Aerospace Medicine Symposium

Enhancing Aircrew Performance

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Visual Aspects of Advanced Sensors and Sensor Fusion

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Enhancing Aircrew Performance, RAeS, 5 March 2013
Visually coupled systems & general visual issues
Depth perception & hyperstereopsis
Accommodation & eyestrain
Ocular dominance & binocular rivalry
Field of view, spectral sensitivity & displaced visual inputs
Symptomatology – pilot surveys
Visual challenges of integrating systems
Introduction

- Visually coupled systems, including HUD/HMD

- Integrate natural visual & motor skills of an operator into the system (s)he is controlling

- Flight, targeting, environmental data

+ Increase situational awareness & performance

- Potential visual conflicts/illusons/symptoms

Bayer et al., Introduction to Helmet Mounted Displays. 2009
Requirements of VCS

- Mounting platform – e.g. helmet
- Image source – generates info / imagery (I2, CRT)
- Relay optics – couple imagery to the eye (lenses, combiner)
- Tracker – head tracker, eye tracker, slaves imagery to direction of regard

Bayer et al., Introduction to Helmet Mounted Displays. 2009
Monocular – HMD imagery presented to single eye

Biocular – 2 images from single sensor, identical image presented to both eyes

Binocular – 2 images, from 2 sensors, provides perspective
Optical design

- System latency critical
- Temporal delay inherent in mechanical systems
- Symbology overlay on visual scene (real/sensor)
- Sensor response time must keep up
- >50 ms latency visually confusing
- Rapid head movement may lose track of sensor
General visual issues

- Importance of fit/comfort

- Vibration – rotary aircraft tri-axial vibration 0.5–100Hz, HMD susceptible to vibration

- Compensatory eye movements ineffective at image stabilisation at low frequency (<20Hz)

- Visual blur, helmet slip, image loss

- Compensate with careful fit & improved visibility – illumination/contrast

General visual issues

- Eye / optical relief
- Distance from optical element to eye
- Refractive correction
- Field of view
- Comfort
Depth Perception

- 2 eyes horizontally separated in space
- IPD: inter-pupillary distance
- Each eye slightly different retinal image
- Binocular disparity allows *stereopsis*
- Useful for near depth perception (<30m)
Depth Perception

Points away from fixation will usually have **binocular disparity**:

the point will project to different places on the two retinas.

In this example, the disparity on the left is smaller than the disparity on the right.
Depth Perception

- Monocular depth cues
- Relative size
- Interposition
- Geometric perspective
- Contours
- Shading/shadows
- Motion parallax
Monocular systems cause loss of stereopsis

Reliance on monocular cues

Texture, gradient, shade, contours may be degraded by HMD imagery

Training & experience can overcome loss of binocular depth perception

Hyperstereopsis

- Normal IPD average 64mm (57–72mm)
- HMDs may have input sources greater than normal IPD (e.g. TopOwl = 286mm)
- Hyperstereopsis – problem in binocular systems
Hyperstereopsis

- Increased input separation
- Increased convergence angle
- Shorter distance perception
- Objects appear closer
- Effects within 1000ft
Hyperstereopsis

- Crater / bowl effect

- Helicopter on ground, pilot perception that ground at chest height

- Can be improved with training

Temme et al. Visual perception conflicts and illusions, 2009
Priot et al. Hyperstereopsis in night vision devices: basic mechanisms and impact for training requirements. 2006
Accommodation

- Eyes accommodate to focus near targets
Accommodation reflex linked to convergence (and pupillary constriction)
Accommodation

- Reflex accommodation driven by stimulus blur

- Empty field, should ‘relax’ and focus at infinity, but lapses to approx 0.5–2 dioptres

- HMD images collimated, should be optical infinity

- Accommodation linked to convergence, so change of attention to cockpit may induce convergence

- Potential issues with phorias (latent squint)
Accommodation

- Image combiner should be transparent, but reflections may induce ‘inappropriate’ accommodation

- Users accommodate to knowledge of HMD being close to eye

- Processing collimated images may induce accommodation of up to 1 dioptre

- Luminance/contrast may affect accom via pupil size

Edgar et al. Visual accommodation problems with head-up and helmet-mounted display? 1994
Accommodation

- Presented symbology only merged at optical infinity

- Inappropriate accom gives divergent symbology

- AH–64 pilot study – mean focus setting of –2.28 d

- Positive accommodation required to offset errors in settings, would lead to eyestrain/headache

Rash. A 25 year retrospective review of visual complaints and illusions associated with a monocular helmet–mounted display, 2008
Ocular Dominance

- Tendency for individuals to have a ‘preferred’ eye
- Left eye dominance vs right eye display/symbology
- Issue in monocular systems and bi(n)ocular systems if unilateral symbology
- Eyestrain / “burning pain” a possibility if attending to stimuli in non-dominant eye for long periods
- Head-tracking accuracy impaired? No functional performance deficit
Binocular Rivalry

Probably the major ophthalmic issue with HMDs

Presentation of dissimilar images to each eye

“Dichoptic viewing”

Colour / resolution / field of view / motion / luminance / displaced input (FLIR)

Brain resolves problem by ‘suppression’ of one image

Temme et al. Visual perception conflicts and illusions, 2009
Binocular Rivalry

- Difficulty making necessary attention switches

- Significant fatigue, esp if long sortie, system flicker, poor image quality

- Symptoms ease with practice / experience, but a recurrent pilot stressor

- Linked to ocular dominance

Temme et al. Visual perception conflicts and illusions, 2009
Binocular Rivalry

- Examples:
  - Bright green phosphor in R eye, difficult to attend darker visual scene (e.g. cockpit) via L eye
  - Bright city lights, difficulty in shifting view to HMD
  - Difficulty seeing cockpit instruments if “seeing” outside world through sensor input

Temme et al. Visual perception conflicts and illusions, 2009
Binocular Rivalry

- Difficulty in adjusting to one dark-adapted and one light-adapted eye

- “Brown eye” effect – after shut down of night vision system, merging of night vision with day vision gives monochromatic effect

- ‘Pulfrich effect’ – optical illusion – object moving in parallel plane appears to approach and/or recede from viewer – if luminance contrast between eyes

Temme et al. Visual perception conflicts and illusions, 2009
Field of View

- Normal human visual field
- Monocular 120x150°, binocular 120x200°
Field of View

- Most HMDs give restricted FoV – 40–50° common
- Allows smaller objective lens and related optics

Temme et al. Visual perception conflicts and illusions, 2009
Field of View

- Field of view related to eye relief – system needs to be close to eye to prevent vignetting

- Small FoV: visual illusions, reduced depth cues, increased workload, reduced reaction time, tracking tasks

- Increased compensatory head movements

- System latency needs to keep up

- Risk of neck pain

Hiatt et al. Visual issues associated with the use of the integrated helmet and display sighting system (IHADSS) in the Apache helicopter– three decades in review, 2008
Image Chromaticity

- Imagery / symbology is monochromatic
- “Green” due to phosphor in system – 543nm peak
- Related to human chromatic sensitivity
Image Chromaticity

- No variation in hue, so luminance contrast is key
- Background luminance affects gain of system – can be troubling
- Probably little functional problem
- Adding false colour to imagery may create problems – pilots are used to shades of green

Rash et al. Visual helmet mounted displays, 2009
Sensor Spectrum

- Visible part of EM spectrum 400–700nm (0.4–0.7µm)
- FLIR sensor 8–12µm spectral sensitivity
- Thermal imaging detects thermal characteristics, reflectance/absorbance & ambient temperature
- Sensor representation completely different from normal visual representation
- (some information is better than none!)

Rash et al. Visual perceptual issues of the integrated helmet and display sighting system (IHADSS): four expert perspectives, 2008
Sensor Spectrum

- Climate, terrain impact sensitivity of FLIR images
- Training / experience to rationalise imagery

Rash et al. Visual perceptual issues of the integrated helmet and display sighting system (IHADSS): four expert perspectives, 2008
System Resolution

- Ability of optical system to reproduce “viewed” scene
- Normal human acuity 6/6 (20/20)

(most pilots have BCVA 6/5 or 6/4)
Most HMD systems dramatically reduce resolution

FLIR system approximates to 6/18
Decreasing resolution impairs object recognition

Height estimation impaired

Fatigue due to increased visual/cognitive workload

Add in ambient conditions, reduced field of view, monochromic images etc, bigger workload

Typhoon imagery poorer resolution than NVG

Rash et al. Visual perceptual issues of the integrated helmet and display sighting system (IHADSS): four expert perspectives, 2008
Displaced Visual Input

- FLIR sensor primary visual input at night / foul weather

- Apache: sensor is 3m forward, 1m below head

- Unobstructed view of areas below aircraft

- Exocentric positioning – parallax, motion estimation, distance estimation, spatial orientation all affected
Displaced Visual Input

- Aircraft manipulation from point-of-view different to own visual system
- Substantial training for proficiency of unnatural viewpoint
- Transition between viewpoints problematic
- Binocular rivalry – attending to cockpit data vs sensor data
- Continual re-orientation required to maintain positional awareness (esp on landing)

Rash et al. Visual perceptual issues of the integrated helmet and display sighting system (IHADSS): four expert perspectives, 2008
## Pilot symptoms – questionnaire

- 1990 study of Apache pilots
- 58 questionnaires
- 80% reported at least one visual complaint
- “Visual discomfort”, headache, blurred vision
- Symptoms may persist *AFTER* flight

<table>
<thead>
<tr>
<th>Complaint</th>
<th>During Flight</th>
<th>After flight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Sometimes</td>
</tr>
<tr>
<td>Visual discomfort</td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td>Headache</td>
<td>65</td>
<td>35</td>
</tr>
<tr>
<td>Double vision</td>
<td>86</td>
<td>12</td>
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<tr>
<td>Blurred vision</td>
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<td>21</td>
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<tr>
<td>Disorientation</td>
<td>81</td>
<td>19</td>
</tr>
<tr>
<td>Afterimages</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Behar et al. Visual survey of Apache aviators. 1990
Pilot symptoms – questionnaire

- 2000 study
- 216 Apache pilots (monocular IHADSS system)
- 92% reported visual complaint / symptom

- Slope estimation (80%)
- Faulty height judgement (74%)
- Undetected aircraft drift (78%)
- Illusory drift (71%)

Pilot symptoms – combat

- 2003 “combat” flying questionnaire

- Significant reduction in visual discomfort & disorientation during/after combat flying

- Reduced static & dynamic visual illusions

- Peacetime – limited flying hours, pilots “fly-the-system” to maximise proficiency

- Combat – lots of flying, other stressors

Hiatt et al. Apache aviator visual experiences with the IHADSS helmet-mounted display in Operation Iraqi Freedom, 2004
Integrating NVG / FLIR / symbology technically challenging

- Monocular vs binocular systems, number/location of sensors, system latency/lag, resolution

- Numerous trade-offs to reduce binocular rivalry / hyperstereopsis / perceptual distortions

- Cannot have simultaneous hyperstereopsis & binocular rivalry

Kalich et al. Perceptual design tradeoff considerations for viewing I2 and FLIR with current helmet-mounted displays
Summary

- Performance enhancement with visually coupled systems
- Potential visual conflicts and symptoms
- System optics/latency/resolution
- Depth perception/hyperstereopsis/accommodation
- Ocular dominance/binocular rivalry
- Field of view/spectral sensitivity
- Displaced visual inputs
- Inter-individual differences in tolerance
- Challenging design trade-offs to integrate systems
Acknowledgements

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