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Abstract

This study was conducted to determine whether night vision goggles (NVGs) with hyperstereo viewpoint offsets produced a significant difference in the magnitude and direction of throwing errors compared to NVGs without hyperstereo viewpoint offsets. A second reason for the study was to disambiguate the visual motor performance effects of an NVG design with mixed vertical and horizontal viewpoint offsets.

Each of 32 National Guardsmen threw simulated grenades onto a trap-door target, a task that was modeled after a "door-kicking" military operation. Each time the participant threw a grenade, the radial direction and distance of the grenade's landing position were recorded. The results of the study indicated that wearing NVGs with hyperstereo viewpoint offsets resulted in a statistically significant increase in the magnitude and direction of errors in throwing compared to non-hyperstereo viewpoint offsets. Results also indicated that the horizontal component of a mixed horizontal and vertical offset NVG design accounts for most of the errors in performance. The results suggest that soldiers will need to practice throwing grenades while wearing NVGs with viewpoint offsets in order to approach the same accuracy level as with non-offset NVGs.

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1. Introduction

In many military operations, soldiers depend on views of the environment imaged by sensors and presented on visual displays, such as those on night vision goggles (NVGs). These sensor views of the scene often have the same perspective as the soldier's own direct view. In some cases, however, the sensors cannot be situated directly in front of the observer's eyes (see Figure 1). Consequently, the displays present the scene from viewpoints that are offset with respect to the soldier's eyes.

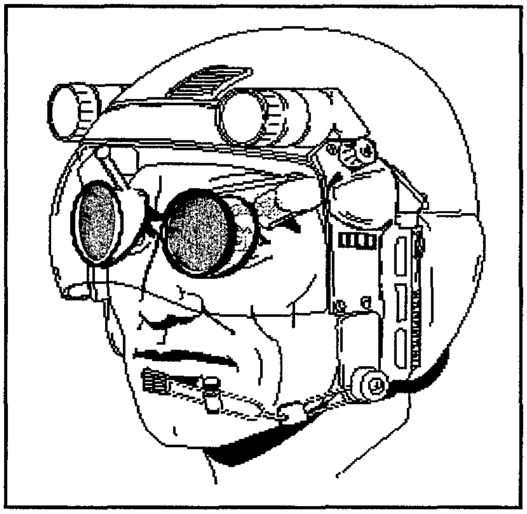

Figure 1. Example of Combined Horizontal and Vertical Sensor-Viewpoint Offsets in a Proposed Helmet-Mounted Display for Helicopter Pilots (adapted from Klymenko & Rash, 1995).

One reason that sensors may be offset is to prevent occlusion of the observer's direct line of sight (LOS), thus making possible a "see-through" design like the display shown in Figure 1. A second reason is to provide potential benefits of exaggerated interocular separation (i.e., hyperstereo) for enhancing the perception of depth at greater viewing distances. (However, this enhanced depth acuity at greater distances may be accompanied by adverse side effects, which are discussed later.) Hyperstereo is a design feature in some new NVGs, and for this reason, this study was concerned with the possible side effects of sensor-viewpoint offsets. In this study, the authors used behavioral measures to infer the magnitude and direction of the perceptual impact of offset viewpoints. We now discuss research that illustrates the effect of hyperstereo on depth perception.

1.1 Offsets and Perception

Viewing the environment from offset viewpoints creates retinal images that produce a distorted percept of the physical layout of the scene. Objects in the scene may appear to have sizes and locations that do not match the actual geometry of the scene. Even with 1x magnification so that retinal images of individual objects are the same size as with normal direct vision, perspective relationships in the scene (how foreground objects are aligned with more distant objects) are altered by the displacement of the observer's viewpoints.

Moreover, hyperstereo offsets have the potential to be considered not only as a *distortion* of the observer's perception of physical space but also as a *correction* of typically observed visual compression in the observer's perception of physical space (primarily when objects are viewed at distances beyond 30 meters). Specifically, compared to the observer's direct view perception of visual space, the retinal images produced by wider viewpoint separation may overcome the observer's natural tendency to compress the depth dimension along the LOS. (A common example of depth foreshortening is the persistent illusion that the 9-foot dashed highway lane lines are only about 3 feet long.)

1.2 Compression of the Depth Dimension

Research in visual perception indicates that observers who binocularly view distant objects in the natural environment foreshorten the Z axis (LOS) separation between the objects relative to the X axis (lateral) separation (Sipes, CuQlock-Knopp, & Torgerson, 1995; Todd, Tittle, & Norman, 1995; Toye, 1986, Wagner, 1985). This under-representation of the depth component of space relative to the lateral component of space is denoted here as depth compression.

Given this natural tendency to compress space in the depth dimension in direct unaided vision, we should expect that displays designed to duplicate normal binocular vision would also exhibit perceptual depth compression; this compression becomes increasingly significant for viewing distances beyond 30 meters. By contrast, displays designed to exaggerate the binocular disparity between two retinal images (i.e., hyperstereo display systems) should enhance the perception of the depth component of physical space and possibly compensate for perceptual depth compression.

Vision research studies have used telestereoscopes to increase an individual's effective interocular separation (Bennett, van der Kamp, Savelsbergh, & Davids, 1999, 2000). For instance, Sipes, CuQlock-Knopp, Torgerson, and Merritt, (1997) found that participants' judgments showed less visual depth compression when they used a telestereoscope to judge the relative spatial positions among objects in an open field than when they directly viewed the same array of objects.

Other studies comparing normal 2.5-inch interocular separation with zero interocular separation showed that viewpoint separation is a key factor in depth perception. Rosenberg (1992) found that using a display that reduced ocular separation to zero yielded performance 10 times poorer than a display with normal interocular separation of 62 mm. Some of the present authors, using a variety of dependent measures, also found that displays that provided images with no binocular separation between the two viewpoints produced significantly more errors in performance than normal binocular displays (CuQlock-Knopp, Torgerson, Sipes, Bender, & Merritt, 1995, 1996; CuQlock-Knopp, Myles, & Merritt, 1996; Merritt, CuQlock-Knopp, & Myles, 1997).

So far, we have focused primarily on offsets and visual perception. We now turn to the literature relevant to offsets and visual motor task performance.

1.3 Offsets and Visual Motor Task Performance

Although hyperstereo, a special type of offset, has been shown to enhance the *perception* of depth, research has shown that advantages in perception do not necessarily lead to advantages in the *physical interactions* based on those perceptions. One consequence of offset sensors, for instance, is an inconsistency between the information from the haptic modality and the information from the visual modality. This type of inconsistency has been shown to have adverse implications for perceptual motor task performance.

In the vision research literature, studies of prism adaptation are related to the visual motor conditions created by offsets. This paradigm required participants to view the task apparatus through prisms that deliberately rearranged vision to produce incongruency between eye and hand coordination. Tasks such as underwater magnitude estimation, piano playing, throwing, simple motor reaction time, and target pointing are some of the typical tasks used in these studies (Redding & Wallace, 1994, 1996, 1997; Fisher & Ciuffreda, 1990; Welch, 1974).

This research has shown that there is a significant decrement in visual motor performance when the participants view the tasks through a prism instead of directly viewing the task. Moreover, this research indicates that it can take a substantial amount of time (perhaps weeks) for observers to develop mechanisms to compensate for the discrepancy between the felt and seen position of their limbs.

1.4 Individual and Combined Effect of Offsets

As mentioned earlier, one motivation for this study relates to the use of hyperstereopsis. A second motivation for this study is the need to disambiguate the separate individual contributions of the two types of offsets to visual motor performance. Specifically, we wanted to determine, for tasks involving distances well beyond arm's reach, how performance with the normal NVG compares to performance with (a) an NVG with a vertical offset, (b) an NVG with a horizontal offset, and (c) an NVG with a vertical and horizontal (mixed) offset.

1.5 Objectives

One objective of this study was to see if the magnitudes and the directions of errors in throwing grenades are statistically different when participants wear NVGs with hyperstereo viewpoints instead of NVGs without hyperstereo viewpoints. A second objective of the study was to determine if the magnitudes and the directions of errors are statistically different for the individual and combined effects of horizontal and vertical viewpoint offsets, when compared to standard binocular NVGs.

2. Method

2.1 Task: Grenade Throw

We selected a grenade-throwing task because it requires visual motor coordination indicative of perceived target location and thus reveals the spatial distortion caused by offset viewpoints. The magnitude and direction of throwing errors show the accuracy of the perceived target location in visual space.[1]

Although we were convinced of the value of the grenade-throwing task for assessing the effects of the offsets, we nevertheless interviewed special forces and conventional Army soldiers to determine if there might be any supplementary value of direct military interest. The consensus from the interviews was the confident expectation that grenades and other riot-control devices would be thrown during nighttime urban and counter-terrorist operations while soldiers wear NVGs. We concluded that it would be worthwhile to collect data about the hit rate for throwing grenades at short-range targets while soldiers wear NVGs for "door-kicking" operations.

The present task required each participant to throw 10 grenades, one at a time, onto a simulated trap door from 20 feet away. Experimental data were collected for the magnitude and direction of the errors of the grenade-throwing task. Errors were grenades that missed the trap-door target.

[1]Individual differences in throwing error were controlled by the selection of a sample of participants who received the same military training in grenade throwing. A within-groups design would have been an additional control, but we believed the residual effects from one offset to another would have introduced additional uncontrolled variability into the data analysis.

2.2 Experimental Design

A between-groups design was used for this study, with four groups of subjects defined by the four different goggle types shown in Figure 2: (1) (normal [an unmodified binocular NVG]), (2) vertical displacement, (3) a symmetrical, outward, horizontal displacement, which created hyperstereo, and (4) a displacement outward and downward, which mixed hyperstereo with a downward displacement of the viewpoints. In Figure 2, the upper two goggle types produced non-hyperstereo viewpoints and the lower two goggle types produced hyperstereo viewpoints. (The down and outward configuration was chosen in order to best emulate some NVGs that have recently been obtained for evaluation by the Army's Dismounted Battlespace Battle Lab [DBBL]. These particular NVGs were binocular with holographic eye-piece optics. It was planned that these NVGs would be used in an ensuing study after completion of the DBBL evaluation.)

2.3 Independent Variable

The independent variable was *goggle type,* which was defined by the four different goggle types just described.

2.4 Dependent Variables

2.4.1 Variable 1: Hits

The number of grenades that landed on the 2-foot by 2-foot trap door area was defined as the number of hits for each participant.

2.4.2 Variable 2: Range Error

The distance of the grenade from the center of the trap door along the y axis (long or short along the LOS) was defined as range error. Range error was computed by the conversion of the radial direction closest to where the grenade landed (e.g., 9, 10, 11 o'clock, etc.) to an angle in degrees. The distance of the grenade from the center of the trap door without regard to direction was denoted the radial error. This was then multiplied by the sine of the angle to obtain the range error for each throw.

2.4.3 Variable 3: Pull Error

The distance of the grenade from the center of the trap door along the x axis (left or right) was defined as pull error. Pull error was computed by first converting the radius closest to where the grenade landed to an angle in degrees. The radial error was then multiplied by the cosine of the angle to obtain the pull error for each throw.

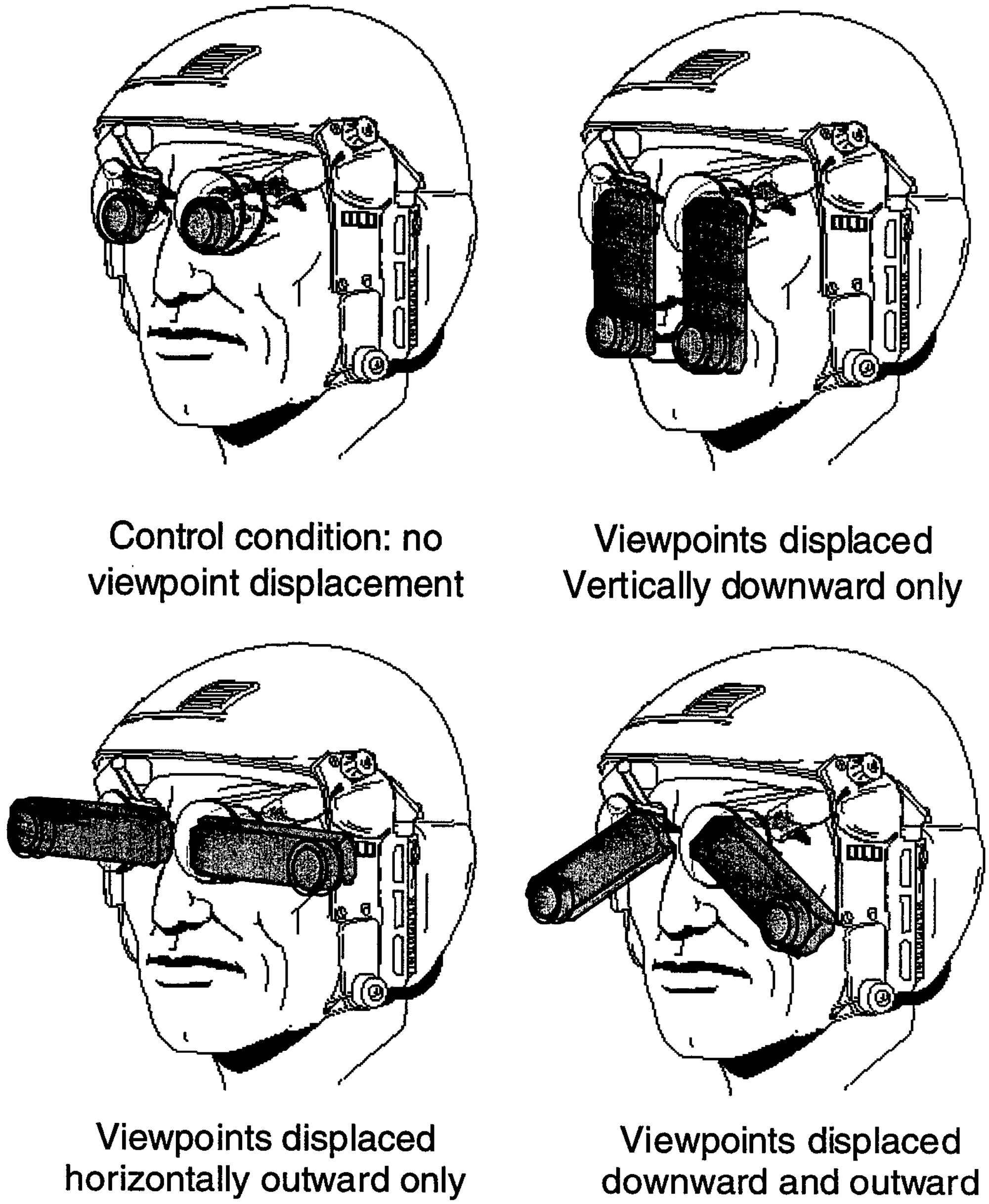

Figure 2. The Four Viewpoint Conditions.

2.5 Study Site

The experiment was conducted in a 27- by 19-foot area that consisted of a 19- by 8-foot light-sealed passageway leading to a 19- by 19-foot light-sealed room. This room was illuminated by an incandescent 15-watt light bulb that was dimmed almost to extinction. The illumination at the trap-door target was less than 0.016 footcandle; the passageway was minimally illuminated from the light in the room.

2.6 Apparatus

2.6.1 Apparatus for the Displaced Viewpoints

Three different "zig-zag mirror" attachments were designed and fabricated to displace the viewpoints of standard binocular NVGs, in order to allow displaced viewpoint testing to proceed before actual displaced viewpoint NVGs were available. These three mirror systems were attached to three standard binocular (AN/AVS-9V) via two high-quality front-surface mirrors per eye to displace the standard NVG viewpoints as described next.[2,3]

The mirror attachments were adjustable for aligning the left eye and right eye LOSs so that objects 10 feet away required the same ocular convergence as in direct viewing. Although it would have been possible to converge the hyperstereo mirror attachments (outward-downward and outward) at arm's length for close work, this would not have been practical because the user could not simply look up from a close range manual task and be able to diverge beyond parallel to fuse objects farther than arm's length. Hyperstereo goggle convergence would have to have been continually readjusted from arm's length to 20 feet, for example, and this would seem to be impractical in a combat setting. A user working on an arm's-length task should be able to glance up at an object 30 yards away without seeing double. With normal (non-hyperstereo) binocular NVGs, this is not a problem; when one looks up from an arm's length task, the image is not doubled, just out of focus. (Note: Automatic convergence control, analogous to the autofocus function in many modern cameras, could relieve the user of the need to manually reconverge hyperstereo goggles, but that would create the strange perceptual side effect of making objects seem to recede and advance in their distance from the observer.)

The simple zig-zag mirror apparatus (see Figure 3) displaces viewpoints backward as well as outward because of increased path length, but when this displacement is combined with the forward displacement inherent in standard NVGs to which the mirrors are attached, the net result is a fore-aft viewpoint location similar to that of a new hyperstereo NVG. Because of strict requirements for binocular alignment, it was best to construct four separate viewing devices, one for each of the goggle types shown in Figure 2.

The final set of binocular NVG viewing devices consisted of four aviator's helmets, each fitted with an NVG power supply and a helmet visor adapter for

[2]These zig-zag mirrors did not significantly change the resolution or display color of the displaced viewpoint systems, which were thus comparable to a standard NVG with normal "straight-ahead" viewpoints.

[3]A zig-zag-mirror device not only displaces the viewpoints of the left and right eyes downward or outward, but it also displaces the viewpoints backward because of the length of the zig-zag mirror pathways, as shown in Figure 3. When this backward displacement was combined with the forward displacement inherent in standard NVGs, the net result was a neutral fore-aft viewpoint location similar to that of the NVGs of interest to this study.

mounting an aviator's NVG. Three of the NVGs had an attached zig-zag mirror system to displace the viewpoint of each eye 3 inches from the LOS in normal unaided viewing.

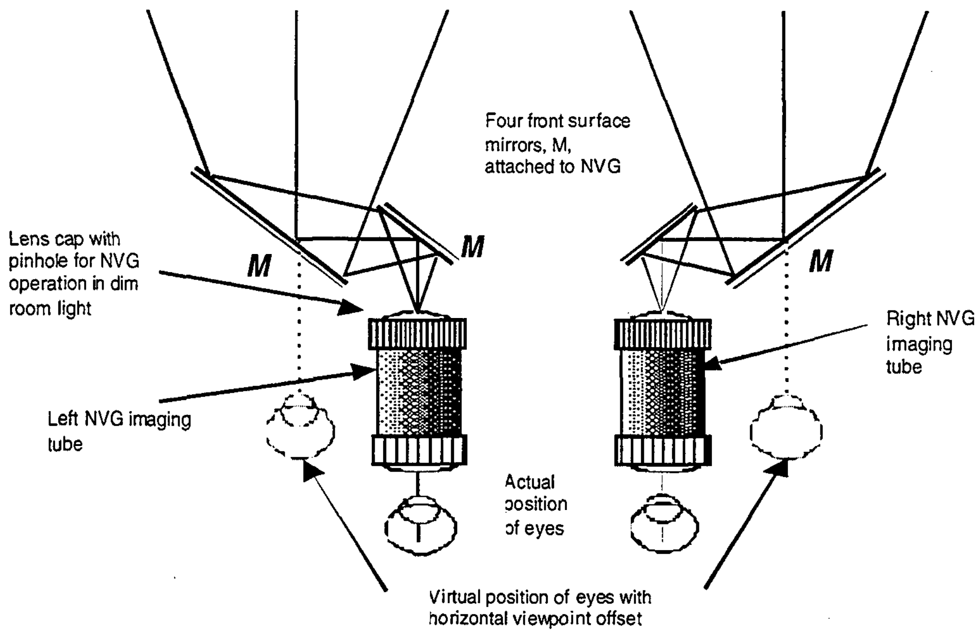

Figure 3. The Offset Apparatus.

To minimize weight on the participant's helmet, these mirror systems were constructed of lightweight materials such as sheet aluminum, foam core, and thermal glue; thin, front-surface glass mirrors were mounted by means of self-adhesive Velcro®. To counteract the forward-tipping torque on the participant's helmet, 1-pound bags of metal shot were attached with Velcro® to the back of the helmets as counterweights.

Lens caps with pinholes were fitted to the objective lenses of the NVGs to permit them to be used in semi-dim illumination (approximately 0.016 ft). The field of view (FOV) for these viewing devices was approximately 40°, equivalent to typical NVG FOVs, with a visual Snellen acuity approaching 20/25.

2.6.2 Apparatus for Grenades

Replicas of training grenades were constructed from heavy fabric filled with metal shot and were designed to weigh 1 pound and be spherical—the same shape and weight as U.S. Army training grenades. A 2- by 2-foot piece of black plywood was placed flat on the floor to simulate an open trap door.

2.7 Participants

Thirty-two male participants, between 18 and 45 years of age, from the Maryland National Guard, served as participants in this experiment. Each participant was randomly assigned to one of the four groups defined by the four goggle types. All participants had at least 20/40 acuity (corrected or uncorrected) in both eyes and normal stereoscopic vision.

2.8 Procedures

Each of the 32 participants began the experiment by reading and signing a consent form. Each was then tested for stereoscopic vision and at least 20/40 visual acuity. A TITMUS® vision tester was used to screen for these two requirements.

Next, the participant was shown a helmet fitted with an NVG and was informed about the procedures for focusing and adjusting it. Each participant then donned the helmet-NVG combination. that was dictated by his group assignment. He then followed the experimenter to the passageway that led to the room containing the trap door. The participant was told that his mission was to throw each of 10 grenades onto the 2- by 2-foot simulated trap-door opening and that the top three performers would receive an extra $10 in addition to the $30.00 that all participants were paid.

The participants had five practice throws at a distance of 20 feet from the trap door. The participants stood in the passageway and threw into the room through an open double door. The purpose of this practice was to give the participants a feel of throwing the grenade; the practice was not intended to allow the participants to reach asymptotic performance of the throwing task. The experimenter told the participants that she would record how many grenades landed on the trap door as well as the position of the other grenades that did not reach it. Each participant then threw each of five grenades as practice.

The experimenter then gathered the grenades and returned them to the participant. Then, each participant again threw 10 grenades. This time, the experimenter recorded the landing positions of the grenades at the end of the 10 throws. At the completion of the 10 grenade throws, the participant was debriefed.

For each grenade thrown, radial direction and radial distance were recorded. The first measure was which of the 12 radials was closest to the grenade's displacement from the trap door. Radials were denoted as hours on a clock, spaced 30° apart around a 360° circle centered on the trap door. The second measure was the distance of the grenade from the center of the trap door along the nearest radial.

3. Results

Two issues directed the data analysis. First, we wanted to determine if hyperstereo, in general, produced a significant difference in performance for a task that depended on an accurate perception of depth. Second, we wanted to compare the different offset types to determine the relative contribution of the horizontal and vertical components of the viewpoint offset. Since new NVG designs can incorporate various types of viewpoint offsets, it was of special interest to determine if there was a relative performance difference for each offset type, compared to the normal binocular goggle (i.e., the aviators' night vision imaging system [ANVIS]).

To address these issues, we conducted four planned orthogonal contrasts on each of the three measures: hits, range error, and pull error (see Table 1). Comparison 1 (hyperstereo versus non-hyperstereo) compared the *combined data* from the normal goggle and the vertical offset goggle to the *combined data* from the horizontal offset goggle and the (mixed) horizontal and vertical offset goggle. This comparison assesses the effect of hyperstereo.

Table 1. Planned Comparisons

Goggle 1 = Normal Binocular Goggle

Goggle 2 = Vertical Offset Goggle

Goggle 3 = Horizontal Offset Goggle

Goggle 4 = Horizontal and Vertical (Mixed) Offset Goggle

Comparison 1:	Goggles 1 & 2	Versus	Goggles 3 & 4
Comparison 2:	Goggle 1	Versus	Goggle 2
Comparison 3:	Goggle 1	Versus	Goggle 3
Comparison 4:	Goggle 1	Versus	Goggle 4

The other three comparisons contrast each type of offset to the standard binocular goggle. The first of these three comparisons contrasts the normal goggle with the vertical offset; the second contrasts the normal goggle with the horizontal offset; and the third comparison contrasts the normal goggle with the (mixed) horizontal and vertical offset.

3.1 Planned Orthogonal Contrast 1: Hyperstereo Versus Non-hyperstereo

Compared to the non-hyperstereo condition, the hyperstereo offsets significantly reduced the number of hits (the number of grenades that landed on the trap door area) $F(1,28) = 5.75$ ($p < .02$). Of the 10 grenades thrown by each of the 32 participants (320 grenades), 86 landed on the trap door area. Of this 86, 57 landed on the trap door for the non-hyperstereo participants, whereas only 29 landed on the trap door for the hyperstereo participants. The mean number of grenades of 10 for the hyperstereo group was 1.81 per subject, and the mean for the non-hyperstereo group was 3.56 per subject.

For the range error, the hyperstereo condition resulted in grenades overshooting the trap door by a significantly larger extent than the number of grenades that overshot the trap door for the non-hyperstereo condition, (means of 30.4 inches versus means of 23.5 inches) $F(1,28) = 8.62$ $p < .01$. The hyperstereo condition resulted in no significant difference with regard to a tendency or bias to err to the right or left (pull) when the grenades were thrown on the trap door, compared with the non-hyperstereo condition.

3.2 Planned Orthogonal Contrast 2: The Normal NVG Compared to the Vertical Offset NVG

The performance of the participants who wore the NVGs with the vertical offset was not significantly different from the performance of the participants who wore the normal goggle on any of the three measures: hits, range, or pull.

3.3 Planned Orthogonal Contrast 3: The Normal NVG Compared to the Horizontal Offset NVG

The participants who wore the NVGs with the horizontal offset showed significantly poorer performance than those who wore the normal goggles on the *hits* measure, (mean of 1.8 versus mean of 4.1), $F(1,28) = 5.23$ $p < .03$. Although the mean of the range error was 23.1 inches for the normal goggle, compared to the mean of 29.5 inches for the horizontal offset goggle, this difference was not statistically significant. As with the vertical offset goggles, there was no statistically significant difference on the pull measure between the wearing of the horizontal offset goggles versus the wearing of the normal goggle.

3.4 Planned Orthogonal Contrast 4: The Normal NVG compared to the (Mixed) Horizontal and Vertical Offset NVG

This contrast compares NVGs that combine the two types of offsets, horizontal and vertical, with the normal NVGs. The results of the analysis indicated that wearing goggles that combine the vertical and horizontal offsets produced significantly poorer performance for *hits* (mean of 1.9 hits) than wearing the normal goggles (mean of 4.1 hits), $F(1,28) = 4.76$ $p < .03$. For the range error, wearing the study goggles also significantly increased overshooting of the target, compared to wearing the normal goggle (mean of 31.4 inches versus a mean of 23.1 inches), $F(1,28) = 5.25$ $p < .04$. Again, the pull measure did not show a statistically significant difference between wearing the offset goggles and wearing the normal goggles in any bias of erring to the right or left when the grenades were thrown on to the trap door.

Table 2 shows the mean errors for the range, pull, and hits across participants for each goggle type. The radial error is the overall deviation of the grenade from the trap door without the separation of the x and y components of the overall deviation. Table 2 clearly illustrates the relatively high contribution of range error to the overall error (radial error), compared to the contribution of the pull error, that is, the tendency to err to the right or left of the target. Averaged across conditions, range errors were 27 inches away from the trap door, whereas pull errors were only 3 inches away from the trap door.

Table 2. Mean of Range Error, Pull Error, and Hits for Each Goggle Type

Goggle type	Range (inches)	Pull (inches)	No. of hits
(1) Normal	23.1	1.6	4.1
(2) Vertical	23.9	3.5	3.0
(3) Horizontal	29.5	2.7	1.8
(4) Horizontal and vertical (mixed)	31.4	4.0	1.9

Figures 4 and 5 are provided to show the placement of the grenades on each of the 12 radials on the trap door and on each of the 12 radials beyond the trap door. The height of a stack indicates how often grenades landed in that position. (Some grenades within a stack are staggered to aid the reader in counting them.) Both figures show that the participants had a bias to throw to the left. There were 111 grenades that missed the target and landed to the left of the trap door (radials 11, 10, 9, 8, and 7) versus 45 that landed to the right (radials 1, 2, 3, 4, and 5). An analysis of the left-versus-right throwing data indicated that there were significantly more errors to the left than to the right, $t(156) = 5.22$ $p < .001$.

Throwing long rather than short is another attribute that both hyperstereo and the non-hyperstereo participants shared. Across conditions, 171 grenades missed the target and were long (radials 2, 1, 12, 11, and 10), compared to 48 grenades that missed the target and were short (radials 4, 5, 6, 7, and 8). (As previously noted, the hyperstereo participants threw grenades significantly farther in depth than the non-hyperstereo participants.) An analysis of the long-versus-short throwing data indicated that there were significantly more errors that were long than were short, $t(156) = 9.42$ $p < .001$.

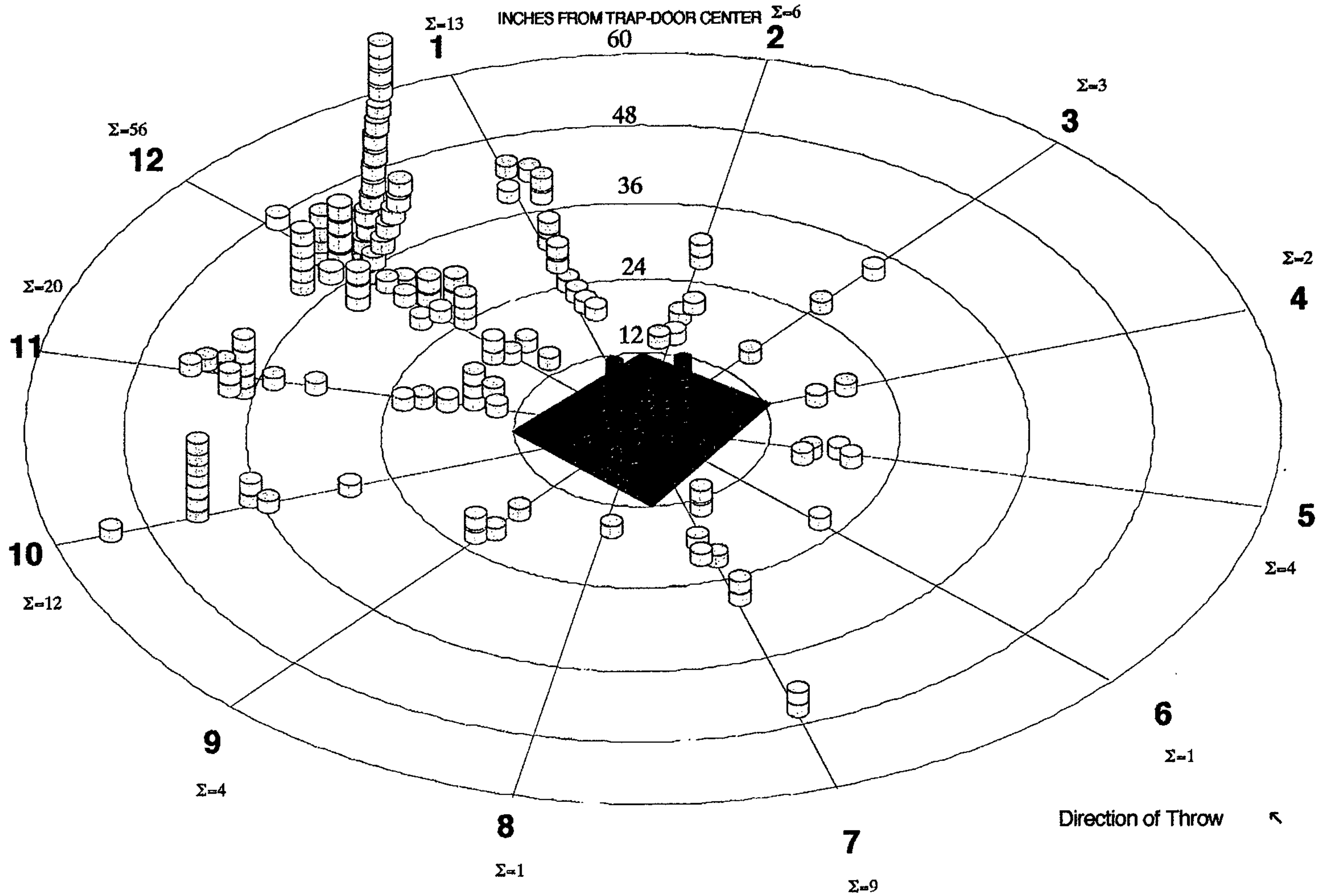

Figure 4. Landing Position of the Grenades for the Hyperstereo Condition.

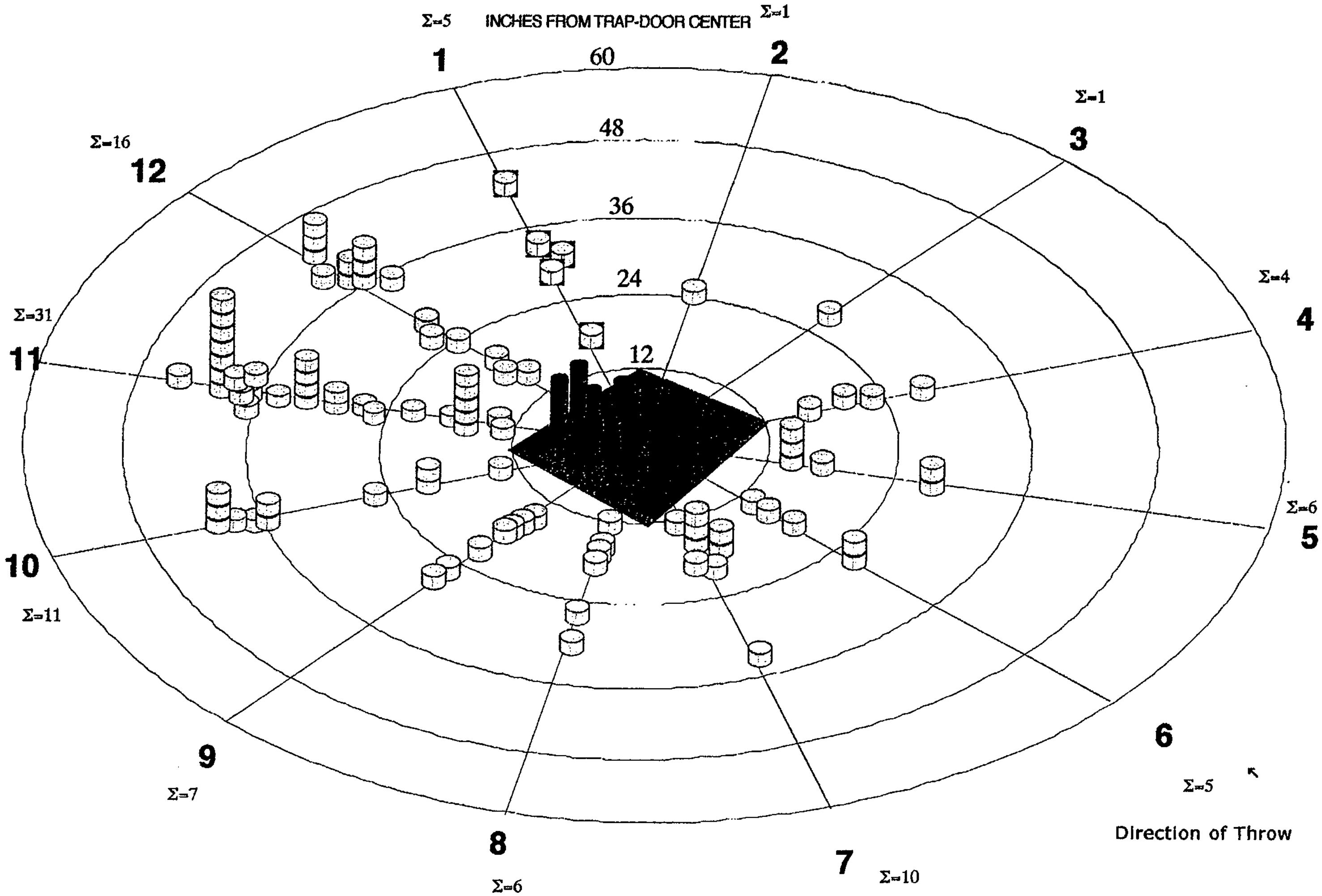

Figure 5. Landing Position of the Grenades for the Non-hyperstereo Condition.

4. Discussion

The authors had two primary objectives in conducting this study: (1) to provide data about the general magnitude and direction of hyperstereo effects on visual motor performance and (2) to assess the individual and mixed effects of vertical and horizontal viewpoint offsets, compared to the normal binocular goggle (i.e., ANVIS AN/PVS9). We were specifically concerned with the potential adverse visual motor effects that may accompany the use of hyperstereo to enhance the *perception* of depth at far distances. We used behavioral measures that we felt would directly map the magnitude and direction of the perceptual distortion to the magnitude and direction of the error in eye-hand coordination.

The results of the study indicated that wearing NVGs with hyperstereo viewpoint offsets resulted in a statistically significant increase in the magnitude and direction of throwing errors, compared to non-hyperstereo offsets. We hypothesized that hyperstereo would cause space to be perceived as stretched in depth and that this elongation would produce adverse effects in eye-hand coordination. Overshooting the target, for example, would be evidence that the target was perceived as farther away along the LOS.

The results of the study indicate that there was a statistically significant increase in overshooting the target with the hyperstereo viewpoint offsets; the failure to hit the target was more frequently the result of overshooting than undershooting.

Also consistent with our expectation, the viewpoint offset data did not show any systematic error bias (pull error) to the left or right of the target for the hyperstereo condition, compared to the non-hyperstereo condition. Overall, however, the research participants showed a bias to pull to the left in their throws. Seventy-one percent of the grenades that did not reach the trap door landed near radials that were to the left of the target. Nevertheless, pull errors accounted for a small proportion of the total errors relative to the range errors.

With regard to the relative contributions of the various offset types, the results indicate that the horizontal component accounts for the problem in visual motor coordination for a mixed horizontal and vertical offset design. The performance of the participants who wore the purely vertical offset was not statistically different from the performance of the participants who wore the normal goggle. Compared with the normal goggle, the performance of participants with the purely horizontal offset and the mixed horizontal and vertical offset goggles showed significantly more error, both in hitting the targets and in range errors.

There is evidence that participants can learn to adapt to rearrange visual input, as was the case in the prism studies reported in Section 1. Since this experiment did not allow time for participants to adapt to the viewpoints, our data can address only the *magnitude* of the expected effect of hyperstereo. These data indicate that the hit rate for the hyperstereo participants was approximately half the hit rate for the non-hyperstereo participants. Additional research is needed to address adaptation and recovery issues.

5. Summary

Hyperstereo viewpoint offsets produced the expected effects on visual motor task performance, operationally defined as behavioral measures of elongated perceived distance along the LOS. The behavioral indices (range error and hits) revealed that fewer grenades landed on the target in the hyperstereo condition, compared to the normal goggle condition. Our data suggest that NVGs with offset viewpoints would require some time for adaptation to distorted visual space before tasks requiring visual motor coordination can be performed.

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13. ABSTRACT *(Maximum 200 words)*

This study was conducted to determine whether night vision goggles (NVGs) with hyperstereo viewpoint offsets produced a significant difference in the magnitude and direction of throwing errors compared to NVGs without hyperstereo viewpoint offsets. A second reason for the study was to disambiguate the visual motor performance effects of an NVG design with mixed vertical and horizontal viewpoint offsets.

Each of 32 National Guardsmen threw simulated grenades onto a trap-door target, a task that was modeled after a "door-kicking" military operation. Each time the participant threw a grenade, the radial direction and distance of the grenade's landing position were recorded. The results of the study indicated that wearing NVGs with hyperstereo viewpoint offsets resulted in a statistically significant increase in the magnitude and direction of errors in throwing compared to non-hyperstereo viewpoint offsets. Results also indicated that the horizontal component of a mixed horizontal and vertical offset NVG design accounts for most of the errors in performance. The results suggest that soldiers will need to practice throwing grenades while wearing NVGs with viewpoint offsets in order to approach the same accuracy level as with non-offset NVGs.

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