	0D	Local	
H-6	V6	M0	R0	0D	Local	Combination degrades comfort
H0	V45	M0	R0	0D	Global	Up to 5x V local
H0	V0	M0	R1	0D	Global	Ratings for global R not consistent
H-60	V60	M0	R0	0D	Global	
H0	V0	M0	R0	-1/2D	Local	Note ordering of focus, small + to large -

Rating of 5: Extremely uncomfortable to view

H-12	V0	M0	R0	0D	Local
H0	V0	M0	R2	0D	Local
H0	V0	M0	R3	0D	Local
H0	V60	M0	R0	0D	Global
H0	V60	M1	R0	0D	Global

In agreement with previous studies, these preliminary data suggest that we are more sensitive to vertical than horizontal misalignment. We are also much more sensitive to local or relative misalignment than to global misalignment. Combinations of misalignments produced some of the highest ratings of viewing discomfort. We also respond differently to the same amount of convergence and divergence, as well as focus nearer and further than the reference.

For a preliminary sample of three observers with minimal practice and only cursory instructions, the data are remarkably consistent. Some of the few inconsistencies, such as global rotation, may actually indicate that smaller values create more discomfort. This could be due to torquing of the eyes in response to the smaller value and the resulting tension, while larger values are simply seen as a confused image. A reasonable sample size would allow for a more confident explanation.

Despite a variety of conditions that were presented in a random order, the three observers had no trouble rating each image for level of discomfort. This suggests that non-binocular conditions that simulate a monocular display or that replicate perceptual effects could be included. These types of conditions could further help place binocular alignment into a cohesive viewing-comfort context.

References

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