USING MONOCULAR AND BICULAR HEAD MOUNTED DISPLAYS
WITH WEAPON-MOUNTED OFF-BORE SYSTEMS

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Abstract

This experiment compared the target detection and engagement performance of weapon-mounted off-bore systems using monocular and biocular head-mounted displays for infantry soldiers in urban streets, wooded terrain, and in-buildings terrain. Specifically, this trial compared the performance of soldiers using a weapon-mounted off-bore video sight in conjunction with a monocular and biocular head mounted display (HMD) to the in-service C79 optical sight.

Participant performance measures included: time to detect targets, exposure to the target during target search, percentage accuracy, and target detection accuracy. Subjective measurements from questionnaire data included acceptability of the sight and HMD conditions. Subjective data were also collected from a post-experiment focus group discussion.

The results of this study indicated that participants preferred a monocular HMD to a biocular HMD for use with off-bore weapon systems. There was no difference in target detection performance between the monocular and biocular displays for any of the three terrain conditions: urban streets, wooded, and in-building. The rejection of the biocular display can be traced to the participants’ loss of situation awareness when visually immersed with both eyes.

Participants were able to detect targets in urban streets three times faster with the C79 optical sight, with a greater likelihood of detection, than with the off-bore video sight. In wooded and in-building terrain participants were twice as fast at detecting targets with the optical sight over the off-bore sight, but the likelihood of target detection was similar. However, at the completion of the study, participant ratings did not indicate any differences between the two sights for lethality, tactical feasibility, or overall preference due to the strong preference participants assigned to the off-bore sight for survivability. In the end participants did not indicate an overall preference for either sight because each sight had a different mix of strengths and weaknesses depending on the tactical and battlefield situation.

Based on the results of this experiment, areas for improvement and future research are recommended.
Résumé

Cette expérience comparait le rendement de détection et d’engagement d’objectifs offert par des systèmes hors axe montés sur arme utilisant des afficheurs monoculaires et bi-oculaires sur casque, pour des fantassins menant des opérations dans des rues, sur du terrain boisé et à l’intérieur d’immeubles. Plus précisément, l’expérience comparait le rendement de soldats utilisant un viseur vidéo hors axe monté sur arme et un afficheur monocular et bi-oculaire sur casque avec le viseur optique C79 en service.


Les résultats de l’étude ont démontré que les participants préféraient l’afficheur monoculaire à l’afficheur bi-oculaire pour les systèmes d’arme hors axe. Le rendement de détection des objectifs ne différait aucunement entre les afficheurs monoculaires et bi-oculaires, que ce soit dans des rues, sur du terrain boisé ou à l’intérieur d’immeubles. Le rejet de l’afficheur bi-oculaire peut s’expliquer par la perte de connaissance de la situation que subissaient les participants au moment d’une immersion visuelle par les deux yeux.

Les participants ont pu détecter des objectifs dans les rues trois fois plus vite avec le viseur optique C79 qu’avec le viseur vidéo hors axe, tout en atteignant une probabilité de détection supérieure. Sur le terrain boisé et à l’intérieur des immeubles, les participants ont été deux fois plus rapides dans la détection des objectifs lorsqu’ils utilisaient le viseur optique plutôt que le viseur hors axe, mais la probabilité de détection était semblable. Toutefois, à la fin de l’étude, les évaluations des participants n’ont indiqué aucune différence entre les deux viseurs pour ce qui est de la mortalité, de la faisabilité tactique ou d’une préférence globale. Cette absence de différence peut s’expliquer par la nette préférence qu’accordaient les participants au viseur hors axe au point de vue de la surviabilité. En somme, les participants n’ont manifesté aucune préférence globale pour l’un ou l’autre des viseurs du fait que chacun offrait une combinaison différente de points forts et de points faibles, selon la situation tactique et de combat.

Des aspects à améliorer et des recherches à effectuer sont recommandés en fonction des résultats de l’expérience.
Executive Summary

At the dismounted infantry soldier level, an off-bore video sight, in combination with a helmet-mounted display, enables the soldier to detect and fire at targets from behind cover without exposing their head or upper body to the enemy. With only the arms exposed to enemy fire, such “off-bore” shooting offers potential improvements to survivability for the infantry soldier.

This experiment compared the target detection and engagement performance of weapon-mounted off-bore systems using monocular and biocular head-mounted displays for infantry soldiers in urban streets, wooded terrain, and inside buildings. A five-day field trial was undertaken at Fort Benning, Georgia over the period November 10 to November 14, 2003. Sixteen volunteer regular force infantry soldiers from the First and Third Battalion of the Princess Patricia Canadian Light Infantry (PPCLI) participated. From predetermined firing positions in the urban village (McKenna MOUT site), wooded terrain and along a route through buildings, soldiers were required to detect and engage targets using the two off-bore display configurations (ie. monocular or biocular) and the C79 optical sight. Fire postures included target engagements around corners to the left and right sides, and over the top of a barrier (e.g. windowsill or trench).

The results of this study indicated that participants preferred a monocular HMD to a biocular HMD for use with off-bore weapon systems. While some considered the monocular HMD to be unacceptable (20%), many more participants rejected the use of a biocular display (40%). The rejection of the biocular display can be traced to the participants’ loss of situation awareness when visually immersed with both eyes. While the local situation awareness afforded by the monocular display was still problematic, in terms of the extent of visual field obstruction, the loss of vision to both eyes when viewing the biocular displays was judged to be unacceptable and dangerous in battle. This was evidenced when soldiers were “clearing” buildings and walking with the off-bore weapon system. With the monocular display, soldiers were observed using their free eye to navigate around obstacles and seemed to retain better awareness of the terrain space and the activities going on within it. Using the biocular display, soldiers were observed tripping and bumping into obstacles, and often complained about being “blind” to the situation around them.

For target detection performance there was no difference between the monocular and biocular displays for any of the three terrain conditions: urban streets, wooded, and in-building. Subjective assessments confirmed these results and also suggested that participants did not perceive any differences for image quality, colour, and stability, or for display viewing in various lighting conditions, or any physical effects relating to eye strain, nausea, or headaches.

Participants were able to detect targets in urban streets three times faster with the C79 optical sight, with a greater likelihood of detection (86% vs 66%), than with the off-bore video sight. In wooded and in-building terrain participants were twice as fast at detecting targets with the optical sight over the off-bore sight, but the likelihood of target detection was similar. Subjective results supported these findings and indicated that the optical sight was also preferred for battlefield
situation awareness, ease of target scanning, field of view, and adjusting to different lighting conditions.

However, at the completion of the study, participant ratings did not indicate any differences between the two sights for lethality, tactical feasibility, or overall preference. This lack of overall differences can be explained by the strong preference participants assigned to the off-bore sight for survivability. In the end participants did not indicate an overall preference for either sight because each sight had a different mix of strengths and weaknesses depending on the tactical and battlefield situation. When speed and aggression are key in the assault the optical sight is preferred for its speed and ease of target detection and engagement and for enabling the soldier to maintain their situation awareness in a rapidly changing pace of battle. The off-bore video sight offers advantages in static defensive positions for minimizing detection by the enemy, where the high-speed zoom capability can be employed effectively, and in close quarter battle situations in complex urban terrain where survivability risks can be reduced at dangerous crossing areas and in-buildings. Ideally, future weapon systems would include both on-bore and off-bore sighting and engagement options.

Based on the results of this experiment, areas for improvement and future research are recommended.
Sommaire

Au niveau du fantassin débarqué, un viseur vidéo hors axe, combiné à un afficheur sur casque, permet au soldat de détecter des objectifs et de tirer sur ces objectifs en restant à couvert, sans exposer la tête ou le torse. Comme seuls les bras sont exposés au tir ennemi, le tir hors axe pourrait améliorer la surviabilité du fantassin.

Cette expérience comparait le rendement de détection et d’engagement des objectifs offert par des systèmes hors axe montés sur arme utilisant des afficheurs monoculaires et bi-oculaires sur casque, pour des fantassins menant des opérations dans des rues, sur du terrain boisé et à l’intérieur d’immeubles. Un essai en campagne de cinq jours a eu lieu à Fort Benning, en Géorgie, durant la période du 10 au 14 novembre 2003. Seize fantassins volontaires de la Force régulière, du premier et du troisième bataillons du Princess Patricia Canadian Light Infantry (PPCLI), y ont participé. À partir de positions de tir prédéterminées dans le village urbain (au MOUT McKenna), sur du terrain boisé et le long d’une route, les soldats devaient détecter et engager des objectifs au moyen des deux configurations d’afficheur hors axe (monoculaire et bi-oculaire) et du viseur optique C79. Les postures de tir comprenaient des engagements d’objectifs autour des coins à gauche et à droite et par-dessus une barrière (p. ex. un appui de fenêtre ou un bord de tranchée).

Les résultats de l’étude ont démontré que les participants préféraient l’afficheur monoculaire à l’afficheur bi-oculaire pour les systèmes d’arme hors axe. Bien que certains aient considéré l’afficheur monoculaire comme inacceptable (20 %), beaucoup plus de participants ont rejété l’utilisation de l’afficheur bi-oculaire (40 %). Le rejet de l’afficheur bi-oculaire peut s’expliquer par la perte de connaissance de la situation que subissaient les participants au moment d’une immersion visuelle par les deux yeux. Alors que la connaissance de la situation locale fournie par l’afficheur monoculaire posait encore des problèmes quant à l’étendue du champ de vision bloqué, la perte de vision des deux yeux liée à l’utilisation de l’afficheur bi-oculaire était jugée inacceptable et dangereuse en situation de combat. C’est ce qu’a révélé l’observation de soldats menant des opérations de « nettoyage » d’immeubles et se déplaçant avec le système d’arme hors axe. Avec l’afficheur monoculaire, les soldats utilisaient leur œil libre pour contourner des obstacles et semblaient avoir une meilleure connaissance de l’espace environnant et des activités qui s’y déroulaient. Les soldats équipés d’un afficheur bi-oculaire trébuchaient et se frappaient contre des obstacles, et ils se plaignaient souvent d’être « aveugles » à la situation qui les entourait.

Le rendement de détection des objectifs ne différait aucunement entre les afficheurs monoculaires et bi-oculaires, que ce soit dans des rues, sur du terrain boisé ou à l’intérieur d’immeubles. Les évaluations subjectives ont confirmé ces résultats et ont aussi révélé que les participants ne percevaient aucune différence du point de vue de la qualité, de la couleur et de la stabilité des images, de la visualisation de l’affichage sous diverses conditions d’éclairage ou de tout effet physique lié à de la fatigue oculaire, à des nausées ou à des maux de tête.

Les participants ont pu détecter des objectifs dans les rues trois fois plus vite avec le viseur optique C79 qu’avec le viseur vidéo hors axe, tout en atteignant une probabilité de détection supérieure (86 % contre 66 %). Sur le terrain boisé et à l’intérieur des immeubles, les participants ont été deux fois plus rapides dans la détection des objectifs lorsqu’ils utilisaient le viseur optique plutôt que le viseur hors axe, mais la probabilité de détection était semblable. Confirmant ces conclusions, les résultats subjectifs ont indiqué que le viseur optique était également préférable du point de vue de ...
la connaissance de la situation de combat, de la facilité de balayage des objectifs, du champ de vision et de l’adaptation aux différentes conditions d’éclairage.

Toutefois, à la fin de l’étude, les évaluations des participants n’ont indiqué aucune différence entre les deux viseurs pour ce qui est de la mortalité, de la faisabilité tactique ou d’une préférence globale. Cette absence de différence peut s’expliquer par la nette préférence qu’accordaient les participants au viseur hors axe du point de vue de la surviabilité. En somme, les participants n’ont manifesté aucune préférence globale pour l’un ou l’autre des viseurs du fait que chacun offrait une combinaison différente de points forts et de points faibles, selon la situation tactique et de combat. Lorsque la rapidité et l’agressivité constituent des éléments clés d’un assaut, le viseur optique est préféré en raison de sa vitesse, de ses fonctions de détection et d’engagement des objectifs et du fait qu’il permet au soldat de maintenir sa connaissance de la situation lorsque le combat change rapidement de rythme. Le viseur vidéo hors axe présente des avantages dans des positions défensives statiques lorsqu’il importe de minimiser la détection par l’ennemi, lorsque la fonction de zoom à haute vitesse peut être utilisée efficacement et dans des situations de combat rapproché sur un terrain urbain complexe, alors que les risques à la surviabilité peuvent être réduits dans des zones dangereuses à des points de passage et à l’intérieur d’immeubles. Idéalement, les futurs systèmes d’armes intégreraient à la fois des options d’engagement et de visée dans l’axe et hors axe.

Des aspects à améliorer et des recherches à effectuer sont recommandés en fonction des résultats de l’expérience.
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1 Background

Visual display systems for wearable computers have been used by the military for many years. Military aircraft have been using head mounted displays (HMDs) for over 20 years to assist fighter pilots in maintaining visual awareness outside the cockpit and facilitating quick decision-making in air-to-air combat (Blanchard, Lane, Lee, and Teittinen, 1997, as referenced by Bos and Tack, 2002). At the dismounted infantry soldier level, several nations have explored the use of HMDs for displaying computer information, sensor information, and weapon sight cameras. Use of a video camera mounted to the soldier’s personal weapon has been explored as a possible means of improving survivability by minimizing soldier exposure to enemy fire. An off-bore daylight video sight (DVS), in combination with a HMD, enables the soldier to fire at targets from behind cover without exposing their head or upper body. With only the arms exposed to enemy fire, such “off-bore” shooting offers potential improvements to survivability for the infantry soldier. Reference Figure 1. Unfortunately efforts to establish a base criterion to test the effectiveness of this equipment in a field research venue has been limited (National Research Council, 1997).

![Soldier Using LW Off Bore System](image)

Figure 1: Soldier Using LW Off Bore System

Previous scientific investigations on target engagement performance with the current version of the U.S. Land Warrior (LW) off-bore system, as part of the SIREQ-TD\(^1\) programme, have identified several deficiencies (Angel et al, 2002 and 2001). First, the LW’s Kaiser Electronic DVS is a colour video camera displaying low resolution imagery. Second, the horizontal field of

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\(^1\) SIREQ TD stands for Soldier Information REQuirements Technology Demonstration project. This is a 4-year research effort, led by DRDC Toronto, to scientifically validate the information and display capabilities that will dramatically improve the situation awareness, target acquisition and command execution performance of the Canadian dismounted soldier of the future.
view (FOV) is limited to 26°. Third, the targets presented to the DVS are occasionally washed out by sun glare. Fourth, zeroing of the camera through software adjustment requires selected computer proficiency. Fifth, the reticle pattern is large (keyboard plus sign) and obscures a soldier-sized target at distances as short as 70m. But the most prevalent disadvantage is the low frame refreshing rate, illustrated by the slow detecting, tracking and engaging of faster moving targets as compared to conventional on-bore sights (iron, C79, red-dot and holographic). Another major drawback is the limited temporal and spatial resolution afforded by this system. Previous focus groups have identified that current off-bore DVS systems are not acceptable to infantry soldiers; however, if the latter improvements were made to the systems with the inclusion of a magnification capability, soldiers could foresee a role for this type of capability (Angel et al, 2002).

Visual perception research and field studies have identified a number of advantages and disadvantages with the use of monocular versus biocular HMD’s (National Research Council, 1997). Monocular HMDs have the advantages of being lightweight and enable the unoccluded eye to observe the free field for local situation awareness. The disadvantages of monocular HMD’s include loss of stereoscopic vision, binocular rivalry between eyes, and differential accommodation to lighting levels, contrast, and colour between the two eyes. We would also suggest that the attentional narrowing demands of the monocular display image would effectively disable the performance of the other eye to the extent that free-field situational awareness cannot be acquired during monocular HMD use, although switching attention between eyes can be relatively quick. Biocular HMD’s have the advantages of little to no binocular rivalry or accommodation differences between eyes, and no distractions in the free-field of vision. As well, since each eye has an independent chance of detecting a target, using both eyes in target detection and engagement tasks should prove superior in the field. The disadvantages of biocular HMD’s include a higher cost per display, higher weight on the head, and require more time to switch between display viewing and free-field viewing. Currently, the U.S. Land Warrior soldier modernization programme includes an occluded monocular HMD as it primary visual display while the British FIST programme employs an occluded biocular HMD display.

While several studies have been performed in an aviation environment (Wells and Griffin, 1987), (Velger, 1998), (Caldwell et al, 1990), using head-tracking for air-to-air aiming, few controlled studies have been conducted which compare monocular and biocular displays on target detection performance in dismounted infantry tasks. This experiment investigated these issues by quantitatively and qualitatively comparing the performance of a new prototype monocular HMD off-bore system, and a new prototype biocular HMD off-bore system, against the current in-service C79 optical sight, during target detection and engagement tasks in a wooded terrain, urban village, and inside buildings. This experiment built on previous SIREQ-TD studies to identify the operational advantages, if any, of an off-bore system, and to establish the criteria for a future off-bore system.
2 Objectives

This experiment compared the target detection and engagement performance of weapon-mounted off-bore systems using monocular and biocular HMD’s for infantry soldiers in urban streets, wooded terrain, and inside buildings.

The following objectives were pursued:

- Compare the target detection and engagement performance of a weapon-mounted off-bore video sight to the in-service C79 optical sight.
- Compare the target detection and engagement performance and usability issues of a monocular HMD and a biocular HMD.
- Determined the performance requirements for a weapon-mounted off-bore system for infantry soldiers for the SIREQ-TD project.
3 Method

3.1 Overview

The following description provides a general overview of the trial method. Further details are provided in subsequent sections.

A five-day field trial was undertaken at Fort Benning, Georgia over the period November 10 to November 14, 2003. Reference Figure 2. Sixteen volunteers regular force infantry soldiers from the First and Third Battalions of the Princess Patricia Canadian Light Infantry (PPCLI) participated in this study. From predetermined firing positions in the urban village (McKenna MOUT site), wooded terrain and inside buildings, soldiers were required to detect and engage targets using the two off-bore display configurations (i.e. monocular or biocular) and the C79 optical sight. Fire postures included target engagements around corners to the left and right sides, and over the top of a barrier (e.g. windowsill or trench).

Three visual display configurations were investigated:

1. A monocular full colour HMD in conjunction with a power zoom (up to 10 times), one-mega pixel CCD weapon mounted off-bore camera system.
2. A biocular full colour HMD in conjunction with a power zoom (up to 10 times), one-mega pixel CCD weapon mounted off-bore camera system.
3. An on-bore C79 optical sight with a fixed 3.4 power optical telescope.

During each of the three experimentation conditions (i.e. Urban Streets, Wooded terrain, In Buildings), the presentation of conditions and sighting configurations were balanced to minimize order effects amongst participants, and the target difficulty level was randomized and
standardized as much as possible. Human factors (HF) tests included assessments of detection and engagement performance, visual acuity and colour sensitivity, compatibility, user acceptance and criteria of importance. Data collection included performance measures (time to detect targets), HF observer assessments, questionnaires, and focus groups.

Statistical differences between the three visual display conditions were determined using a balanced, repeated-measures analysis of variance for the target detection time, specific target detection data (i.e. true positives, false negatives, true negatives, and false positives) (Table 1), and Exit Questionnaire results. Duncan’s post hoc analyses were conducted on significant differences found in the objective and subjective Exit Questionnaire data between the three visual display conditions.

<table>
<thead>
<tr>
<th>Participant Decision</th>
<th>Shot</th>
<th>No Shot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Target</td>
<td>True Positive</td>
<td>False Negative</td>
</tr>
<tr>
<td>No Target</td>
<td>False Positive</td>
<td>True Negative</td>
</tr>
</tbody>
</table>

Table 1: Decision Table

True Positive = a shot was taken on an actual target (i.e. correct)
False Negative = no shot was taken when a target was present (i.e. a miss)
False Positive = a shot was taken when no target was present (i.e. false alarm)
True Negative = no shot was taken when no target was present (i.e. correct)

3.2 Participants

Sixteen infantry soldiers from the First and Third Battalion of the PPCLI participated in this study. The group consisted of four Privates (25%), eight Corporals (50%), three Master Corporals (19%) and one Sergeant (6%). The average length of military service for the participants was $3.6 \pm 1.4$ years. All of the participants were screened to meet the Colour Vision 1 CF Standard\(^2\) for colour vision deficiency.

3.3 Materials

The following section describes the weapon-mounted sighting systems, head-mounted display systems and pop up targets.

\(^2\) While the target population for the results of this study (Infantry) are permitted to have a lower visual standard (CV3), this study selected only those subjects who have no colour vision defect in an attempt to control for a potential confounding variable.
3.3.1 Weapon Sight Systems

3.3.1.1 Video Sight
A Sony Micro MV video camera was mounted to the sight-mounting rail of the C7A1 rifle. The Sony Micro MV video sight was a Commercial-Off-The-Shelf (COTS) product with a Mega Pixel CCD. Reference Figure 3. It had an auto focus and auto iris control/gain control that let more or less light through, depending on the brightness at the center of the area of focus. The video sight was also equipped with an image stabilizing device (Super SteadyShot™), night vision capability, and adjustable zoom that could magnify images in this experiment up to ten times. For the In Building target detection trial, the zoom function mentioned above was disabled because it was deemed unnecessary for the short distances in the close quarters. However a 0.6 x wide angle field of view lens attachment was used for just the In Building trial. The aiming reticle on the video sight was produced using the text-on-screen feature of the camcorder superimposed over the image (i.e. “-.-“).

Figure 3: Sony Micro MV Video Sight Mounted on C7 Rifle

The Sony Micro MV Video Sight had the following specifications:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>0.480 kg (1 lb) with NP-FF50 battery</td>
</tr>
<tr>
<td>Dimensions (W x H x D)</td>
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</tr>
<tr>
<td>Magnification</td>
<td>1x – 120x (10x optical/120x digital) adjustable zoom</td>
</tr>
<tr>
<td>Resolution</td>
<td>1/4.7” Mega Pixel CCD 1,070K pixels</td>
</tr>
<tr>
<td>Image Stabilization</td>
<td>Super SteadyShot™</td>
</tr>
<tr>
<td>--------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Focus System</td>
<td>Automatic focus</td>
</tr>
<tr>
<td></td>
<td>Automatic iris control</td>
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<tr>
<td></td>
<td>Automatic gain control</td>
</tr>
<tr>
<td>Connection</td>
<td>NTSC S-Video</td>
</tr>
</tbody>
</table>

### 3.3.1.2 Monocular and Biocular HMD

The biocular, colour HMD display, by Cy-Visor, was used for both the biocular (Figure 4 Left) and monocular (Figure 4 Right) display conditions. To achieve the monocular configuration, the right eye display and associated goggle housing were removed from the biocular product. A single HMD product was chosen to ensure that the display image characteristics would be identical in both the monocular and biocular configurations.

The display engine was a complete optical microdisplay module with 1.44 million effective pixels, accepting both NTSC and PC signals. The microdisplay on the HMD provided 800 x 600 SVGA resolution. The virtual image size was equivalent to a forty-four inch monitor viewed two metres away. The left eye monocular HMD, in the monocular condition, consisted of the same microdisplay platform with the right eye display removed for unobstructed right eye vision.

![Figure 4: Cy-Visor HMD Biocular (Left), Monocular (Right)](image-url)
The Cy-Visor Biocular HMD has the following specifications:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Specification</th>
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</thead>
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<td>Control Box 180 g</td>
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<tr>
<td>Display Type</td>
<td>0.49 inch 1.44 million pixel LCD</td>
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<td>Resolution per LCD</td>
<td>800(H) x 600(V) x RGB</td>
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<td>Eye Relief</td>
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<tr>
<td>Dimensions (W x H x D)</td>
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<td></td>
<td>Control Box: 58 x 45 x 140 mm</td>
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<tr>
<td>Connection</td>
<td>NTSC S-Video</td>
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</tbody>
</table>

### 3.3.1.3 C79 Optical Sight

The Elcan C79 standard optical sight for the Canadian Army was used in this experiment. Reference Figure 5. The waterproof and ruggedized sight had shockproof optics and an adjustable reticle. The reticle in the C79 sight was a black vertical post. The sight picture provided 3.4 power magnification of the targets, however, when using the C79 sight for aiming, the user had a restricted field-of-view. As the standard sight for the Canadian army, most soldiers were extensively trained with using it for aiming.

![Figure 5: Elcan C79 Optical Sight](image)

The C79 Optical Sight had the following specifications:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Specification</th>
</tr>
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<tbody>
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<td>Weight</td>
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<tr>
<td>Magnification</td>
<td>3.4 power standard</td>
</tr>
<tr>
<td>Field of View</td>
<td>8°</td>
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</table>
3.3.2 Targets

The targets that were used for this experiment were ¾ height 3-D moulded plastic pop-up figures. Reference Figure 6. For the Urban Streets (MOUT) and Wooded terrain trials, each target figure was attached to a remotely controlled base unit which could be raised on command. Target arrays were balanced for difficulty as well as distance. For the in building target engagement (C4 AB, C2) trials, the 3-D figures were used without the base.

3.3.2.1 Urban Streets MOUT Targets

The targets that were populated within the MOUT village ranged in distance from 21 m to 72 m away. Thirty different upright targets were placed within windows, doorways, and around building structures prior to the start of the trial.

3.3.2.2 In Building (C4AB, C2) Targets

The targets that were populated within the C4AB, and C2 buildings were designed for close quarter combat and ranged in distance from 5 m up to approximately 10 m away. A combination of six different upright targets was placed within windows, doorways, and around building structures prior to the start of each run.

3.3.2.3 Wooded Terrain Targets

The targets that were populated within the wooded terrain ranged in distance from 32 m to 94 m away. Thirty-five different upright ground targets were placed beside trees, and behind foliage prior to the start of the trial.
3.4 Procedure

In an effort to characterize the participants prior to the commencement of this study, soldiers were tested for visual acuity (20/20 corrected required), colour vision (Colour Vision 1 CF Standard) and contrast sensitivity by Canadian Forces medical personnel.

Participants were informed, both verbally and in writing, of the conditions of testing and the experimental protocol. This experiment offered minimal risk to the participant’s health and well-being. All participants were required to read and sign an approved Human Research ethics consent form.

All participants were first briefed on the experimentation goals, target detection task in each terrain condition, off-bore megapixel camera sight, the monocular and biocular HMD’s, and the protocol for the experiment. For the HMD/megapixel visual conditions, prior to the start of data collection soldiers were fitted with the HMD head harness and the display was adjusted to suit the participants desired eye relief, angular orientation, and interpupillary distance. Participants were also given five minutes to adjust to the illumination of the goggles, and were reminded of the megapixel camera zoom functionality. Participants were also given the opportunity to practice with the off-bore weapon handling and zoom controls until a minimum level of proficiency was reached.

Each participant was also instructed in the most effective postures for left-side, right-side, and window/trench approaches to off-bore sighting. Following these instructions, participants were given ample opportunity to practice and refine their off-bore sighting technique for each firing posture.

During the experiment participants were required to adopt one of three firing postures (i.e. left-side, right-side, or window) behind a barrier, according to a balanced order of posture presentation. In the case of the urban streets and wooded terrain conditions, a target was selected from a predetermined matrix and activated to “pop-up” in the target field. Participants were required to wear hearing protection so as not to aurally detect the “pop-up” noise. Inside the buildings, targets were pre-placed prior to each route mission through the buildings (i.e. pop-up targets were not used).

Once the target was raised, a “GO” command was issued by the HF observer to signal the start of the trial. At this command the participant positioned their weapon around the barrier and began their search pattern for the target using one of the three visual display conditions. Upon detection of the target, the participant indicated that the target was situated in their target reticle using the verbal signal “TARGET”. The HF observer then recorded this time to detect the target from the initial “GO” command, visually confirmed the sighting, and also collected a video record of the extent and duration of exposure of the participant to the “enemy” target. Participants were required to detect each target within a two minute search time limit. If this time limit was exceeded a missed score was recorded on the data sheet. At the completion of the test the participant adopted a resting posture while the target was dropped and the next target in the matrix was raised. All of the targets were standardized for detection difficulty and balanced for the combination of actual and null targets (i.e. no target was presented and the time required for the participant to be sure the target field was clear was recorded) in each of the firing positions for each of the weapon sighting configurations. The presentation of the target locations
were also randomized within each sighting configuration. Each participant repeated this procedure in a standard repeated-measures design.

Following the completion of all three firing postures, each participant was required to complete an Off-Bore Task Questionnaire. After the completion of all three experimentation terrain conditions, participants were required to fill out a Sight Exit Questionnaire and a HMD Exit Questionnaire.

The following outlines the specific procedures for each of the three experimentation terrain conditions.

**Urban Streets Terrain:**

A single firing position (5’ x 5’ barrier under a modular tent) was established at the east side of the McKenna MOUT site for the Urban Streets trial. Reference Figure 7.

![Urban Streets Terrain Set-up (inset – participants vantage)](image)

*Figure 7: Urban Streets Terrain Set-up (inset – participants vantage)*

Three firing postures were established from this one firing position. Participants were required to manoeuvre their weapon around either the left side or right side of the barrier, or over the barrier according to the balanced order shooting schedule.
**Wooded Terrain:**

Similar to the Urban Streets terrain, one firing point (5’ x 5’ barrier under a modular tent) was established along the northwest tree line in the wooded terrain located to the east of the McKenna MOUT site. Reference Figure 8.

![Wooded Terrain Image](image)

**Figure 8: Wooded Terrain (inset – participants vantage)**

Three firing positions were established from this one firing point, which required the participant to maneuver their weapon around either the left side or right side of the barrier, or over the barrier.
**In-Building Terrain:**

A series of eight possible left-side and right-side fire positions were established along a route through the two instrumented 2-storey buildings (i.e. C4A and C4B). Reference Figure 9.

![Sample Target Location LH, RH Firing Position](figure.png)

**Figure 9: C4A and C4B Building**

As well, a series of four possible window firing positions were established around the perimeter of a one-story building (i.e. C2). Participants were required to scan the rooms in the C2 building by adopting fire positions at the window from the outside looking into the building. Sandbags were placed on the sill of the window for added comfort. Reference Figure 10.
Dependent Measures:

Each terrain condition was analyzed separately; however, the same dependent measures were collected for all three terrain conditions. Participant performance measures collected by HF observers included: time to detect targets, exposure to the target during target search, percentage accuracy, and target detection accuracy (i.e. number of true positives, false negatives, true negatives, and false positives). Statistical differences between the three visual display conditions were determined using a balanced, repeated-measures analysis of variance for the time to detect target data, target detection accuracy and Exit Questionnaire results. Duncan’s post hoc analyses were conducted on significant differences found in the objective data and subjective Exit Questionnaire data between the various conditions.

3.5 Acceptability Scale

Questionnaire ratings are based on the seven-point scale shown in Figure 11.

Figure 10: C2 Building

Figure 11: The Seven-Point Acceptability Scale
3.6 Limitations

This study had several limitations.

- A potentially confounding factor related to participant performance was the condensation build-up experienced similarly on both the HMD conditions due to cold temperatures and body heat.

- Due to the electrical hardware and housing configuration of the HMD’s, the prototype monocular display that was used had the right eye display and associated goggle housing removed from the biocular product. Therefore the display could only be used with the left eye.
4 Results

Results are organized into two main sections: objective and subjective performance measures. Objective performance results are further segmented into urban, wooded, and in-building terrains. Subjective results are provided first for the weapon sight comparisons and then for the head-mounted display comparisons.

4.1 Objective Performance Measures

Each terrain condition was analyzed separately, however, the dependent variables common to all three experiment components were target detection time from stopwatch recordings, percent accuracy, and target detection accuracy (i.e. number of true positives, false negatives, true negatives, and false positives) based on HF observer scoring.

Statistical analysis consisted of a repeated measures ANOVA for the time to detect targets between the three weapon mounted visual display conditions (monocular, biocular, C79) for each of the three different postures (left side, window/trench, right side), and for target detection accuracy. The analysis was carried out separately for the three terrain conditions; Urban Streets, Wooded, and In Buildings. Duncan’s post-hoc analyses were conducted on significant differences. Differences were identified at $p \leq .05$, with n=12 for the Urban Streets and Wooded terrain, and n=16 for the C2, C4 AB In Building terrain. Unless otherwise noted on the following graphs, a geometric shape denotes the objective means, the ‘box’ denotes $\pm 1$ standard error, and the ‘whiskers’ denote $\pm 1$ standard deviation.

4.1.1 Urban Streets Objective Data

The following section describes the objective data from the Urban Streets terrain. The mean target detection time, percent accuracy, number of true positives, false negatives, true negatives, and false positives were used as measures of the target detection performance for the three visual display conditions and three postures.

4.1.1.1 Urban Street Target Detection Time

For each participant and each condition, the target detection time for each posture was recorded by the HF observer. Participants were required to detect each target within a two minute search time limit. If this time limit was exceeded a missed score was recorded on the data sheet.

A highly significant effect was observed for the target detection time between the three visual displays (monocular, biocular, C79 sight), $F(2, 22)=61.18$, $p=.000$. Reference Figure 12. Duncan’s post-hoc analyses indicated that the time to detect targets was significantly quicker with the C79 condition as compared to the two digital display conditions. When comparing the mean target detection time between the three display conditions, the C79 was more than three times quicker than the monocular, and biocular HMD times. The mean time for the C79 condition was $18.54 \pm 12.88$ s, while the monocular and biocular conditions scored $61.36 \pm 25.40$ s, and $63.20 \pm 22.69$ s respectively. No significant effect was observed between the monocular and
biocular HMD conditions. This finding was in agreement with comments from participants
during the focus group who felt that the in-service sight (C79 sight) was the quickest method for
detecting targets.

![Graph showing target detection time](Image)

**Figure 12: Urban Streets Target Detection Time (All Postures Combined)**

A significant effect was also observed for the target detection time between the three adopted
postures (left, window, right), $F(2, 22)=5.43$, $p<.02$. Reference Figure 13. Duncan’s post-hoc
analysis indicated that participants spent a significantly longer time to detect targets while
adopting a right sided posture as compared to the window/trench posture ($p<.01$). This trend
was also observed for the right sided posture when compared to the left sided posture ($p<.06$).
4.1.1.2 Urban Streets True Positive

A significant effect was observed between the three display conditions for the number of true positives (targets hit), F(2, 22)=9.37, p=.001. Reference Figure 14. Duncan’s post-hoc analysis indicated that the number of true positives was higher with the C79 condition when compared to the two digital displays.

Overall participants were more accurate with the C79 condition (86.29%), than when using the monocular display (66.67%) or the biocular display (66.13%). This finding was reinforced by several of the participants’ subjective comments. Participants felt that they were more accurate with the C79 optical sight, and felt more confident in their target detection abilities under these conditions. With respect to the digital displays, participants also commented that they experienced a difficult time detecting targets especially when looking into low light areas through windows and doorways.
4.1.1.3 Urban Streets True Negative

No significant effect was observed between the three display conditions for the number of true negatives, $F(2, 22) = .20, p = .82$. Participants were able to correctly identify when no targets were present in their weapons display similarly between the three display conditions.

4.1.1.4 Urban Streets False Positive

No significant effect was observed between the three display conditions for the number of false positives (i.e. false alarms), $F(2, 22) = 1.57, p = .23$. The number of false positives incurred by the participants under each of the three conditions was similar.

4.1.2 Wooded Terrain Objective Data

The following section describes the objective data from the Wooded Terrain. The mean target detection time, percent accuracy, number of true positives, false negatives, true negatives, and false positives were used as measures of the target detection performance for the three visual display conditions and three postures.

Figure 14: Urban Streets True Positive
4.1.2.1 Wooded Terrain Target Detection Time

For each participant and each condition, the target detection time for each posture was recorded by the HF observer. Participants were required to detect each target within a two minute search time limit. If this time limit was exceeded a missed score was recorded on the data sheet.

A highly significant effect was observed for the target detection time between the three visual displays (monocular, biocular, C79 sight), F(2, 22)=18.63, p=.000. Reference Figure 15. Duncan’s post-hoc analyses indicated that the time to detect targets was significantly quicker with the C79 condition as compared to the two digital display conditions. When comparing the mean target detection time between the three display conditions, target detection with the C79 was more than two times quicker than the monocular, and biocular HMD. The mean time for the C79 condition was 15.06±9.37 s, while the monocular and biocular conditions scored 36.10±17.17s, and 39.26±21.85s respectively. No significant effect was observed between the monocular and biocular HMD conditions. Similar to the Urban Streets comments, this finding was also in agreement with comments from participants during the focus group who felt that the in-service sight (C79 sight) was the quickest method in detecting targets.

![Figure 15: Wooded Terrain Target Detection Time (All Postures Combined)](image_url)

Unlike the finding from the MOUT trial, no significant effect was observed for the target detection time between the three adopted postures (left, window, right), F(2, 22)=.02, p=.98. Participants detected targets in a similar time regardless of posture.
4.1.2.2 Wooded Terrain True Positive

No significant effect was observed between the three display conditions for the number of true positives (targets hit), $F(2, 22)=1.65, p=.21$. Reference Figure 16. Overall, participants were 81%-93% accurate in detecting targets in the Wooded environment.

![Figure 16: Wooded Terrain True Positive](image)

4.1.2.3 Wooded Terrain True Negative

No significant effect was observed between the three display conditions for the number of true negatives, $F(2, 22)=1.38, p=.27$. Participants were able to correctly identify when no targets were present in their weapons display similarly between the three display conditions.

4.1.2.4 Wooded Terrain False Positive

No significant effect was observed between the three display conditions for the number of false positives (i.e. false alarms), $F(2, 22)=1.18, p=.32$. The number of false positives incurred by the participants under each of the three conditions was similar.

4.1.3 In Building Objective Data

The following section describes the objective data from the C2, C4 AB In Building terrain. The mean target detection time, and percent accuracy were used as measures of the target detection performance for the three visual display conditions and three postures.
4.1.3.1 In Building Target Detection Time

Due to the setup of this experiment, the data was analyzed in a slightly different manner than the previous two terrain conditions. For each participant and each condition, the total time to “clear” the C4 AB building (i.e. left, right posture) of targets along a predetermined route through the two-storey buildings was calculated based on the participants’ initial entry time into the building up until the exiting of the building. Unlike the Urban Streets and Wooded terrain experiments, the left and right side postures for this experiment were not analyzed separately. However, the presentation of the targets for the left and right side were balanced. As well for the “clearing” of the C4 AB buildings, target accuracy was not recorded.

Following the “clearing” of the C4 AB buildings, participants were required to detect targets from the outside looking into the C2 building from four separate windows adopting the window posture. The time to detect targets within the C2 building (i.e. window posture) was recorded separately from the total time required to “clear” the entire C4 AB buildings (left, right posture). In this experiment participants were not restricted to a search time limit. As well for the target detection task for the C2 building only true positives (targets hit) and false negatives (target miss) were recorded.

For clearing the inside of the two-storey C4 AB buildings (left, right posture) condition, a highly significant effect was observed for the time to “clear” the entire building when comparing the three visual displays (monocular, biocular, C79 sight), F(2, 30)=40.18, p=.000. Reference Figure 17. Duncan’s post-hoc analyses indicated that the total time to clear the building was significantly quicker with the C79 condition as compared to the two digital display conditions. The mean time for the C79 condition was 224.93 ± 79.80 s, while the monocular and biocular conditions scored 416.20 ± 129.51 s, and 416.33 ± 138.95 s respectively. No significant effect was observed between the monocular and biocular HMD conditions. Similar to the Urban Streets, and Wooded terrain, this finding was in agreement with comments from participants during the focus group who felt that the in-service sight (C79 sight) was the quickest method in detecting targets.
Figure 17: C4 AB In Building Target Detection Time (Left, Right Posture)

For the target search from perimeter windows in building C2 (i.e. window posture), a highly significant effect was observed for the target detection time between the three visual displays (monocular, biocular, C79 sight), \( F(2, 30) = 12.90, p = .000 \). Reference Figure 18. Duncan’s post-hoc analyses indicated that the time to detect targets in each window was significantly quicker with the C79 condition as compared to the two digital display conditions. When comparing the mean target detection time between the three display conditions, the C79 was close to two times quicker than the monocular, and biocular HMD times. The mean time for the C79 condition was \( 7.07 \pm 3.78 \) s, while the monocular and biocular conditions scored \( 13.56 \pm 5.98 \) s, and \( 14.81 \pm 5.98 \) s respectively. No significant effect was observed between the monocular and biocular HMD conditions. Similar to the Urban Streets, Wooded and C4 AB In Building terrain, this finding was also in agreement with comments from participants during the focus group who felt that the in-service sight (C79 sight) was the quickest method in detecting targets.
No significant effect was observed between the three display conditions for the number of true positives (targets hit) for the C2 (window posture), $F(2, 30) = 1.18, p = .32$. Reference Figure 19. Overall, participants were 66%-74% accurate in detecting targets for the window posture in the C2 building.
4.2 Subjective Performance Measures

Statistical analysis consisted of a repeated measures ANOVA for the Sight and HMD Exit Questionnaire data between the various conditions for each of the three terrain conditions; Urban Streets, Wooded, and In Buildings. Duncan’s post-hoc analyses were conducted on significant differences. Unless otherwise noted, differences were identified at p ≤ .05, with n=16 for the Sight Exit Questionnaire and n=15 for the HMD Exit Questionnaire.

Planned comparisons were performed on specific parameters to determine the effect of the two sighting systems and to determine the effect of the two HMD’s. In addition the participants’ agreement statements of Sight and HMD conditions as well as their assessment of the digital video sight and HMD features were examined.

Unless otherwise noted on the following graphs, a geometric shape denotes the subjective means, the ‘box’ denotes ± 1 standard error, and the ‘whiskers’ denote ± 1 standard deviation.

4.2.1 Exit Sight Subjective Data

To determine the effect of the two different types of sighting systems, questionnaire responses related to target detection, sight image, tactical issues, overall and overall acceptability were compared.
4.2.1.1 Target Detection

Participants rated the acceptability of the target detection capabilities of the two sighting conditions with the statements, ‘Ease of Detecting Targets,’ ‘Time to Detect Targets,’ ‘Ease of Aiming Sight,’ ‘In-building Target Engagement,’ ‘Urban Streets Target Engagement,’ ‘Wooded Target Engagement,’ ‘Unmagnified Target Detection,’ ‘Magnified or Zoomed Target Detection,’ and ‘Ease of Scanning Target Field with Sight’.

4.2.1.1.1 Overall Target Detection

When comparing all nine target detection variables between the two sight conditions (C79 and DVS), participants’ mean acceptability rating of the C79 sight was between “Barely Acceptable” and “Reasonably Acceptable,” compared to the DVS which was rated between “Borderline” and “Barely Acceptable”. Reference Figure 20.
4.2.1.1.1 Ease of Detecting Targets

A significant effect was observed between the two weapon sights for the ease of detecting targets, $F(1, 15)=4.95$, $p<.05$. Reference Figure 21. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was between “Barely Acceptable” and “Reasonably Acceptable,” while the DVS was rated between “Borderline” and “Barely Acceptable.” Participants commented that they found it more difficult to detect targets with the DVS, especially when combined with the biocular HMD.

![Figure 21: Ease of Detecting Targets](image)

4.2.1.1.2 Time to Detect Targets

A significant effect was observed between the two weapon sights for the time to detect targets, $F(1, 15)=15.48$, $p=.001$. Reference Figure 22. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was between “Reasonably Acceptable” and “Completely Acceptable,” while the DVS was rated slightly greater than “Borderline.”
4.2.1.1.3  Ease of Aiming Sight

A significant effect was observed between the two weapon sights for the ease of aiming sight, $F(1, 15)=13.97, p=.002$. Reference Figure 23. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability compared to the DVS. The mean acceptability rating for the C79 sight was “Reasonably Acceptable,” while the DVS was rated between “Borderline” and “Barely Acceptable.” Participants commented that the C79 sight was very simple to use because of its basic design and function, compared to the DVS which required more training and was slightly more complex in design.
4.2.1.1.4 In-building Target Engagement

No significant difference was observed between the two weapon sights for the in-building target engagement, $F(1, 15) = .36, p = .56$. Both sights were rated between “Borderline” and “Reasonably Acceptable.”

4.2.1.1.5 Urban Streets Target Engagement

A significant effect was observed between the two weapon sights for the acceptability for urban street target engagement, $F(1, 15) = 10.82, p < .005$. Reference Figure 24. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability as compared to the DVS. The mean rating for the C79 sight was “Reasonably Acceptable,” while the DVS was rated between “Borderline” and “Barely Acceptable.”
4.2.1.1.6 *Wooded Target Engagement*

A highly significant effect was observed between the two weapon sights for the acceptability for wooded target engagement, $F(1, 15)=30.62, p=.000$. Reference Figure 25. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability as compared to the DVS. The mean rating for the C79 sight was greater than “Reasonably Acceptable,” while the DVS was rated between “Borderline” and “Barely Acceptable.”
4.2.1.1.7  **Unmagnified Target Detection**

A highly significant effect was observed between the two weapon sights for the acceptability for unmagnified target detection, $F(1, 15)=33.30$, $p=.000$. Reference Figure 26. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability compared to the DVS. The mean rating for the C79 sight was greater than “Reasonably Acceptable,” while the DVS was rated “Borderline.”
4.2.1.1.8 Magnified or Zoomed Target Detection

No significant difference was observed between the two weapon sights for the magnified or zoomed target detection, $F(1, 15)=.16$, $p=.69$. Both sights were rated between “Barely Acceptable” and “Reasonably Acceptable.”

4.2.1.1.9 Ease of Scanning Target Field with Sight

A highly significant effect was observed between the two weapon sights for the ease of scanning target field with sight, $F(1, 15)=18.75$, $p<.001$. Reference Figure 27. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability as compared to the DVS. The mean rating for the C79 sight was between “Barely Acceptable” and “Reasonably Acceptable,” while the DVS was rated less than “Borderline.” Participants commented during the trial that at times they found it difficult to orient the video image in the DVS within the larger search field.
4.2.1.2 Sight Image

Participants rated the acceptability of the sight image between the sighting conditions with the statements, ‘Field of View,’ ‘Quality of Image Detail,’ ‘Adjusting to Different Lighting Levels,’ ‘Reticle Pattern,’ ‘Extent of Magnification or Zoom Capability,’ and ‘Speed of Image Magnification’.

4.2.1.2.1 Overall Sight Image

When comparing all six sight image variables between the two sight conditions (C79 and DVS), participants’ mean acceptability rating of the C79 sight was between “Barely Acceptable” and “Reasonably Acceptable,” compared to the DVS which was rated slightly less than “Barely Acceptable.” Reference Figure 28.
4.2.1.2.1.1  **Field of View**  
A significant effect was observed between the two weapon sights for the field of view, F(1, 15)=5.15, p<.04. Reference Figure 29. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was between “Barely Acceptable” and “Reasonably Acceptable,” while the DVS was rated between “Borderline” and “Barely Acceptable.”
4.2.1.2.1.2 Quality of Image Detail

There was no significant difference found between the two sight conditions for the quality of image detail, F(1, 15) = 3.03, p = .10. The participants’ mean acceptability rating for both the C79 and DVS was between “Barely Acceptable” and “Completely Acceptable.”

4.2.1.2.1.3 Adjustment to Different Lighting Levels

A highly significant effect was observed between the two weapon sights for the adjustment to different lighting levels, F(1, 15) = 29.16, p = .000. Reference Figure 30. Duncan’s post-hoc analysis indicated that the C79 sight was rated significantly higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was “Reasonably Acceptable,” while the DVS was rated between “Barely Unacceptable” and “Borderline.” During focus group discussions participants commented that it was difficult to use the DVS especially when looking into rooms through windows and doorways. Participants found that the auto iris adjustment was too slow and not accommodating enough, especially on very sunny days.
4.2.1.2.1.4 *Reticle Pattern*

A significant effect was observed between the two weapon sights for the reticle pattern, $F(1, 15)=13.29$, $p=.02$. Reference Figure 31. Duncan’s post-hoc analysis indicated that the C79 sight was rated higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was greater than “Reasonably Acceptable,” while the DVS was rated between “Borderline” and “Barely Acceptable.”
4.2.1.2.1.5 Extent of Magnification or Zoom Capability

A significant effect was observed between the two weapon sights for the extent of magnification or zoom capability, $F(1, 15)=7.40$, $p=.02$. Reference Figure 32. Duncan’s post-hoc analysis indicated that the DVS was rated higher in acceptability as compared to the C79 sight. The mean acceptability rating for the DVS was between “Barely Acceptable” and “Reasonably Acceptable,” while the C79 sight was rated between “Borderline” and “Barely Acceptable.” Participants commented that they liked the continuous, high speed zoom adjustment and the higher power zoom capabilities (up to 10 times magnification) afforded by the DVS as compared to the 3.4 power C79 sight.
4.2.1.2.1.6 Speed of Image Magnification

A significant effect was observed between the two weapon sights for the speed of image magnification, $F(1, 15) = 9.15$, $p < .01$. Reference Figure 33. Duncan’s post-hoc analysis indicated that the DVS was rated higher in acceptability as compared to the C79 sight. The mean acceptability rating for the DVS was “Reasonably Acceptable,” while the C79 sight was rated between “Borderline” and “Barely Acceptable.” Participants commented that they preferred the speed of the DVS zoom function which enabled them to quickly interrogate objects within the field of view and zoom out to search the entire target field.
4.2.1.3 Tactical Issues

Participants rated the acceptability of the tactical issues between the sighting conditions with the statements, ‘Ease of Maintaining Stealth,’ ‘Surveillance,’ ‘Extent of Exposure to Enemy Fire during Target Search,’ ‘Extent of Exposure to Enemy Fire during Firing,’ and ‘Detectability by the Enemy’. Participant ratings reflected their opinions of how tactically effective the off-bore systems would be based on their experiences with the systems employed in this study.

4.2.1.3.1 Overall Tactical Issues

When comparing all five tactical variables between the two sight conditions (C79 and DVS), participants’ mean acceptability rating of the DVS was between “Barely Acceptable” and “Reasonably Acceptable”. By comparison, the C79 sight was only rated between “Borderline” and “Barely Acceptable.” Reference Figure 34.
4.2.1.3.1.1 Ease of Maintaining Stealth

There was no significant difference found between the two sight conditions for the ease of maintaining stealth, F(1, 15) = .01, p = .92. The participants’ mean acceptability rating for both the C79 and DVS was slightly less than “Barely Acceptable.” Participants commented that although you have protection from a direct line of fire with the DVS, the element of stealth is compromised because the weapon is still exposed and gives away your position.

4.2.1.3.1.2 Surveillance

There was no significant difference found between the two sight conditions for surveillance. Although not statistically significant, there was a trend in the DVS being rated higher in acceptability than the C79 sight, F(1, 15) = 3.73, p < .08. Reference Figure 35. The participants mean acceptability rating of the DVS was between “Barely Acceptable” and “Reasonably Acceptable,” compared to the C79 sight which was rated “Barely Acceptable.”
4.2.1.3.1.3 Extent of Exposure to Enemy Fire during Target Search

A significant effect was observed between the two weapon sights for the extent of exposure to enemy fire during target search, $F(1, 15) = 14.96$, $p = .002$. Reference Figure 36. Duncan’s post-hoc analysis indicated that the DVS was rated significantly higher in acceptability as compared to the C79 sight. The mean acceptability rating for the DVS was between “Barely Acceptable” and “Reasonably Acceptable,” while the C79 sight was rated between “Barely Unacceptable” and “Borderline.” During focus group discussions participants commented that although using the DVS took longer, they were exposed less to the enemy during the target search task.
4.2.1.3.1.4  Extent of Exposure to Enemy Fire during Firing

A significant effect was observed between the two weapon sights for the extent of exposure to enemy fire during firing, $F(1, 15)=15.43$, $p=.001$. Reference Figure 37. Duncan’s post-hoc analysis indicated that the DVS was rated higher in acceptability as compared to the C79 sight. The mean acceptability rating for the DVS was between “Barely Acceptable” and “Reasonably Acceptable,” while the C79 sight was rated between “Barely Unacceptable” and “Borderline.”
4.2.1.3.1.5 Detectability by the Enemy

There was no significant difference found between the two sight conditions for the detectability by the enemy, $F(1, 15)=1.49$, $p=.24$. The participants' mean acceptability rating for both the C79 and DVS was between “Barely Unacceptable” and “Barely Acceptable.” In this experiment and weapon sight configuration (i.e. the DVS was mounted on the C7 rifle), participants commented that whether you expose your entire body or just your weapon was irrelevant. In both cases you would be detected by the enemy. However participants in this study had limited, if any, combat experience with which to judge the detectability of a soldier vice a weapon alone.

4.2.1.4 Overall

Participants rated the acceptability of the overall variables between the sighting conditions with the statements, ‘Survivability,’ ‘Lethality,’ ‘Battle Awareness,’ ‘Ease of Use,’ ‘Ease of Learning,’ and ‘Tactical Feasibility’.

4.2.1.4.1 Overall Sight Overall

When comparing all six overall variables between the two sight conditions (C79 and DVS), participants mean acceptability rating of the C79 sight was between “Barely Acceptable” and “Reasonably Acceptable,” as compared to the DVS which was slightly lower but also rated between “Barely Acceptable” and “Reasonably Acceptable”. Reference Figure 38.
4.2.1.4.1.1 Survivability

A significant effect was observed between the two weapon sights for survivability, \( F(1, 15)=7.98, p=.01 \). Reference Figure 39. Duncan’s post-hoc analysis indicated that the DVS was rated significantly higher in acceptability as compared to the C79 sight. The mean acceptability rating for the DVS was between “Barely Acceptable” and “Reasonably Acceptable,” while the C79 sight was rated between “Borderline” and “Barely Acceptable.” During focus group discussions participants commented that although using the DVS took longer, they were exposed less to the enemy during the target search task and therefore would have greater survivability.
4.2.1.4.1.2 Lethality
There was no significant difference found between the two sight conditions for lethality, $F(1, 15)=1.00, p=.33$. The participants’ mean acceptability rating for both the C79 and DVS were between “Barely Acceptable” and “Reasonably Acceptable.”

4.2.1.4.1.3 Battle Awareness
A significant effect was observed between the two weapon sights for battle awareness, $F(1, 15)=4.76, p<.05$. Reference Figure 40. Duncan’s post-hoc analysis indicated that the C79 sight was rated significantly higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was between “Barely Acceptable” and “Reasonably Acceptable,” while the DVS was rated between “Borderline” and “Barely Acceptable.” During focus group discussions several participants commented that, especially with the biocular HMD, they were mostly only aware of the image that was presented on the display and not aware of their surrounding environment.
A significant effect was observed between the two weapon sights for the ease of use, $F(1, 15)=16.30$, $p=.001$. Reference Figure 41. Duncan’s post-hoc analysis indicated that the C79 sight was rated significantly higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was between “Reasonably Acceptable” and “Completely Acceptable,” while the DVS was rated between “Barely Acceptable” and “Reasonably Acceptable”.

**Figure 40: Battle Awareness**
4.2.1.4.1.5  *Ease of Learning*

A highly significant effect was observed between the two weapon sights for the ease of learning, F(1, 15)=23.44, p<.001. Reference Figure 42. Duncan’s post-hoc analysis indicated that the C79 sight was rated significantly higher in acceptability as compared to the DVS. The mean acceptability rating for the C79 sight was between “Reasonably Acceptable” and “Completely Acceptable,” while the DVS was rated between “Barely Acceptable” and “Reasonably Acceptable.”
4.2.1.4.1.6 Tactical Feasibility

There was no significant difference found between the two sight conditions for tactical feasibility, F(1, 15)=2.76, p=.12. Reference Figure 43. The participants mean acceptability rating of both the C79 and DVS were between “Borderline” and “Reasonably Acceptable”.
4.2.1.5 Overall Acceptance

Participants rated the overall acceptance between the sighting conditions.

4.2.1.5.1 Overall Acceptance

No significant effect was observed when comparing the overall acceptance between the two sight conditions (C79 and DVS). Although not significant, $F(1, 15) = 3.27$, $p = .09$, there was a trend in the C79 sight being rated higher in acceptability than the DVS. Reference Figure 44. The participants mean acceptability rating of both the C79 and DVS were between “Barely Acceptable” and “Reasonably Acceptable.” During focus group discussions, participants commented that although the DVS was sometimes difficult to use and the configuration was slightly awkward, a few changes to the DVS would make the system more acceptable.
4.2.1.6 Sight Statements of Importance

Participants rated their agreement of importance on the following eleven statements on a progressive scale of 1 to 7 (Strongly Disagree=1, Reasonably Disagree=2, Barely Disagree=3, Neutral=4, Barely Agree=5, Reasonably Agree=6, and Strongly Agree=7). See Table 2.

Table 2: Sight Statements of Importance

<table>
<thead>
<tr>
<th>Statement</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 'I can detect targets faster with a C79 sight.'</td>
<td></td>
</tr>
<tr>
<td>2. 'A sight that adjusts to lighting levels in the target field would be useful to me.'</td>
<td></td>
</tr>
<tr>
<td>3. 'I would feel safer using a C79 sight in a firefight in the woods.'</td>
<td></td>
</tr>
<tr>
<td>4. 'I prefer a fixed magnification to a variable zoom feature.'</td>
<td></td>
</tr>
<tr>
<td>5. 'I have better battlefield awareness with a C79 sight.'</td>
<td></td>
</tr>
<tr>
<td>6. 'I am able to take more time to get a better shot with the DVS.'</td>
<td></td>
</tr>
<tr>
<td>7. 'I would feel safer using a DVS in a firefight in Urban Streets.'</td>
<td></td>
</tr>
<tr>
<td>8. 'I would prefer the C79 sight for stealthy surveillance.'</td>
<td></td>
</tr>
<tr>
<td>9. 'An adjustable zoom sight would improve my target engagement performance.'</td>
<td></td>
</tr>
<tr>
<td>10. 'I would feel safer using a DVS in a firefight in buildings.'</td>
<td></td>
</tr>
<tr>
<td>11. 'I am more accurate with a C79 sight.'</td>
<td></td>
</tr>
</tbody>
</table>
Overall participants were in reasonable agreement (greater than “Barely Agree” but less than “Strongly Agree”) that the C79 optical sight was preferred for speed and accuracy of detecting targets, battle awareness, as well as safety. However participants also tended to support some of the features that the DVS afforded, such as an auto adjusting iris and gain control, and variable magnification. With respect to the suitability of a DVS in urban streets or in buildings during firefights, or the C79 optical sight for maintaining stealthy surveillance, participants were neutral in agreement.

![Figure 45: Sight Statement of Importance](image)

**Figure 45: Sight Statement of Importance**
4.2.1.7 Importance of Digital Video Sight Features

Participants recorded their judgment of importance on the following twelve DVS features on a progressive scale of 1 to 7 (No Importance=1, Slight Importance=2, Little Importance=3, Some Importance=4, Moderately Important=5, Very Important=6, and Extremely Important=7). See Table 3.

Table 3: Digital Video Sight Features

<table>
<thead>
<tr>
<th>1. 'Field of View'</th>
<th>2. 'Quality of Image Detail'</th>
<th>3. 'Quality of Image Colour'</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. 'Adjustable Zoom Capability'</td>
<td>5. 'Automatic Adjustment to Lighting Levels'</td>
<td></td>
</tr>
<tr>
<td>6. 'Ease of Use'</td>
<td>7. 'Ease of Learning'</td>
<td>8. 'Survivability'</td>
</tr>
<tr>
<td>9. 'Lethality'</td>
<td>10. 'Battle Awareness'</td>
<td>11. 'Non-detectability'</td>
</tr>
<tr>
<td>12. 'Stealth'</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall, participants rated all of the features for a DVS to be quite high: greater than “Very Important.” Reference Figure 46.
4.2.2 HMD Subjective Data

The results of the Exit questionnaire for the two head-mounted displays, for questions related to target detection, HMD image, physical effects, ease of use, overall, and overall acceptability, are detailed below.

4.2.2.1 Exit HMD Target Detection

Participants rated the acceptability of the target detection capabilities of the HMD conditions with the statements, ‘Ease of Detecting Targets,’ ‘Time to Detect Targets,’ ‘Ease of Aiming Sight,’ ‘In-building Target Engagement,’ ‘Urban Streets Target Engagement,’ ‘Wooded Target Engagement,’ and ‘Awareness of Sight Picture Location in Target Field’.

4.2.2.1.1 Overall Target Detection

When comparing all seven target detection variables between the two HMD conditions (monocular and biocular), participants rated both displays to be of similar acceptability where the mean ratings were between “Borderline” and “Barely Acceptable”. Reference Figure 47.
4.2.2.1.1 Ease of Detecting Targets

No significant difference was observed between the two HMD’s for the ease of detecting targets, \( F(1, 14) = 1.09, p = .31 \). Both HMD’s were rated between “Borderline” and “Barely Acceptable.”

4.2.2.1.2 Time to Detect Targets

No significant difference was observed between the two HMD’s for the time to detect targets, \( F(1, 14) = 1.89, p = .67 \). Both HMD’s were rated between “Borderline” and “Barely Acceptable.”

4.2.2.1.3 Ease of Aiming Sight

No significant difference was observed between the two HMD’s for the ease of aiming the sight, \( F(1, 14) = .10, p = .75 \). Both HMD’s were rated between “Borderline” and “Barely Acceptable.”
4.2.2.1.4  *In-building Target Engagement*

No significant difference was observed between the two weapon sights for the in-building target engagement, $F(1, 14)=.09, p=.77$. Both sights were rated between “Borderline” and “Barely Acceptable.”

4.2.2.1.5  *Urban Streets Target Engagement*

No significant difference was observed between the two HMD’s for the urban streets target engagement, $F(1, 14)=2.94, p=.11$. Both HMD’s were rated between “Borderline” and “Barely Acceptable.”

4.2.2.1.6  *Wooded Target Engagement*

No significant difference was observed between the two HMD’s for the wooded target engagement, $F(1, 14)=0.00, p=1.00$. Both HMD’s were rated between “Borderline” and “Barely Acceptable.”

4.2.2.1.7  *Awareness of Sight Picture Location in Target Field*

No significant difference was observed between the two HMD’s for the awareness of sight picture location in the target field, $F(1, 14)=3.53, p=.08$. Although not significant, there was a trend in the biocular HMD being rated slightly lower in acceptability than the monocular HMD. The monocular HMD was rated “Barely Acceptable,” where the biocular HMD was rated between “Borderline” and “Barely Acceptable.” Reference Figure 48.
4.2.2.2 HMD Image


4.2.2.2.1 Overall HMD Image

When comparing all nine HMD image variables between the two display conditions (monocular and biocular), participants mean acceptability rating of both displays were between “Borderline” and “Barely Acceptable”. Reference Figure 49.
4.2.2.2.1.1  **Ease of Viewing HMD Image**

There was no significant difference found between the two HMD conditions for the ease of viewing HMD image, $F(1, 14)=3.18$, $p=.10$. The participants’ mean acceptability rating for both the monocular and biocular displays were between “Borderline” and “Barely Acceptable.”

**Figure 49: Overall HMD Image**
4.2.2.2.1.2  **Ease of Orienting Video Sight in the Target Field**
There was no significant difference found between the two display conditions for the ease of orienting the video sight in the target field, $F(1, 14) = .07, p = .79$. The participants’ mean acceptability rating for both the monocular and biocular displays were between “Borderline” and “Barely Acceptable”.

4.2.2.2.1.3  **Quality of Image Detail**
There was no significant difference found between the two display conditions for the quality of image detail, $F(1, 14) = 3.03, p = .10$. The participants’ mean acceptability rating for both the monocular and biocular displays were between “Borderline” and “Reasonably Acceptable”.

4.2.2.2.1.4  **Quality of Image Colour**
There was no significant difference found between the two display conditions for the quality of image colour, $F(1, 14) = 2.15, p = .16$. The participants’ mean acceptability rating for both the monocular and biocular displays were equal to and greater than “Barely Acceptable” but less than “Reasonably Acceptable”.

4.2.2.2.1.5  **Image Stability**
There was no significant difference found between the two display conditions for the image stability, $F(1, 14) = 0.00, p = 1.00$. The participants’ mean acceptability rating for both the monocular and biocular displays were similar, greater than “Borderline” but less than “Barely Acceptable”.

4.2.2.2.1.6  **Viewing in Bright Lighting Conditions**
There was no significant difference found between the two display conditions for the viewing in bright lighting conditions, $F(1, 14) = .11, p = .74$. The participants’ mean acceptability rating for both the monocular and biocular displays were between “Barely Unacceptable” and “Borderline”. HF observations and comments during focus group discussions noted that participants had a difficult time in viewing targets through the displays especially when the sun glare was overhead or behind them.

4.2.2.2.1.7  **Viewing in Dim Lighting Conditions**
There was no significant difference found between the two display conditions for the viewing in dim lighting conditions, $F(1, 14) = .19, p = .67$. The participants’ mean acceptability rating for both the monocular and biocular displays were between “Barely Unacceptable” and “Borderline”.

4.2.2.2.1.8  **Display Glare**
There was no significant difference found between the two display conditions for display glare, $F(1, 14) = 2.50, p = .14$. The participants’ mean acceptability rating for both the monocular and biocular displays were between “Borderline” and “Barely Acceptable”. 
4.2.2.1.9 Image Quality during Camera Movement

There was no significant difference found between the two display conditions for the image quality during camera movement, $F(1, 14)=.65, p=.43$. The participants’ mean acceptability rating for both the monocular and biocular displays were approximately “Borderline”.

4.2.2.3 HMD Physical Effects

Participants rated the acceptability of the physical effects between the display conditions with the statements, ‘Weight on Head,’ ‘Balance on Head,’ ‘Range of Head Movement,’ ‘Eye Strain,’ ‘Nausea’ and ‘Headaches’.

4.2.2.3.1 Overall Physical Effects

When comparing all six physical effects variables between the two display conditions (monocular and biocular) no significant effect was observed, $F(1, 14)=2.34, p=.15$. Reference Figure 50. Participants’ mean acceptability rating of both displays was between “Barely Unacceptable” and “Barely Acceptable”.

![Figure 50: Overall Physical Effects](image)
4.2.2.3.1.1  Weight on Head
There was no significant difference found between the two display conditions for the weight on the head, F(1, 14)=.00, p=1.00. The participants’ mean acceptability rating for both the displays were similar, between “Borderline” and “Barely Acceptable”.

4.2.2.3.1.2  Balance on Head
There was no significant difference found between the two display conditions for the balance on the head, F(1, 14)=1.00, p=.33. The participants’ mean acceptability rating for both the displays was between “Borderline” and “Barely Acceptable”.

4.2.2.3.1.3  Range of Head Movement
There was no significant difference found between the two display conditions for the range of head movement, F(1, 14)=1.00, p=.33. The participants’ mean acceptability rating for both the displays were between “Borderline” and less than and equal to “Barely Acceptable”. During the focus group discussion, participants commented that the cables often got in the way of head movements and also got tangled up with equipment as well as foliage and branches.

4.2.2.3.1.4  Eye Strain
There was no significant difference found between the two display conditions for eye strain, F(1, 14)=1.54, p=.24. The participants’ mean acceptability rating for both the displays were between “Barely Unacceptable” and “Borderline”. During the focus group discussion, some participants commented that these HMD’s caused eyestrain especially when viewing the displays for prolonged periods.

4.2.2.3.1.5  Nausea
There was no significant difference found between the two display conditions for nausea, F(1, 14)=.09, p=.77. The participants’ mean acceptability rating for both the displays were approximately “Borderline”. During the focus group discussion, some participants commented that these HMD’s caused nausea especially when viewing the displays while walking.

4.2.2.3.1.6  Headaches
There was no significant difference found between the two display conditions for headaches. Although not significant, F(1, 14)=3.86, p<.07, there was a trend in the biocular display rated higher in acceptability than the monocular display. Reference Figure 51. The participants’ mean acceptability rating for both the displays were between “Barely Unacceptable” and “Borderline”.
4.2.2.4 HMD Ease of Use

Participants rated the acceptability of the ease of use between the display conditions with the statements, ‘Ease of Fitting to Head,’ ‘Adjustment for Viewing Display,’ ‘Ease of Viewing Local Surroundings (with HMD in place),’ ‘Ease of Viewing Local Surroundings (with HMD moved up),’ and ‘Ease of Moving Display out of Visual Field’.

4.2.2.4.1 Overall Ease of Use

When comparing all five ease of use variables between the two display conditions (monocular and biocular), participants’ mean acceptability rating of both displays was between “Barely Unacceptable” and “Barely Acceptable”. Reference Figure 52.
4.2.2.4.1.1  Ease of Fitting to Head

There was no significant difference found between the two display conditions for the ease of fitting to head, $F(1, 14) = .21$, $p = .66$. The participants’ mean acceptability rating for both the displays was between “Borderline” and “Barely Acceptable”.

4.2.2.4.1.2  Adjustment for Viewing Display

There was no significant difference found between the two display conditions for the adjustment for viewing display, $F(1, 14) = .65$, $p = .43$. The participants’ mean acceptability rating for both the displays was between “Borderline” and “Barely Acceptable”.

4.2.2.4.1.3  Ease of Viewing Local Surroundings (with HMD in place)

A significant difference was observed between the two display conditions for the ease of viewing local surroundings (with HMD in place), $F(1, 14) = 8.41$, $p = .01$. Reference Figure 53. Duncan’s post-hoc analysis indicated that the monocular HMD was rated higher in acceptability than the biocular display. The participants’ mean acceptability rating for the monocular display was between “Borderline” and “Barely Acceptable,” while the biocular display was rated “Barely Unacceptable”. One of the main concerns raised by participants during the focus group discussion was the low level of local situation awareness experienced with the biocular HMD.

Figure 52:  Overall Ease of Use HMD
This was especially true during the “clearing” of the In Building terrain, where participants were seen tripping on furniture, stairs and bumping into walls with the biocular HMD condition.

![Box plot showing acceptability ratings for monocular and biocular displays.](image)

**Figure 53: Ease of Viewing Local Surroundings (with HMD in place)**

4.2.2.4.1.4 *Ease of Viewing Local Surroundings (with HMD moved up)*

There was no significant difference found between the two display conditions for the ease of viewing local surroundings (with HMD moved up). Reference Figure 54. The participants’ mean acceptability rating for both the displays was between “Borderline” and “Barely Acceptable”. During the focus group discussion, some participants commented that the biocular HMD’s occasionally would not remain in the “up” position, and they were concerned with having to remove their hand from their weapon to lift the biocular displays when they wanted to walk around. With the monocular display participants were able to walk around without raising the HMD’s and could still maintain some situation awareness.
4.2.2.4.1.5  Ease of Moving Display out of Visual Field

There was no significant difference found between the two display conditions for ease of moving display out of visual field, $F(1, 14) = 1.52, p = .24$. The participants’ mean acceptability rating for both the displays was between “Barely Unacceptable” and “Barely Acceptable”.

4.2.2.5 HMD Overall

Participants rated the acceptability of the overall variables between the HMD conditions with the statements, ‘Survivability,’ ‘Lethality,’ ‘Battle Awareness,’ ‘Ease of Use,’ ‘Ease of Learning,’ ‘Tactical Feasibility,’ ‘Comfort,’ and ‘Fit and Adjustability’.

4.2.2.5.1 Overall HMD Overall

When comparing all eight overall variables between the two display conditions (monocular and biocular HMD), participants mean acceptability rating of both the displays were between “Barely Unacceptable” and “Barely Acceptable”. Reference Figure 55.

![Boxplot](image)

**Figure 54: Ease of Viewing Local Surroundings (with HMD moved up)**
4.2.2.5.1.1 Survivability

No significant effect was observed between the two display condition for survivability. Although not significant, $F(1, 14)=4.19$, $p<.06$, there was a very strong trend in the monocular display rated higher in acceptability than the biocular display. Reference Figure 56. The mean acceptability rating for the monocular HMD was between “Barely Acceptable” and “Reasonably Acceptable,” while the biocular HMD was rated between “Borderline” and “Barely Acceptable.” During focus group discussions participants commented that the monocular HMD allowed them to have better situational awareness when compared to the biocular HMD.
4.2.2.5.1.2 Lethality
There was no significant difference found between the two display conditions for lethality, F(1, 14) = 3.03, p = .10. The participants’ mean acceptability rating for both the monocular and biocular conditions were between “Borderline” and “Barely Acceptable”.

4.2.2.5.1.3 Battle Awareness
A significant effect was observed between the two display conditions for battle awareness, F(1, 14) = 13.82, p = .002. Reference Figure 57. Duncan’s post-hoc analysis indicated that the monocular HMD was rated significantly higher in acceptability than the biocular HMD. The mean acceptability rating for the monocular HMD was between “Borderline” and “Barely Acceptable,” while the biocular HMD was rated less than “Barely Unacceptable”. During focus group discussions several participants commented that especially with the biocular HMD, they were mostly only aware of the image that was presented on the display and not aware of their surrounding environment.
4.2.2.5.1.4  Ease of Use
There was no significant difference found between the two display conditions for ease of use, F(1, 14)=1.00, p=.33. The participants’ mean acceptability rating for both the monocular and biocular conditions were between “Barely Acceptable” and “Reasonably Acceptable”.

4.2.2.5.1.5  Ease of Learning
There was no significant difference found between the two display conditions for the ease of learning, F(1, 14)=1.00, p=.33. The participants’ mean acceptability rating for both the monocular and biocular conditions were similar, between “Borderline” and “Barely Acceptable”.

4.2.2.5.1.6  Tactical Feasibility
There was no significant difference found between the two sight conditions for tactical feasibility, F(1, 14)=1.65, p=.21. The participants mean acceptability rating of both the monocular and biocular HMDs were greater than “Borderline” but less than and equal to “Barely Acceptable”.

4.2.2.5.1.7  Comfort
There was no significant difference found between the two sight conditions for comfort, F(1, 14)=2.15, p=.16. The participants mean acceptability rating of both the monocular and biocular HMD’s were between “Borderline” and “Barely Acceptable”.

Figure 57: Battle Awareness
4.2.2.5.1.8  *Fit and Adjustability*

There was no significant difference found between the two sight conditions for fit and adjustability, $F(1, 14)=1.00, p=.33$. The participants mean acceptability rating of both the monocular and biocular HMD’s were approximately “Borderline”.

**4.2.2.6 HMD Overall Acceptance**

Participants rated the overall acceptance between the HMD conditions.

4.2.2.6.1  Overall Acceptance

When comparing the overall acceptance between the HMD conditions (monocular and biocular), participants’ mean acceptability rating of the monocular display was between “Borderline” and “Barely Acceptable,” while the biocular display was rated between “Barely Unacceptable” and “Borderline”. During focus group discussions participants commented that the monocular HMD allowed them to have better situational awareness when compared to the biocular HMD.

Reference Figure 58.

![Figure 58: Overall Acceptance](image)

**Figure 58:**  Overall Acceptance
4.2.2.7 HMD Statements of Importance

Participants rated their agreement of importance on the following ten statements on a progressive scale of 1 to 7 (Strongly Disagree=1, Reasonably Disagree=2, Barely Disagree=3, Neutral=4, Barely Agree=5, Reasonably Agree=6, and Strongly Agree=7). See Table 4.

Table 4: HMD Statements of Importance

<table>
<thead>
<tr>
<th>Statement</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>'I am more aware of my immediate surroundings with the monocular display.'</td>
<td></td>
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<tr>
<td>'I am better able to concentrate on target engagement with the biocular display.'</td>
<td></td>
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<tr>
<td>'I am less visually distracted when wearing the biocular display.'</td>
<td></td>
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<tr>
<td>'I have less eyestrain with the monocular display.'</td>
<td></td>
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<tr>
<td>'When viewing the biocular display I am unable to observe my surroundings.'</td>
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<tr>
<td>'I can locate the target faster with the monocular display.'</td>
<td></td>
</tr>
<tr>
<td>'The biocular display is easier to view in bright lighting conditions than the monocular display.'</td>
<td></td>
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<tr>
<td>'The weight of the biocular display is noticeably heavier on my head than the monocular display.'</td>
<td></td>
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<tr>
<td>'I experience more visual strain with the monocular display.'</td>
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<tr>
<td>'Any occluded display in my field of view is always unacceptable.'</td>
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Overall participants were fairly neutral (greater than “Barely Disagree” but less than “Barely Agree”) to both HMD conditions for target engagement speed, accuracy, and concentration, viewing in bright lighting, weight, as well as eye strain. However with respect to the ability to observe surroundings and obstructed vision, participants tended to agree that the biocular HMD decreased situational awareness and an occluded display regardless of monocular or biocular orientation is always unacceptable. Participants’ mean rating for both these statements was between “Barely Agree” and “Reasonably Agree”. Reference Figure 59.
Figure 59: HMD Statement of Importance
4.2.2.8 Importance of HMD Features

Participants recorded their judgment of importance on the following ten HMD features on a progressive scale of 1 to 7 (No Importance=1, Slight Importance=2, Little Importance=3, Some Importance=4, Moderately Important=5, Very Important=6, and Extremely Important=7). See Table 5.

Table 5: HMD Features

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<tr>
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<tbody>
<tr>
<td>1</td>
<td>'Weight on Head'</td>
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<tr>
<td>2</td>
<td>'Balance on Head'</td>
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<tr>
<td>3</td>
<td>'Position Adjustment'</td>
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<tr>
<td>4</td>
<td>'Ease of Use'</td>
</tr>
<tr>
<td>5</td>
<td>'Quality of Image Detail'</td>
</tr>
<tr>
<td>6</td>
<td>'Quality of Image Colour'</td>
</tr>
<tr>
<td>7</td>
<td>'Image Stability'</td>
</tr>
<tr>
<td>8</td>
<td>'Having One Eye Free'</td>
</tr>
<tr>
<td>9</td>
<td>'Ease of Moving Display out of Visual Field'</td>
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<tr>
<td>10</td>
<td>'Image Quality during Camera Movement'</td>
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</table>

Overall, participants rated most of the features for a HMD to be quite high: equal to and greater than “Very Important.” Participants rated the ‘Weight on Head’ and ‘Balance on Head’ of HMD’s to be slightly lower in importance, between “Moderately Important” and “Very Important”. Reference Figure 60.
Figure 60: Importance of HMD Features
5 Discussion

This section presents a summary and discussion of the major results of this study. It also includes recommendations for improving off-bore weapon systems.

5.1 Head-Mounted Display Alternatives:

Participants preferred a monocular HMD to a biocular HMD for use with off-bore weapon systems. While some considered the monocular HMD to be unacceptable (20%), many more participants rejected the use of a biocular display (40%). The rejection of the biocular display can be traced to the participants’ loss of situation awareness when visually immersed with both eyes. While the local situation awareness afforded by the monocular display was still problematic, in terms of the extent of visual field obstruction, the loss of vision to both eyes when viewing the biocular displays was judged to be unacceptable and dangerous in battle. This was evidenced when soldiers were “clearing” buildings and walking with the off-bore weapon system. With the monocular display, soldiers were observed using their free eye to navigate around obstacles and seemed to retain better awareness of the terrain space and the activities going on within it. Using the biocular display, soldiers were observed tripping and bumping into obstacles, and often complained about being “blind” to the situation around them.

For target detection performance there was no difference between the monocular and biocular displays for any of the three terrain conditions: urban streets, wooded, and in-building. Subjective assessments confirmed these results and also suggested that participants did not perceive any differences for image quality, colour, and stability, or for display viewing in various lighting conditions, or any physical effects relating to eye strain, nausea, or headaches. We had expected that the use of both eyes to search for targets in the biocular display would improve search performance over the monocular display due to the probability of summation of both eyes. Such was not the case.

One explanation might be the considerable lengths that participants adopted to avoid binocular rivalry and inter-eye accommodation when using the monocular display. When searching for targets, soldiers would close their free eye and cup their hand around the eye guard to minimize any distracting light from reaching the display, thereby minimizing the problems with the monocular display.

Participants emphasized that the loss of local visual situation awareness was a primary factor in their rejection of the biocular display. Interestingly, we believe that this loss of awareness was the same for both monocular and biocular displays during actual display use. The visual demands of the search task were such that soldiers committed their entire attention to observing the visual display. For the monocular display this attentional focus or tunneling with the visual display eye (left) effectively rendered the free eye (right) blind while engaged in the visual search task. The difference between the monocular and biocular displays then relates more to the transition time required to change from viewing the visual display to viewing the local surroundings. In the case of the biocular display this transition requires the display to be flipped up by removing a hand from their weapon; a dangerous and relatively time consuming practice.
With the monocular display, soldiers only needed to open their free eye and shift their attention from the visual display.

5.2 Weapon Sight Alternatives:

Participants were able to detect targets in urban streets three times faster with the C79 optical sight, with a greater likelihood of detection (86% vs. 66%), than with the off-bore video sight. In wooded and in-building terrain participants were twice as fast at detecting targets with the optical sight over the off-bore sight, but the likelihood of target detection was similar. Subjective results supported these findings and indicated that the optical sight was also preferred for battlefield situation awareness, ease of target scanning, field of view, and adjusting to different lighting conditions.

However, at the completion of the study, participant ratings did not indicate any differences between the two sights for lethality, tactical feasibility, or overall preference. This lack of overall differences can be explained by the strong preference participants assigned to the off-bore sight for survivability. Clearly, a key feature of the off-bore system was the ability of soldiers to search for and engage targets from behind cover with minimal exposure to the enemy. When using the C79 optical sight participants needed to expose their head as a minimum, and typically their upper torso, in all three firing postures investigated in the three terrain conditions. Conversely, using the off-bore system soldiers only exposed their hands and forearms.

In the end participants did not indicate an overall preference for either sight because each sight had a different mix of strengths and weaknesses depending on the tactical and battlefield situation. When speed and aggression are key in the assault the optical sight is preferred for its speed and ease of target detection and engagement and for enabling the soldier to maintain their situation awareness in a rapidly changing pace of battle. The off-bore video sight offers advantages in static defensive positions for minimizing detection by the enemy, where the high-speed zoom capability can be employed effectively, and in close quarter battle situations in complex urban terrain where survivability risks can be reduced at dangerous crossing areas and in-buildings.

Ideally, future weapon systems would include both on-bore and off-bore sighting and engagement options.

5.3 Suggestions to further an Off-bore Weapon System:

While participants could readily see the benefits of an off-bore weapon system, many limitations with the current test system needed to be overcome before the concept would prove effective in battle. Key among these concerns was the use of an occluded display (monocular or biocular) that reduces the soldier’s free field vision, thereby eroding their local situation awareness. Participants also found the cabling distracting and the camera auto-iris was not sufficiently sensitive to the range of lighting conditions, especially in buildings. While the variable, high speed zoom feature was well liked, participants could easily lose their sense of location in their target search area.

The following improvements suggested for a off-bore weapon system:
- Reduce the size and weight of the off-bore video camera. While the weight of the camera was low (lighter than the C79 sight), the mounting location of the camera can affect the weapon's center of gravity. The bulky proportions of the current camera were a concern and should be minimized to limit snagging, contact damage, and detection by the enemy.

- Reduce or eliminate the cabling between the camera and the visual display system. Consider wireless means.

- Investigate the use of unoccluded head-mounted displays to minimize the visual obstruction to local situation awareness (e.g. see-through prism, transparent virtual retinal, holographic, and off-head tablet displays).

- Investigate alternative means of enabling a soldier to maintain awareness of the relative location of their sight image in the larger target search field.

- Investigate the use of other target detection and surveillance enhancements possible with the digital video imagery.
6 References


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<td>Humansystems® Incorporated, 111 Farquhar St., 2nd floor, Guelph, ON N1H 3N4</td>
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<td>David W. Tack; Edward T. Nakaza</td>
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This experiment compared the target detection and engagement performance of weapon-mounted off-bore systems using monocular and biocular head-mounted displays for infantry soldiers in urban streets, wooded terrain, and in-buildings terrain. Specifically, this trial compared the performance of soldiers using a weapon-mounted off-bore video sight in conjunction with a monocular and biocular head mounted display (HMD) to the in-service C79 optical sight.

Participant performance measures included: time to detect targets, exposure to the target during target search, percentage accuracy, and target detection accuracy. Subjective measurements from questionnaire data included acceptability of the sight and HMD conditions. Subjective data were also collected from a post-experiment focus group discussion.

The results of this study indicated that participants preferred a monocular HMD to a biocular HMD for use with off-bore weapon systems. There was no difference in target detection performance between the monocular and biocular displays for any of the three terrain conditions: urban streets, wooded, and in-building. The rejection of the biocular display can be traced to the participants' loss of situation awareness when visually immersed with both eyes.

Participants were able to detect targets in urban streets three times faster with the C79 optical sight, with a greater likelihood of detection, than with the off-bore video sight. In wooded and in-building terrain participants were twice as fast at detecting targets with the optical sight over the off-bore sight, but the likelihood of target detection was similar.

However, at the completion of the study, participant ratings did not indicate any differences between the two sights for lethality, tactical feasibility, or overall preference due to the strong preference participants assigned to the off-bore sight for survivability. In the end participants did not indicate an overall preference for either sight because each sight had a different mix of strengths and weaknesses depending on the tactical and battlefield situation.

Based on the results of this experiment, areas for improvement and future research are recommended.

(U) Soldier Information Requirements Technology Demonstration Project; SIREQ TD; Monocular; Biocular; Head Mounted Display; HMD: Off-bore; off-axis aiming; disconnected rifle sight; video sight; target detection