Task-Based Video Quality Assessment of HVEC

Homeland Security

Science and Technology

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Technical Report

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Public Safety Communications Technical Report

Task-Based Video Quality Assessment of High-efficiency Video Coding

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Abbreviations

AVC	Advanced Video Coding
CIF	Common Intermediate Format (352 x 288 pixels)
DHS	Department of Homeland Security
GUC	Generalized Use Class
HRC	Hypothetical Reference Circuit
HD	High Definition
HEVC	High-efficiency Video Coding
ITS	Institute for Telecommunication Sciences
ITU-T	International Telecommunications Union, Telecommunication Standardization Sector
OIC	Office for Interoperability and Compatibility
PSCR	Public Safety Communications Research program
VGA	Video Graphics Array (640 x 480 pixels)

Abstract

This report details a laboratory study investigating the effects of various scene parameters and network conditions on the ability of viewers to discriminate among objects in recorded video. It is intended to be used both to make minimum bit rate recommendations for encoding of video used in public safety contexts and to compare the encoding performance of the H.265 High-efficiency Video Coding (HEVC) standard to that of H.264 Advanced Video Coding (AVC) using the results of a previous study conducted by the Public Safety Communications Research (PSCR) program. The scene content parameters under study in this test are target size, motion, and lighting. Network conditions include resolution reduction and H.265 HEVC encoding at a variety of bit rates. Recognition rates are calculated and presented as percentages of correctly recognized objects within a particular set of videos, adjusted to account for the probability of correct guesses. As in the previous PSCR study, the task-based subjective tests described here follow the methods outlined in International Telecommunications Union, Telecommunication Standardization Sector (ITU-T) Recommendation P.912.

Keywords: H.265, HEVC, H.264, AVC, task-based video quality, subjective test methods

1 Introduction

Housed within the Department of Commerce Labs in Boulder, Colorado, the Public Safety Communications Research program (PSCR), is a joint effort between the National Institute of Standards and Technology/ Communication Technology Laboratory and the National Telecommunications and Information Administration/ Institute for Telecommunication Sciences, and works in conjunction with the Department of Homeland Security Office for Interoperability and Compatibility (DHS OIC). The PSCR conducted a study to evaluate the performance of the new H.265 High-efficiency Video Coding (HEVC) standard and to compare it against that of the currently ubiquitous H.264 Advanced Video Coding (AVC) standard.

Throughout this report, two previous DHS reports will be frequently referenced:

- Video Quality Tests for Object Recognition Applications (DHS10-LIVE) – September 2010

  The goal of the study detailed in this report was to research the connection between certain scene content and network parameters within H.264-encoded video clips and viewer performance during object recognition tasks. Clips were presented in "real time"; participants were unable to use playback controls and saw each clip only once (U.S. Department of Homeland Security 2010).

- Recorded-Video Quality Tests for Object Recognition Tasks (DHS11-RECORDED) – September 2011

  This experiment was similar in design and goal to its predecessor above, but subjects this time were allowed to pause and replay clips, as well as to step back and forth through them frame by frame (U.S. Department of Homeland Security 2011).

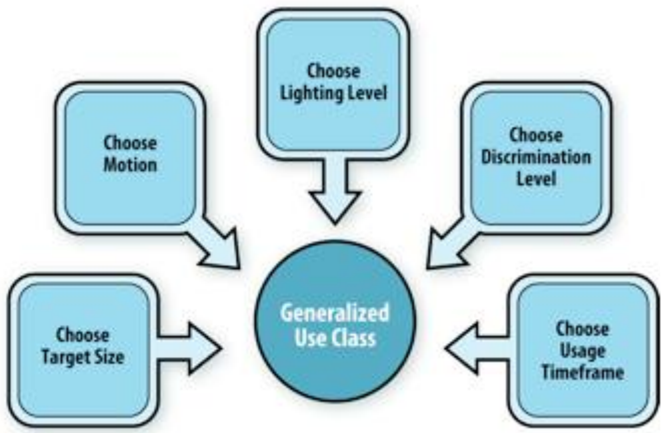
From this point on, these studies will be referred to as DHS10-LIVE and DHS11-RECORDED respectively. The results of DHS11-RECORDED are used in this report to compare the effects of H.264 encoding to those of H.265 encoding.

Many public safety practitioners make regular use of live and recorded video to complete various objectives. Video streams allow security personnel to maintain constant surveillance of a number of areas at once, medical personnel to remotely treat patients, and hazardous device responders to defuse explosives from a safe distance. As noted in previous PSCR reports, a common thread between these and other public safety video applications is the need to effectively identify particular targets within a given video stream.

Of course, minimum levels of video quality are necessary to properly perform object identification tasks, and some tasks demand more in terms of quality than others. However, it is important to balance quality with cost and with efficient use of network bandwidth. To this end, knowing how a certain encoded bit rate (speaking in terms of bandwidth) will affect video quality and the ability of practitioners to complete their tasks is very important.

It is necessary to consider that the performance of a viewer trying to complete a task may vary greatly depending on the content of the video. An encoder may not be able to retain sufficient information at a certain bit rate for a viewer to make correct identifications of objects in all situations. Taking this into consideration, the Video Quality in Public Safety working group included in their report, "Defining Video Quality Requirements: A Guide for Public Safety", the concept of generalized use classes (GUCs) (U.S. Department of Homeland Security 2010). As Figure 1 illustrates, a GUC is defined by the target size, lighting level, amount of motion in a particular scene, desired discrimination level, and whether the video will be viewed live or recorded.

Figure 1. Generalized Use Class Concept



The major concentration of this test focuses on network conditions and the effect of these conditions on video quality across a number of environments and situations. The parameters under study are compression with H.265 HEVC and resolution reduction to both Common Intermediate Format (CIF) (288x352) and Video Graphics Array (VGA) (640x480) formats. The results of this study are then used to calculate recognition rates that are compared to those of DHS11-RECORDED to illustrate the relative capabilities of H.265 HEVC versus H.264 AVC and to provide recommendations for video quality in the arena of public safety.

The test design described here is nearly identical to the one against which its results are being compared, and both tests comply with the recommendations set forth in ITU-T P.912 (ITU-T 2008). The previous test compared the recognition rates of viewers watching various scenes in recorded settings (where they are able to pause the video and step back and forth, frame by frame) against those in which the viewer must make discriminations in scenes using live feeds. It was found in DHS11-RECORDED that there was little difference in recognition rates of recorded-video viewers and live-video viewers (U.S. Department of Homeland Security 2011).

Results of this study and DHS11-RECORDED are represented as recognition rates—the percentage of properly identified objects, after adjusting for the probability of correct guesses.

2 Targets, Scenario Groups and Processed Scenes

2.1 Targets

Seven objects are used as targets for the object recognition task in this study. They are the following:

- Gun
- Electroshock weapon
- Hand-held mobile radio
- Mug
- Soda can
- Flashlight
- Cell phone

2.2 Scenario Groups

ITU-T P.912 laid out the concept of scenario groups, which are defined as "a collection of scenes of the same basic scenario with very slight differences between the scenes." In each scenario group, a unique video is made to present each object (ITU-T 2008). No other details are changed. Because of the similarities of the videos within a scenario group, the video tests the participants' ability to identify targets across several bit rates and resolutions.

Two rates of motion, four levels of lighting, and two object sizes were employed in combination with one another to create the resultant 14 scenario groups shown in Table 1. To reduce the size of the study and limit viewer fatigue, small objects were not used in dark lighting situations, and stationary objects were not filmed under bright, indoor light (U.S. Department of Homeland Security 2011). It is not likely that these scenario groups would have generated particularly useful data as the identification of stationary bright-light targets would be excessively easy, and identification of small, dark-light targets unnecessarily difficult. Scenes with flashlights were also omitted from dark-light, walking scenario groups.

To vary motion between scenario groups, objects were placed on pedestals in the "stationary" videos, and objects in motion were carried by an actor in each "moving-object" scene. The actor was filmed walking from both the left and right side of the screen, creating, in effect, two separate scenario groups, but the data was combined during analysis to calculate generalized recognition rates for motion in each context. The actor held all items in a neutral, non-contextual manner to avoid providing information about the nature of the object through body language.

All daylight scenes were filmed at the same sunny rural location, and all indoor scenes were filmed at an underground shooting range operated by a local law enforcement agency. Object size was varied by changing the distance of the actor and pedestal from the camera, and these distances were specifically decided upon prior to filming the clips.

Table 1. Summary of Scenario Groups

Scenario Group #	Lighting Condition	Motion	Target Size
1	Daylight	Stationary	Large
2	Daylight	Walking Speed, Right	Large
3	Daylight	Walking Speed, Left	Large
4	Daylight	Stationary	Small
5	Daylight	Walking Speed, Right	Small
6	Daylight	Walking Speed, Left	Small
7	Bright/Flashing	Walking Speed, Right	Large
8	Bright/Flashing	Walking Speed, Left	Large
9	Dim/Flash	Stationary	Large
10	Dim/Flash	Walking Speed, Right	Large
11	Dim/Flash	Walking Speed, Left	Large
12	Dark/Flash	Stationary	Large
13	Dark/Flash	Walking Speed, Right	Large
14	Dark/Flash	Walking Speed, Left	Large

2.3 Processed Scenes

Source scenes were adjusted to two resolutions, VGA (640x480 pixels) and CIF (352x288 pixels); frame rate was kept consistent throughout the clips at 29.97 frames per second (fps). Each downsized clip was then encoded at five different bit rates. Each combination of resolution and bit rate form a unique hypothetical reference circuit (HRC), a term used by the Video Quality Experts Group to refer to the distortion to a signal under study (U.S. Department of Homeland Security 2011). Table 2 identifies the five bit rates each for VGA and CIF resolutions, which equals 10 HRCs.

Table 2. Hypothetical Reference Circuits

Resolution	Bit Rates [kbps]
VGA	16, 32, 64, 128, 256
CIF	16, 32, 64, 128, 256

3 Test Design

3.1 Test Size

The clips presented to viewers in this study comprised of 14 scenario groups, 7 objects, and 10 HRCs. Taking into consideration the exclusion of the flashlight from two scenario groups, 96 source videos were filmed. Upon completion of the transformations to each resolution and encoding at the various desired bit rates, 960 videos were created for use in the test. Each clip was between five and nine seconds long.

Because viewer fatigue can degrade a viewer's performance, each participant only viewed 420 videos within the main part of the experiment, along with four videos presented as part of the practice test designed to familiarize him or her with the test software. Before the test, clips of the objects up close and on a pedestal were also displayed clearly to participants showing them which objects they were to identify during the test.

A Python script was used to randomly distribute the selection of videos viewed by each participant. While each viewer saw fewer than half of the total videos created for this study, every viewer was presented with three clips from each combination of the 14 scenario groups and 10 HRCs.

3.2 Viewers

This test was conducted using 38 participants. Each participant had a background in law enforcement, firefighting, or emergency medical service. The mean, median, and standard deviation in years of experience for the group were 20.65, 20, and 9.63 years respectively, so it follows that around 80-percent of participants had at least 10 years of experience in their field, with the least experienced person in the test having had 3.5 years of experience. Several participants had 30 years of experience or more.

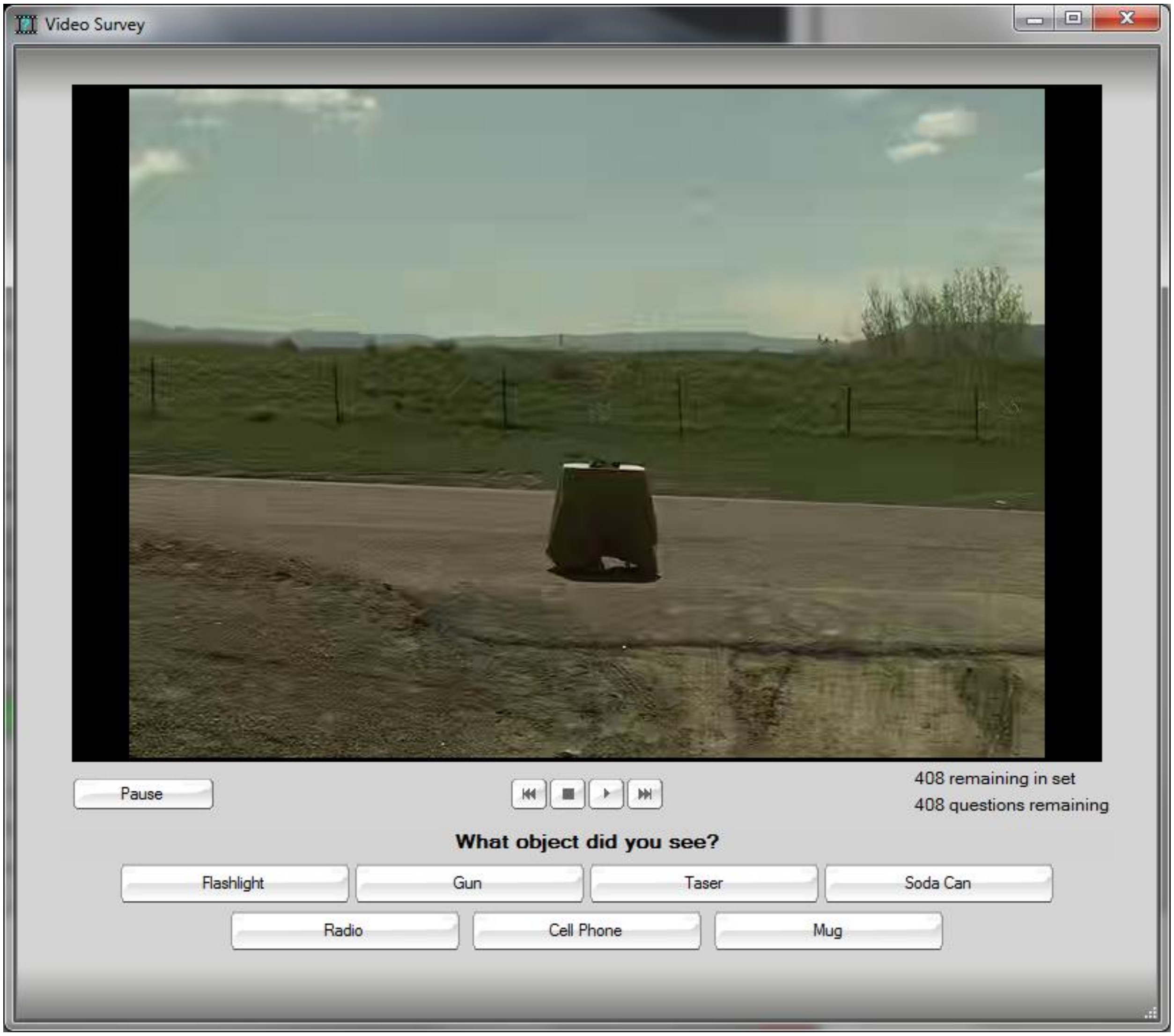
The Snellen and Ishihara tests were utilized to test every participant for vision acuity and color perception. Viewers with impaired acuity or color deficiencies were not excluded automatically, although additional analysis was performed on the results of their tests to determine whether their responses varied significantly from those of the other participants. One participant had strong deutan red-green deficiency and another tested positive for strong deutan red-green deficiency with general weakness of color vision, but nothing was found to suggest that either of their results corrupted the data as a whole.

3.3 Test Environment and Software

The software used on this test was the same as that used in DHS11-RECORDED, with one slight difference outlined below. A survey file for each viewer was inputted into the test software, and used to display videos in a predetermined unique order. All survey files were created using a Python script, which randomly distributed the selection and order of videos, while presenting three videos from each HRC-scenario group combination.

Using the software, viewers are able to pause, replay, and step back and forth through each clip frame by frame. No restriction was placed on participants' use of these features, but use of all playback features was recorded precisely by the software to make possible future analysis of each participant's behavior, if necessary.

Figure 2. Test Software Example



Viewers were not presented an option for *unsure* or *I don't know*, and were forced to make their best educated guess to progress to the next video. Figure 3 shows a screenshot of the test software. The primary difference in the operation of the testing software between this study and DHS11-RECORDED was that each survey file created for this test mandated a randomly selected order in which the response buttons appeared at the bottom of the window. This was done to reduce, as much as possible, response bias resulting from viewers clicking the same button every time they were unsure of an answer (U.S. Department of Homeland Security 2011).

Figure 3. Example of Randomly Placed Response Buttons

Viewing conditions followed the recommendations in ITU-T P.910 with one notable exception, in that viewing distance and angle were not controlled, as practitioners in real-world situations will inevitably position themselves in a way relative to the screen that would optimize their identification task performance. It is reasonable to assume that given

the approximate image height of five inches, their viewing distance fell within the one to eight picture heights recommended by ITU-T P.910 (ITU-T 1999).

4 Results

The charts in this section exhibit the results for each scenario group used in this study. The left-facing and right-facing videos for each group that included motion were combined into larger resulting groups, and the results of these are, therefore, based on twice as many samples as the stationary scenes. Recognition rates are given as the percentage of correct responses after adjusting for the probability of correct guesses, and are displayed in ascending order of bit rate in each chart. Information on both the data and analysis is located in the appendices.

4.1 Best-Case Recognition Rates

The following charts show the scenario groups with the highest overall recognition rates for each HRC. Unsurprisingly, H.265 HEVC is most effective in situations with limited motion and bright lighting.

Figure 4. Recognition Rates for Large Moving Targets in Bright Indoor Lighting

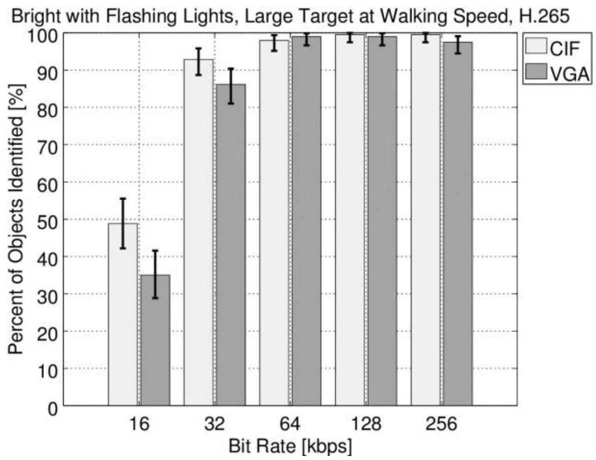


Figure 5. Recognition Rates for Large Stationary Targets in Dim Indoor Lighting

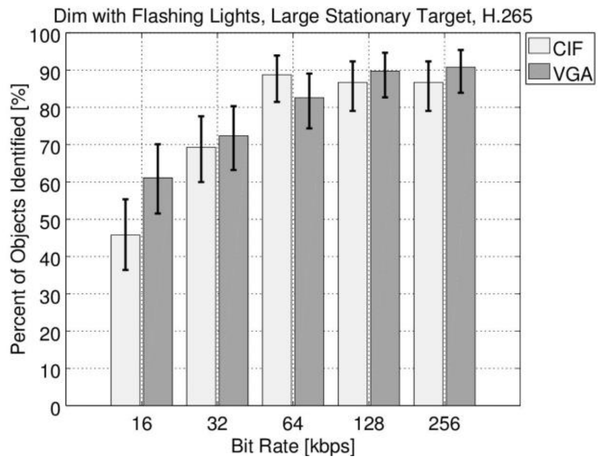
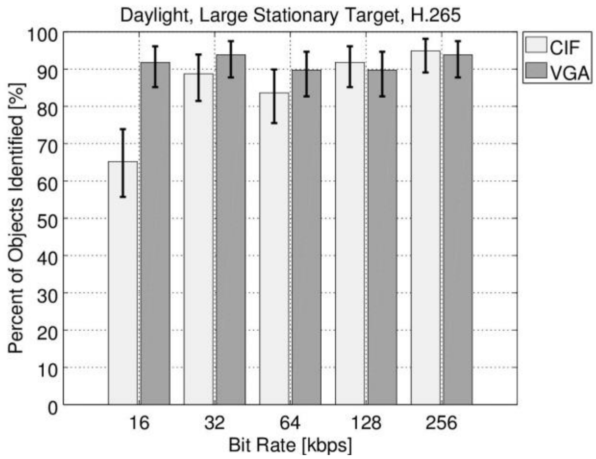


Figure 6. Recognition Rates for Large Stationary Targets in Daylight



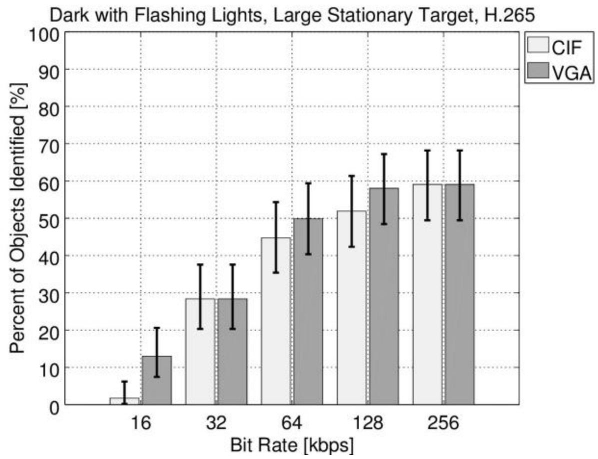
4.2 Recognition Rates and Lighting

While reviewing Figure 4, Figure 5, and Figure 6, it is clear that brighter lighting has a strong positive impact on the performance of participants. Holding motion and target size constant, we see that recognition rates of objects in daylight saw little decline based on HRC. All daylight recognition rates shown in Figure 6, save one, were above 80 percent, and five were above 90 percent.

As expected, recognition rates declined as lighting was lowered. When lighting was made dim, it was only for bit rates of 64 kbps or greater that 80-percent recognition rates were achieved, and the recognition rate of only one HRC actually exceeded 90 percent. Finally, in dark lighting conditions, recognition rates never reached the level of 60 percent, although 50 percent was observed in four HRCs.

A saturation effect is visible in Figure 4, Figure 5, and Figure 6, much like what was observed in DHS10-LIVE (U.S. Department of Homeland Security 2010). This is to say that recognition rates for large, stationary targets in daylight were near 90-percent at bit rates as low as 16 kbps and increases in bit rate did not yield significant improvement at any point. The same can be said for recognition rates of large, stationary objects in dim lighting, although the threshold of saturation is slightly higher than in daylight. As discussed in DHS11-RECORDED, these results imply that lighting conditions affect recognition rates in ways that cannot simply be compensated for by increasing coding bit rate (U.S. Department of Homeland Security 2011).

Figure 7. Recognition Rates for Large Stationary Targets in Dark Indoor Lighting



4.3 Recognition Rates and Target Distance

Changes in target size, by way of adjusting the distance of targets from the camera, had strong effects on recognition rates. Observing Figure 7 and Figure 8, we see a pronounced difference in viewer performance at lower bit rates when target size is reduced. Unlike Figure 7, however, Figure 8 shows fewer signs of saturation indicating that increases in coding bit rates might yield higher rates of recognition. Figure 8 and Figure 9 show a comparable drop in recognition rates as target size is reduced, although neither scenario group actually saw recognition rates that differed significantly from zero in three of the lower-bit-rate HRCs. It must be mentioned that the near-zero recognition rates for moving targets in the daylight setting indicate that actual performance differed insignificantly from the probability of correctly guessing all answers in those HRCs (i.e., there were no identifiable objects in those clips).

Figure 8. Recognition Rates for Small Stationary Targets in Daylight

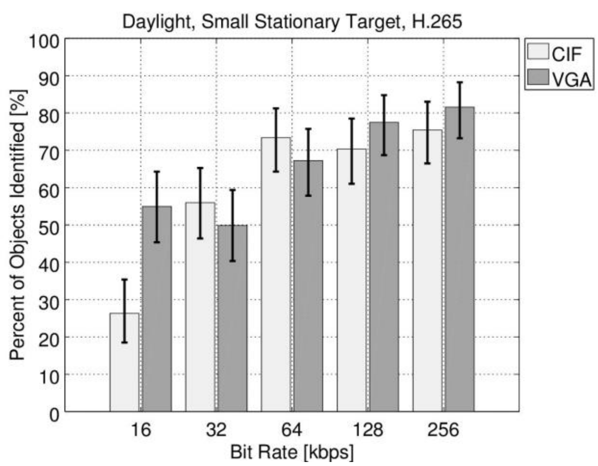
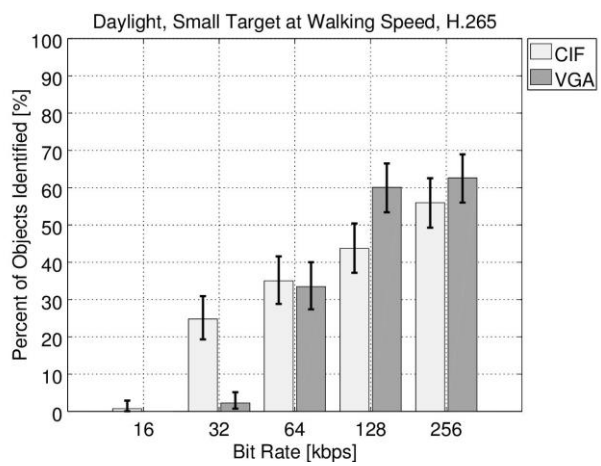


Figure 9. Recognition Rates for Small Moving Targets in Daylight



4.4 Recognition Rates and Motion

While Figure 4 shows that a scenario group with motion *can* yield ideal recognition rates over 90 percent, this does not hold true for most situations. Consistent reductions in recognition rates of 10- to 20-percentage points for any given HRC are seen when

comparing the charts below to their stationary counterparts. Lower-bit-rate HRCs saw even greater differences in recognition.

Motion, above all other conditional changes, had the greatest negative impact on viewers' ability to identify objects. For example, recognition rates all approach or exceed 90 percent in Figure 6, but when motion is introduced in Figure 10, rates for only one HRC exceed 90 percent, while rates for seven HRCs are below 80 percent and four do not exceed 40 percent. This same kind of degradation is also illustrated by comparing Figure 8 to Figure 9, Figure 5 to Figure 11, and Figure 7 to Figure 11. It must be pointed out that in Figure 12, recognition rates of 50 percent were not achieved, and it may be inferred based on the results of this test and (U.S. Department of Homeland Security 2011) that it is unlikely that an increase in bit rate would provide any major increase in viewer performance.

Figure 10. Recognition Rates for Large Moving Targets in Daylight

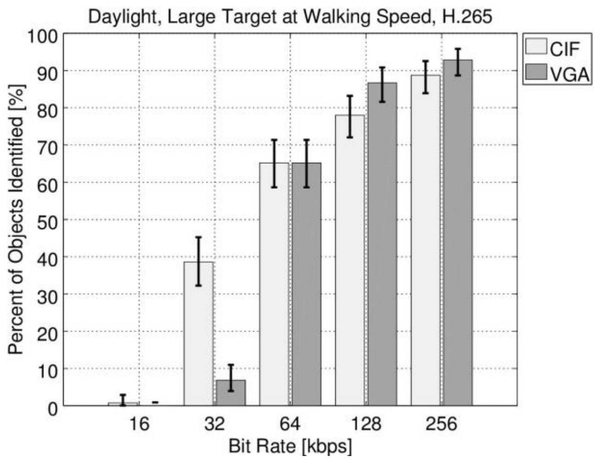


Figure 11. Recognition Rates for Large Moving Targets in Dim Indoor Lighting

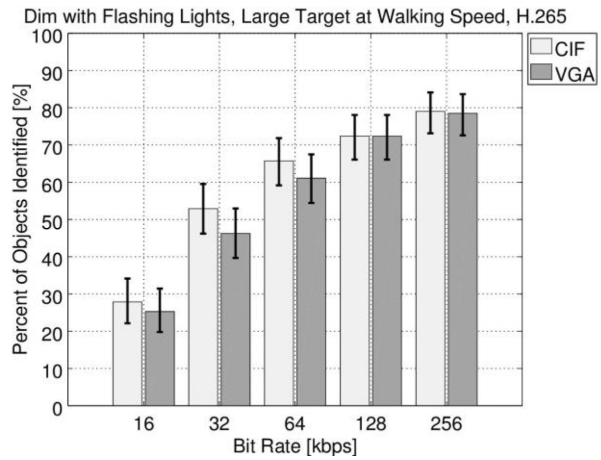
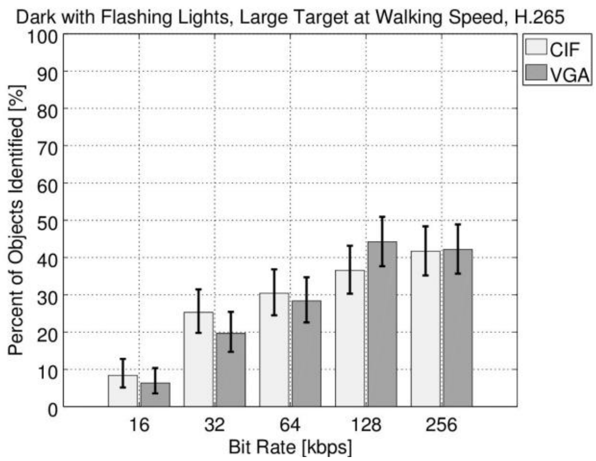


Figure 12. Recognition Rates for Large Moving Targets in Dark Indoor Lighting



4.5 Comparison between H.264 and H.265 Coding Performance

The overarching purpose of this test was to compare the differences in performance of viewers executing object recognition tasks using videos encoded with H.265 HEVC and H.264 AVC. The key difference between this test and the one against which its results are being compared is that clips used for this test were encoded according to the H.265 HEVC (whereas DHS11-RECORDED employed H.264 AVC).

Charts in Figure 13 through Figure 21 provide a side-by-side comparison between H.265 HEVC results and corresponding H.264 AVC results from DHS11-RECORDED for each scenario group presented in the same order as in the four subsections immediately preceding this one. The test scenes, testing methods, and testing conditions were identical to DHS11-RECORDED, and the same number of viewers were tested (U.S. Department of Homeland Security 2011).

Immediately it is apparent that the previous test used clips of much higher bit rates than the ones used in this test. During the design of this test, it was determined that clips encoded at bit rates of 512 kbps and above using H.265 HEVC would not likely produce valuable data for most scenario groups. As H.265 HEVC has been purported to produce equivalent quality to H.264 AVC encoded videos with 30- to 60-percent reduction in coding bit rates, we decided to lower the floor on bit rates used for this test. Thus, while the previous test used clips encoded only as low as 64 kbps for CIF and 128 kbps for VGA, clips of both resolutions were encoded at 16 kbps and 32 kbps in this test.

As evidenced by the first four sets of charts, H.265 HEVC performs well for large objects at all tested levels of light. It even handily outperformed H.264 AVC in the indoor, bright light, walking scenario group. Recognition rates of 90 percent, or greater, were maintained in the daylight, stationary, large target scenario all the way down to 16 kbps (VGA), and performance at 64 kbps (VGA) using H.265 HEVC in the dark, stationary, large object category was nearly as good as 256 kbps (VGA) using H.264 AVC.

It is interesting to note that H.265 HEVC underperformed H.264 AVC in all daylight scenario groups. We propose that this may be the result of increased background detail in the outdoor scenes, as opposed to the relatively limited level of background detail in the indoor scenes. The effect is particularly pronounced when motion is introduced, and is at its most severe when employing small targets. These results show that clips produced at the lower-two bit rates provided insufficient information for viewers to make even educated guesses, let alone true correct recognitions. Further study on the relationship between spatial complexity of the source material and the performance of H.265 HEVC is required.

Alternately, coding according to H.265 HEVC produced, for the most part, better results in the indoor scenario groups than coding with H.264 AVC. These scenes had both limited background detail and higher contrast between the actor, target, and the surrounding environment, which resulted in performance closer to what is reputed for the standard. The results for these groups appear as translations along the bit rate axis of their corresponding results from DHS11-RECORDED with less delineation in performance based on resolution (U.S. Department of Homeland Security 2011). Whereas there was a fairly pronounced difference in recognition rates of CIF-resized videos in the H.264 AVC tests, resolution seemed to matter little when coding with H.265 HEVC, except at the lowest bit rate.

After reviewing these results, the use of 16 kbps and 32 kbps encoding seems impractical in most situations, and is effectively unusable in daylight.

Figure 13. H.265 and H.264 Recognition Rates for Large Moving Targets in Bright Indoor Lighting

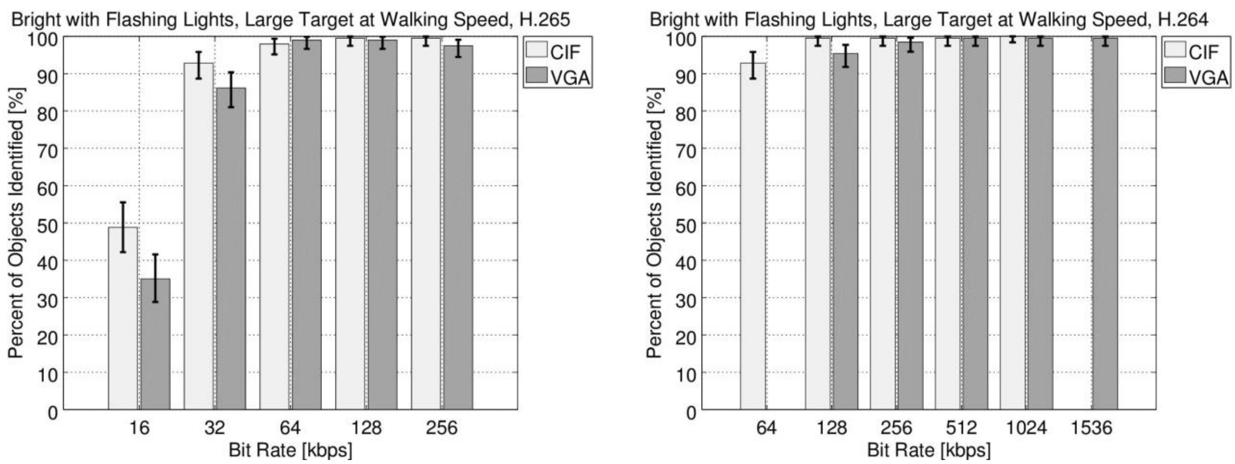


Figure 14. H.265 and H.264 Recognition Rates for Large Stationary Targets in Dim Indoor Lighting

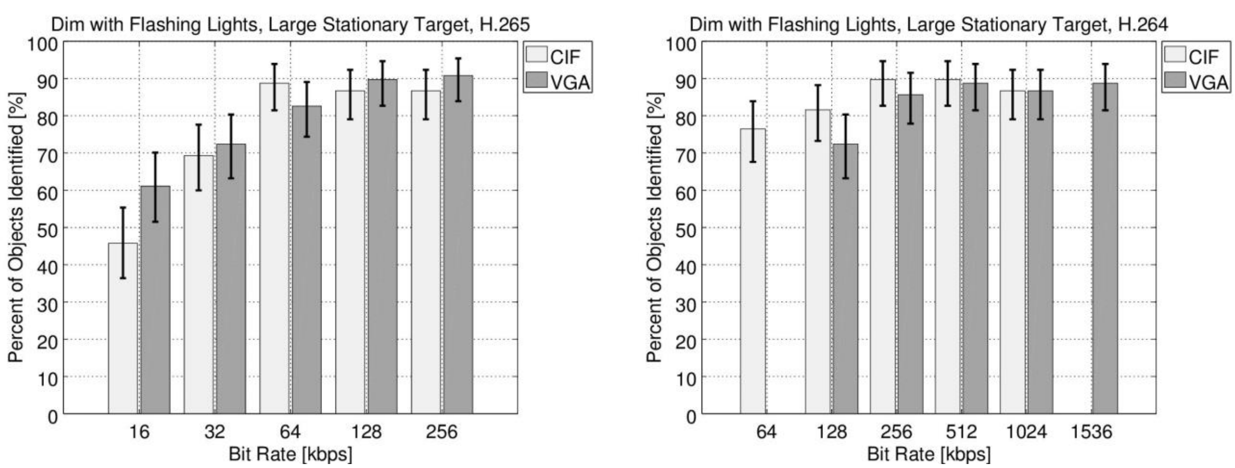


Figure 15. H.265 and H.264 Recognition Rates for Large Stationary Targets in Daylight

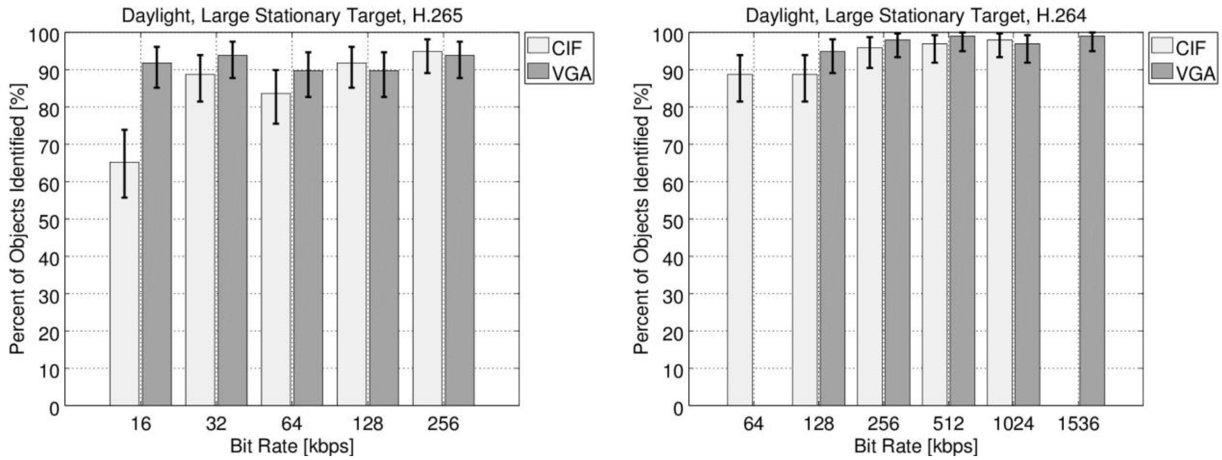


Figure 16. H.265 and H.264 Recognition Rates for Large Stationary Targets in Dark Indoor Lighting

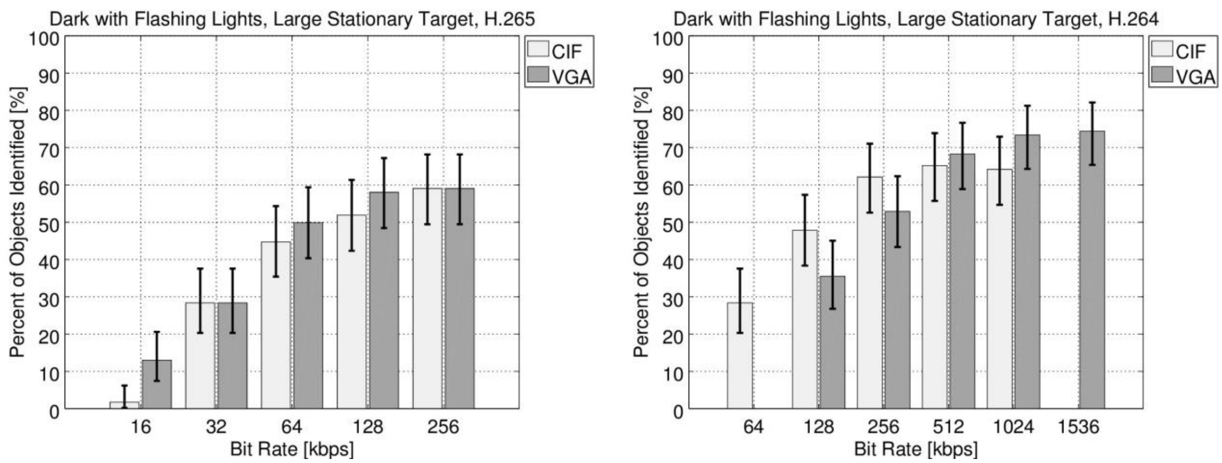


Figure 17. H.265 and H.264 Recognition Rates for Small Stationary Targets in Daylight

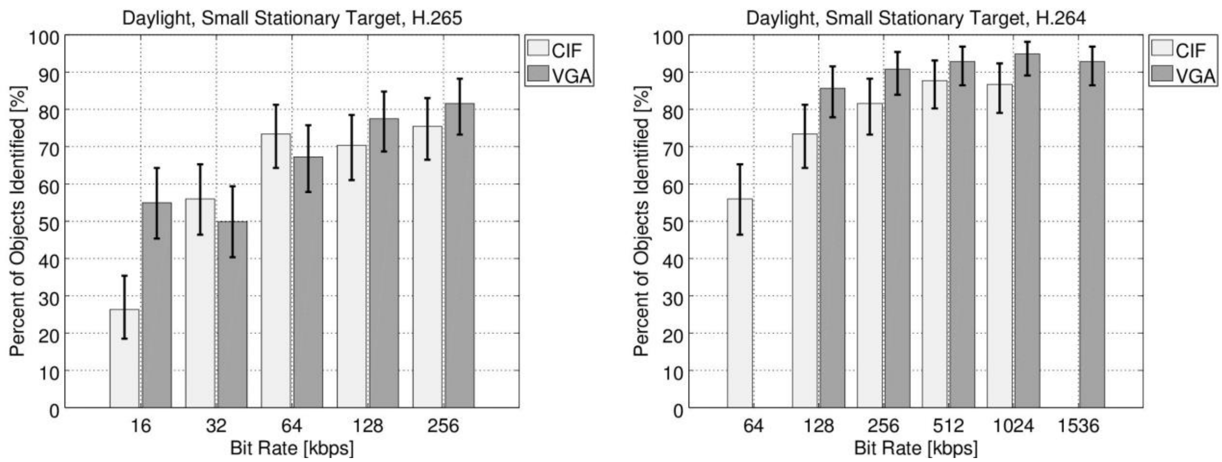


Figure 18. H.265 and H.264 Recognition Rates for Small Moving Targets in Daylight

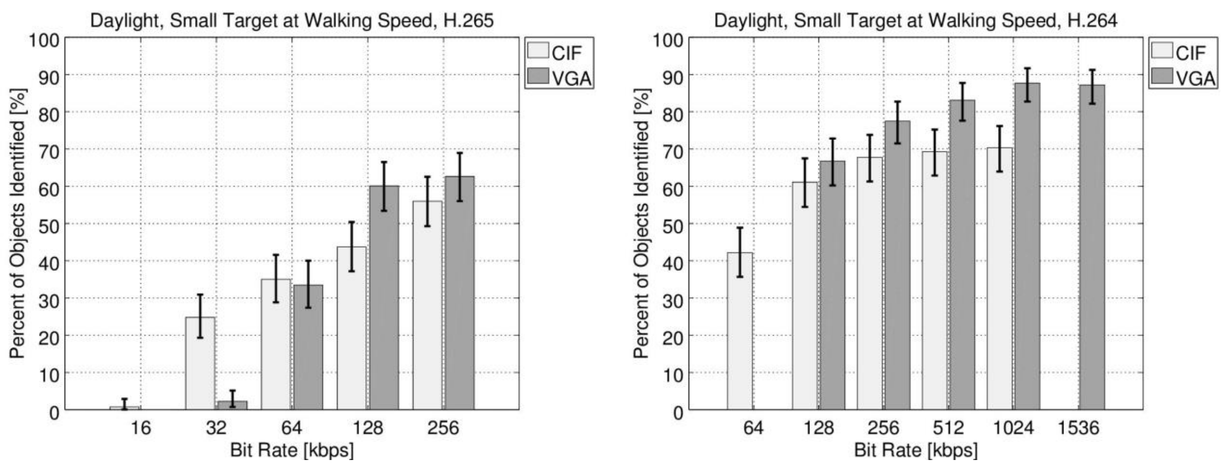


Figure 19. H.265 and H.264 Recognition Rates for Large Moving Targets in Daylight

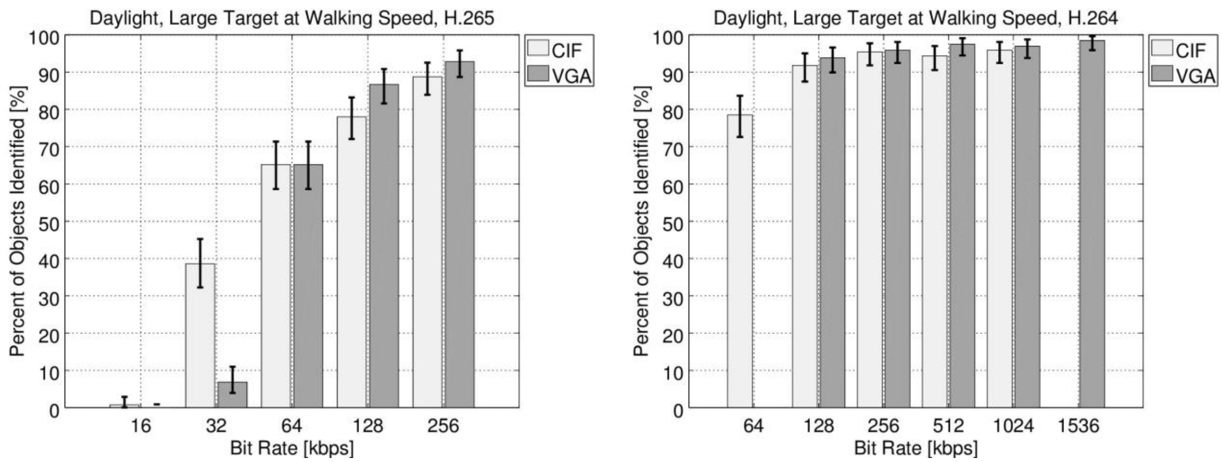


Figure 20. H.265 and H.264 Recognition Rates for Large Moving Targets in Dim Indoor Lighting

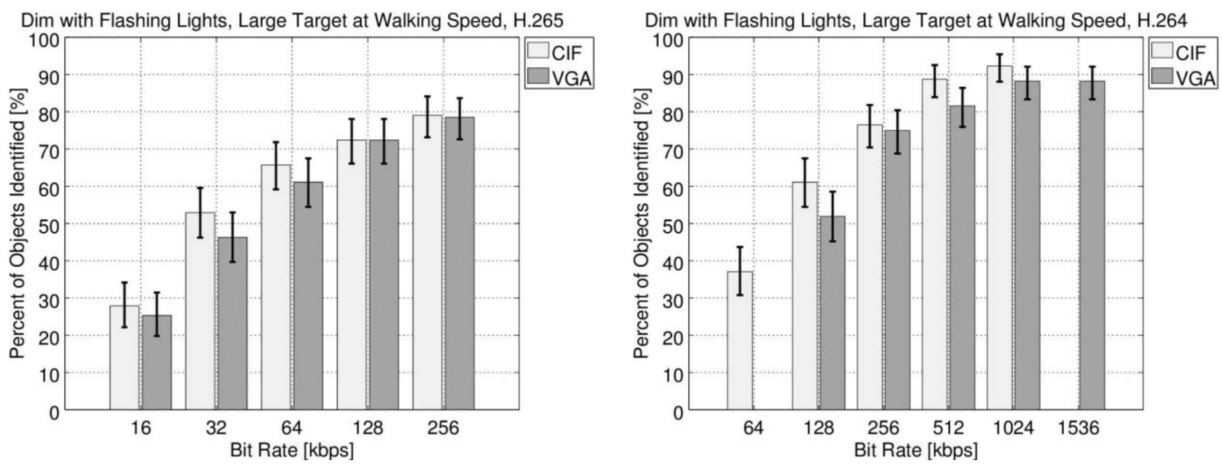
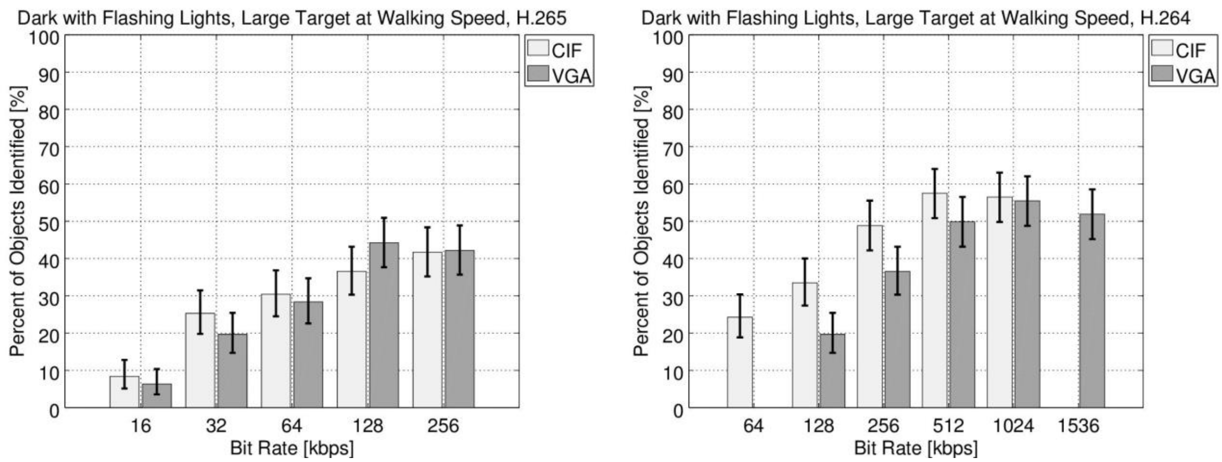


Figure 21. H.265 and H.264 Recognition Rates for Large Moving Targets in Dark Indoor Lighting



5 Recommendations

Table 3 shows the recommendations for minimum bit rates based on filmed scenario group and file resolution. Recommendations are made for both 50- and 90-percent rates of correct recognition based on the results of this test.

Table 3. Recommended Minimum Bit Rates for H.265 Encoding by Scenario Group and Resolution.

Scenario	Bit rate for 90-percent recognition (kbps)		Bit rate for 50-percent recognition (kbps)	
	VGA	CIF	VGA	CIF
Daylight, stationary, large target	16*	128	16*	16*
Daylight, stationary, small target	N/A	N/A	16*	32
Daylight, moving, large target	256	N/A	64	64
Daylight, moving, small target	N/A	N/A	128	256
Bright and flashing lighting, moving, large target	64	32	32	32
Dim and flashing lighting, stationary, large target	256	N/A	16*	32

Table 3. Recommended Minimum Bit Rates for H.265 Encoding by Scenario Group and Resolution.

Scenario	Bit rate for 90-percent recognition (kbps)		Bit rate for 50-percent recognition (kbps)	
	VGA	CIF	VGA	CIF
Dim and flashing lighting, moving, large target	N/A	N/A	64	32
Dark with flashing lights, stationary, large target	N/A	N/A	128	128
Dark with flashing lights, moving, large target	N/A	N/A	N/A	N/A

*A lower bit rate may also meet this criteria; the minimum bit rate tested sufficiently exceeded criteria.

It is worth noting that while encoders are typically effective in matching output bit rate to the bit rate requested by the user, the output bit rates of various videos of different lengths and having different characteristics may vary slightly from those requested. Users encoding video for use in public safety fields may benefit from checking that the resultant bit rates of encoded files or streams match those desired.

6 Limitation, Conclusion, and Future Work

As the source videos in this test were the same used in DHS11-RECORDED and DHS10-LIVE, this test was limited in the same ways described in those studies. Bright, indoor scenes with stationary objects and dark lighting scenes with small objects were not included in either test. To provide recommendations for a greater proportion of recognition rates exceeding 90 percent, it would be useful to run tests using clips of higher bit rates encoded according to H.265 HEVC, particularly in scenes with small targets and motion; however, the observed saturation effects caused by issues in the original, uncompressed scenes may prevent subjects from achieving 90-percent recognition at any bit rate.

Daylight scenario groups resulted in generally poor viewer performance when movement was added or the object size was reduced. The large moving targets in the scenario group represented by Figure 10 resulted in similar recognition rates to H.264 AVC at 256 kbps, but rates of the rest of the HRCs were considerably lower than expected relative to the results of DHS11-RECORDED (U.S. Department of Homeland Security 2011). The fact that the coding techniques of H.265 HEVC provide no improvement over those of H.264 AVC implies that H.264 HEVC may have achieved a nearly optimal representation of the spatial complexity of these scenes, while leaving some room for improvement on the indoor scenes that may have been less spatially complex. Further study is required.

For indoor scenes, H.265-encoded videos produced same-or-better recognition rates compared to the H.264-encoded videos. In fact, the majority of the scenario group/HRC combinations in H.265 HEVC produced similar recognition rates as HRCs of twice the bit rates of clips encoded according to H.264 AVC. This observation of the indoor performance

is very useful for general recognition tasks and allows for more effective bit rate recommendations than can be provided for outdoor scenes.

Due to the relative novelty of the H.265 HEVC standard (resulting in the fairly recent release of available codecs), more research should be done on the performance of the standard under various parameters and with various encoders.

7 References

American National Standards Institute. "American National Standard Method for Measuring the Intelligibility of Speech Over Communications Systems." *S3.2.* American National Standards Institute, 1989.

Fraunhofer HHI. *Wavefronts for HEVC Parallelism.* Fraunhofer Heinrich Hertz Institute. n.d. http://www.hhi.fraunhofer.de/fields-of-competence/image-processing/research-groups/multimedia-communications/wavefronts-for-hevc-parallelism.html (accessed 2014).

ITU-T. "Subjective video quality assessment methods for multimedia applications." Recommendation P.910, Geneva, 1999.

ITU-T. "Subjective video quality assessment methods for recognition tasks." Recommendation P.912, Geneva, 2008.

Johnson, N., S. Kotz, and A. Kemp. In *Univariate Discrete Distributions*, 129. New York: Wiley, 1992.

U.S. Department of Homeland Security. "Defining Video Quality Requirements: A Guide for Public Safety." Recommendation Report, 2010.

U.S. Department of Homeland Security. "Recorded-Video Quality Tests for Object Recognition Tasks." Technical Report, 2011.

U.S. Department of Homeland Security. "Video Quality Tests for Object Recognition Applications." Public Safety Communications Technical Report, 2010.

Video Quality in Public Safety Working Group. "Defining Video Quality Requirements: A Guide for Public Safety." July 2010. http://www.safecomprogram.gov/SiteCollectionDocuments/3aVideoUserRequirementGuidedoc.pdf (accessed September 2014).

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Appendix A Source Scenes

All clips presented to participants of this test used original test sequences recorded for a previous study conducted by the PSCR program with support from DHS OIC (U.S. Department of Homeland Security 2010). This appendix closely resembles a corresponding appendix of DHS11-RECORDED, describing certain characteristics of the course scenes in greater detail than described in DHS10-LIVE (U.S. Department of Homeland Security 2010).

The scenes used in this test were created using the concept of scenario groups, a collection of slightly varying scenes based on the same general situation, a concept introduced in ITU-T P.912 (ITU-T 2008). The goal of scenario groups is to minimize scene memorization and visual cues so viewer performance can be effectively measured. In a given scenario group, all variables aside from the target being displayed are held constant, and seven objects are presented in each scenario group.

The objects used as targets for the identification tests in this study are:

- Gun;
- Electroshock weapon;
- Hand-held mobile radio;
- Mug;
- Soda can;
- Flashlight; and
- Cell phone.

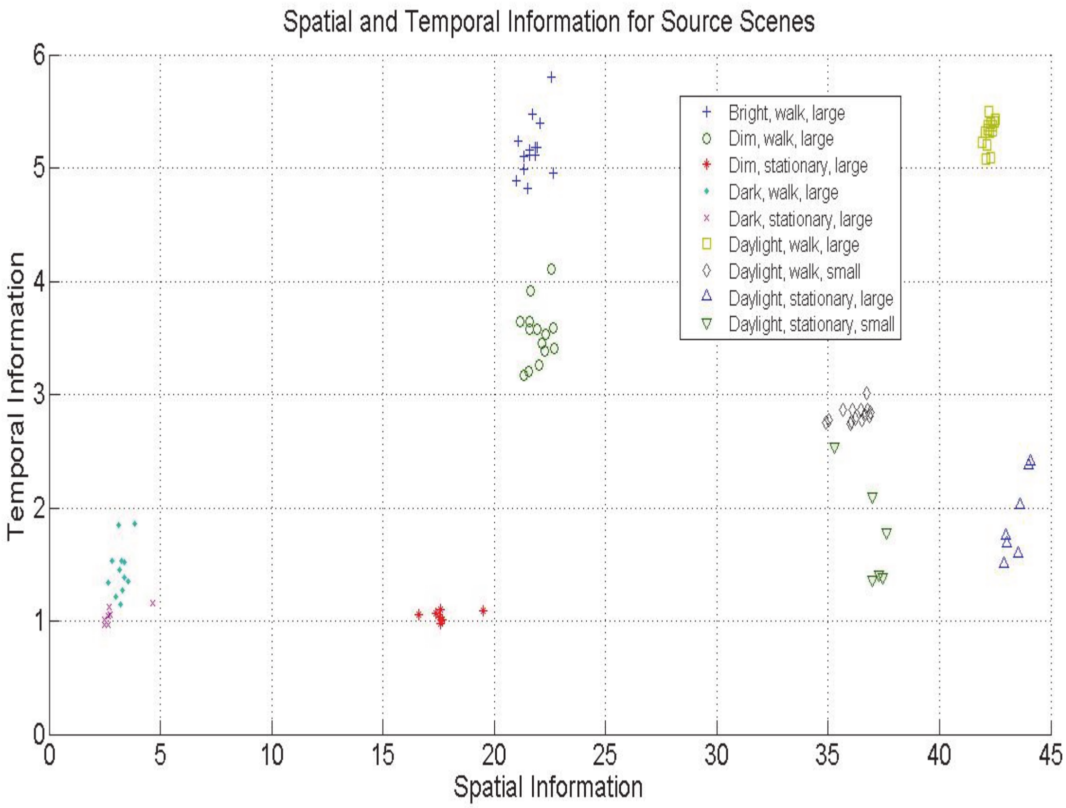
The objects in the scenes were filmed both resting on a pedestal and carried by a person walking. To test two views of the object as it is carried, the person, carrying the object in their left hand, was filmed in both a walking-left and walking-right scenario. The actor did not hold the object in a way that would imply the nature of the object (i.e., the actor did not hold the phone to her ear or the gun in a position to shoot).

Two locations were used for the scenes. The first was a sunny, outdoor rural setting. All indoor scenes were shot in an underground shooting range at a law enforcement agency under various lighting conditions. The lighting conditions represented were: outdoor daylight, indoor bright light, indoor dim light, and indoor nearly, dark conditions. The lighting in the scenes filmed in the underground shooting range was affected by a flashing law-enforcement light bar. Light levels for the indoor dim and indoor dark scenes were measured using a handheld photometer made by Quantum Instruments. Pointed in the same general direction as the camera, the photometer registered a 3.1 lux for the indoor dim scenes, and a 2.2 lux for the indoor dark scenes.

ITU-T Recommendation P.910, in accordance with the recommendations in ITU-T P.912 for test scene selection, suggests that the test scenes with motion levels of walking and stationary positions contain the full range of temporal and spatial information of

interest (ITU-T 1999). To reiterate, this test only used the two levels of motion and the two locales to create all of the scenario groups; thus, the perceptual information of interest, temporal and spatial, is limited. A plot of this information can be seen in Figure 22. The spatial and temporal information was calculated in accordance to ITU-T P.910 (U.S. Department of Homeland Security 2010).

Figure 22. Spatial and Temporal Perceptual Information



Notice that the legend in Figure 22 also refers to a "target size" (i.e., large, small). In this test, target size variance was simulated by the distance of the camera during filming, and only used for the outdoor daylight scenario. This was so both "small" and "large" targets were represented. For the indoor scenes, there was only one camera distance used, and the target size within all indoor clips was the same as the large-target outdoor scenes.

To keep the test at a relatively reasonable size, some lighting level, motion level, and target size combinations were omitted; this was in addition to omitting scenario groups with indoor lighting and small targets. Overall, 14 scenario groups were selected. Each scenario group is comprised of scenes with each of the seven objects, save two exceptions. The exceptions being the scenario groups where there is dark lighting with a carried object, in which the flashlight was not used as an object. Hence, the total number of test scenes was 96.

From here, the combinations of scenario groups and target objects can be described as “clips.” Most clips had a length of five seconds, and the clips with the daylight/walking scenario and the indoor dim/stationary scenario had varying lengths. Indoor dim/stationary groups had lengths of four seconds, daylight/walking/large groups lasted for six seconds, and daylight/walking/small groups were nine seconds long. The reason for the duration difference is due to the time needed to fully walk across the varying fields of view.

All clips were filmed with a Panasonic AJ-HPX3700 in 1080p high definition (HD). The Panasonic AJ-HPX3700 is considered a broadcast-quality camera. The two recording formats this camera supports are AVC-Intra 100/50 and DVCPRO HD.

Table 4. Summary of Scenario Groups

Scenario Group #	Lighting Condition	Motion	Target Size
1	Daylight	Stationary	Large
2	Daylight	Walking Speed, Right	Large
3	Daylight	Walking Speed, Left	Large
4	Daylight	Stationary	Small
5	Daylight	Walking Speed, Right	Small
6	Daylight	Walking Speed, Left	Small
7	Bright/Flashing	Walking Speed, Right	Large
8	Bright/Flashing	Walking Speed, Left	Large
9	Dim/Flash (Lighting: 3.1 Lux)	Stationary	Large
10	Dim/Flash (Lighting: 3.1 Lux)	Walking Speed, Right	Large
11	Dim/Flash (Lighting: 3.1 Lux)	Walking Speed, Left	Large
12	Dark/Flash (Lighting: 2.2 Lux)	Stationary	Large
13	Dark/Flash (Lighting: 2.2 Lux)	Walking Speed, Right	Large

Table 4. Summary of Scenario Groups

Scenario Group #	Lighting Condition	Motion	Target Size
14	Dark/Flash (Lighting: 2.2 Lux)	Walking Speed, Left	Large

The following is information about the field of view based on the various target sizes, and the pixel measured sizes of the stationary target scenario groups.

The horizontal field-of-view as seen by the camera at the distance of the target was measured for each scenario group. These measurements are shown in Table 5.

Table 5. Field-of-View and Camera Distance Measurements

Scenario Group #	Field-of-View	Distance from Camera
1	23’ 6”	35’ 9”
2-3	32’ 7”	35’ 9”
4	48’ 11”	48’
5-6	58’ 8”	48’
7-14	12’ 8”	17’ 2”

The pixel sizes of the objects in the stationary scenario groups were measured in still frames. All frames that these measurements were done in came from clips that were down-converted to the 640x480 resolution. All of these sizes are shown in Table 6. Along with sizes, Table 6 also states the color of the object.

Table 6. Target Sizes in Pixels

Object	Color	Size [pixels] Scenario Group 9	Size [pixels] Scenario Group 1	Size [pixels] Scenario Group 4
Cell Phone	Red	282	100	23
Flashlight	Black	466	105	44
Soda	White and Red	355	111	36
Mug	White	335	145	42
Electroshock Weapon	Yellow	439	158	38

Table 6. Target Sizes in Pixels

Object	Color	Size [pixels] Scenario Group 9	Size [pixels] Scenario Group 1	Size [pixels] Scenario Group 4
Gun	Black	568	204	78
Radio	Black	677	283	77

The still frames of the targets are shown in Figure 23. These still frames are from the training sequence software.

Figure 23. Test Targets, as Seen in Training Sequences

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Appendix B Processed Scenes

All raw HD videos were resized to VGA (640x480) and CIF (352x288) formats using a Lanczos filter. Frame rate was constant throughout all scenes at 29.97 fps.

Table 7. Encoder Bit Rates

Resolution	Bit Rates (kbps)
CIF	16, 32, 64, 128, 256
VGA	16, 32, 64, 128, 256

Clips for this study were encoded according to the H.265 HEVC standard using the x265 codec. To ensure that videos were presented consistently to all subjects and to avoid potential technical issues, videos were decoded using the H.265 HEVC reference decoder and remultiplexed to AVI files before the test was conducted.

We enabled wavefront parallel processing (WPP) because it is marketed as a key feature of H.265 HEVC. It has been introduced in an effort to make parallelism an important part of the H.265 HEVC standard, as opposed to something of an afterthought in H.264 AVC (which used slicing for parallel processing at a cost to coding quality). Detailed explanation of WPP is outside the scope of this paper, but more information can be found at (Fraunhofer HHI n.d.).

Table 8. Software Settings for H.264 Encoding

Parameter	Setting
Preset	Default
Level	Default
Frame Rate	29.97 fps
Audio	Off
Motion Search Method	Hex
B-Frame Max	4
Wavefront Parallel Processing	Enabled

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Appendix C Notes on Experimental Design

C.1 Randomization

A combined total of 960 clips resulted from the resolution transformations and bit rates in which they were encoded. Viewers were not shown all 960 clips; instead each was presented with three clips for each scenario-group/resolution/bit-rate combination for a total of 420 clips. This was intended to reduce test length and prevent excessive fatigue on the part of the viewer. The pre-selected clips to be viewed were uniformly distributed among the viewers and scenario groups, with a different order of clips for every viewer. Scenario groups were used to prevent the viewers from memorizing the clips, and allowing for correct object recognition to be tested.

C.2 Data Analysis

In this test, the percentages of correct answers are referred to as recognition rates, and were calculated for every scenario/HRC combination. Since there was not an *I don't know* or *unsure* answer for this test, some guessing was expected. In light of this, the recognition rates required adjustment that was carried out using the following formula:

$$R_A = R - \frac{W}{n-1}$$

In this formula, R_A represents the adjusted total number of correct responses with respect to R and$W$, where R is the initial number of correct answers for some scenario group/HRC combination, W is the number of wrong answers in the same scenario group/HRC combination, and n is the number of possible answer choices (ANSI 1989). Using the Clopper-Pearson method, confidence levels of 95-percent were calculated (Johnson, Kotz and Kemp 1992). To provide a compiled estimate on how motion affects the viewer's ability to recognize the object, the walking-left and walking-right scenario groups were combined. This effectively doubled the sample for scenario groups with motion.

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Appendix D Viewer Instructions

Viewers received the following text as instruction.

Thanks for coming in today to participate in our study. This study concerns the quality of video images for use in Public Safety applications. As a likely user of next-generation devices for Public Safety applications, we are interested in whether the videos to be presented are of sufficient quality to be used by you to perform several different potential tasks.

Today's study examines video used in a recorded, real-time situation, and the ability to use this video to make real time decisions on how to respond to an incident. This study does not apply to video which has been recorded for later examination. The applications currently being focused on are related to object recognition. You will be asked to answer specific questions regarding content in the video.

Scene Description	*Response*
Person walking by, holding an object *Lighting scenario* ▪ *Indoor flashing lights* ▪ *Indoor, dark, flashing lights* ▪ *Outdoor, daytime*	*Multiple choice: Identify the object from a list*
Stationary objects *Lighting scenario* ▪ *Indoor flashing lights* ▪ *Indoor, dark, flashing lights* ▪ *Outdoor, daytime*	*Multiple choice: Identify the object from a list*

Each scene will be approximately 5 to 9 seconds long. While the clip is playing, you may pause or step backward or forward frame by frame. You may replay each clip as many times as you wish. You will then be asked to answer the question relating to the scene as described in the table above. The test software will record your answers, as well as when you paused, replayed, or stepped through frames of the clip; it will also record the total time you spent on each clip. ****Please wait for the video clip to finish playing before answering the question, and please do not close the media player window at any time during the test.***

Multiple Choice Instructions

Please choose the answer that most closely matches what you saw in the video. For this study there is no "other" or "I don't know" option; therefore, please select the answer you believe to be most likely.

You will be asked to participate in one viewing session which is approximately 90 minutes long. Practice videos will be presented to help you get familiar with the scene

material and rating process, as well as a clip showing the objects you might see in the videos. You may take a break at any time during the session.

Appendix E Data Tables

Note: In Table 9, targets detected and percent correct have been adjusted to account for guesses made by participants in the study.

Table 9. H.265 Video Data

Scenario Groups	Bit Rate (kbps)	16		32		64		128		256	
	Resolution	**CIF**	**VGA**	**CIF**	**VGA**	**CIF**	**VGA**	**CIF**	**VGA**	**CIF**	**VGA**
Daylight Stationary Large	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	74.33	104.67	101.17	107.00	95.33	102.33	104.67	102.33	108.17	107.00
	Percent Correct	65.21	91.81	88.74	93.86	83.63	89.77	91.81	89.77	94.88	93.86
Bright Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	111.33	79.83	211.67	196.50	223.33	225.67	226.83	225.67	226.83	222.17
	Percent Correct	48.83	35.02	92.84	86.18	97.95	98.98	99.49	98.98	99.49	97.44
Daylight Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	1.67	-0.67*	88.00	15.67	148.67	148.67	177.83	197.67	202.33	211.67
	Percent Correct	0.73	-0.29*	38.60	6.87	65.20	65.20	78.00	86.70	88.74	92.84
Dim Stationary Large	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	52.17	69.67	79.00	82.50	101.17	94.17	98.83	102.33	98.83	103.50
	Percent Correct	45.76	61.11	69.30	72.37	88.74	82.60	86.70	89.77	86.70	90.79

Table 9. H.265 Video Data

Scenario Groups	Bit Rate (kbps)	16		32		64		128		256	
	Resolution	**CIF**	**VGA**	**CIF**	**VGA**	**CIF**	**VGA**	**CIF**	**VGA**	**CIF**	**VGA**
Dark Stationary Large	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	2.00	14.83	32.33	32.33	51.00	56.83	59.17	66.17	67.33	67.33
	Percent Correct	1.75	13.01	28.36	28.36	44.74	49.85	51.90	58.04	59.06	59.06
Daylight Stationary Small	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	30.00	62.67	63.83	56.83	83.67	76.67	80.17	88.33	86.00	93.00
	Percent Correct	26.32	54.97	55.99	49.85	73.39	67.25	70.32	77.49	75.44	81.58
Daylight Walking Small	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	1.67	-6.50*	56.50	5.17	79.83	76.33	99.67	137..00	127.67	142.83
	Percent Correct	0.73	-2.85*	24.78	2.27	35.01	33.48	43.71	60.01	55.99	62.65
Dim Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	63.50	57.67	120.67	105.50	149.83	139.33	165.00	165.00	180.17	179.00
	Percent Correct	27.85	25.29	52.92	46.27	65.72	61.11	72.37	72.37	79.02	78.51
Dark Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	19.17	14.50	57.67	44.83	69.33	64.67	83.33	100.83	95.00	96.17

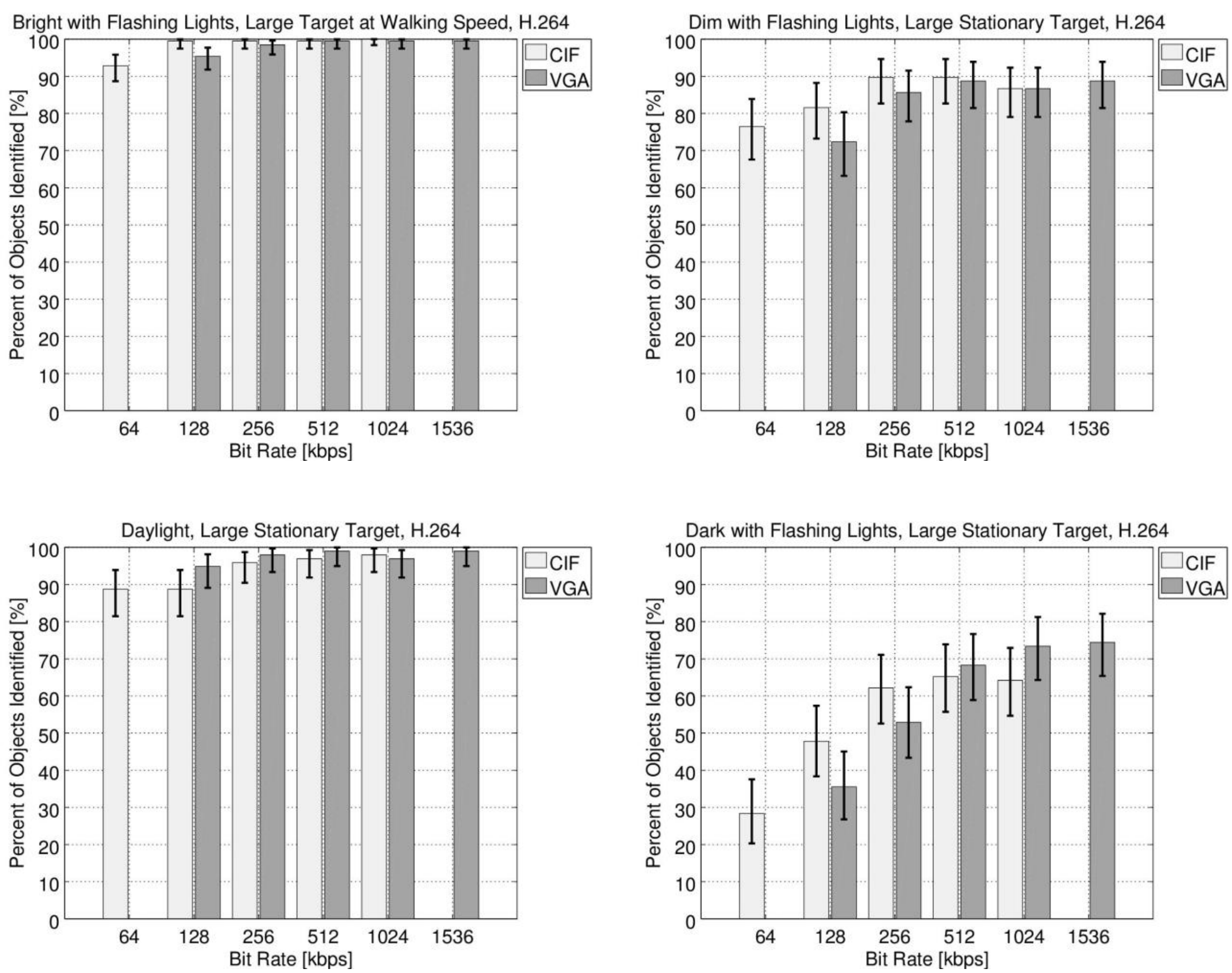
Table 9. H.265 Video Data

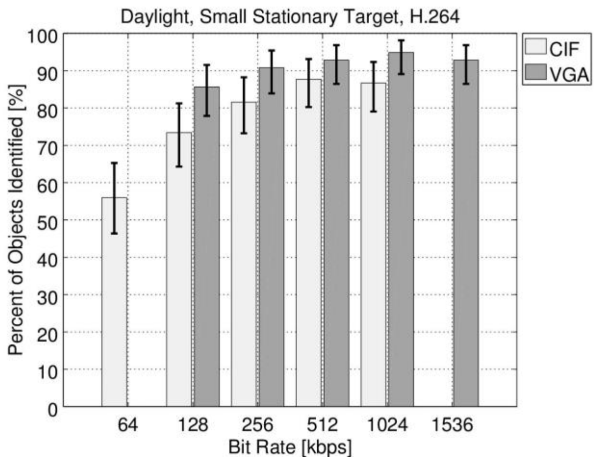
Scenario Groups	Bit Rate (kbps)	16		32		64		128		256	
	Resolution	CIF	VGA	CIF	VGA	CIF	VGA	CIF	VGA	CIF	VGA
	Percent Correct	8.41	6.36	25.29	19.66	30.41	28.36	36.55	44.23	41.67	42.18

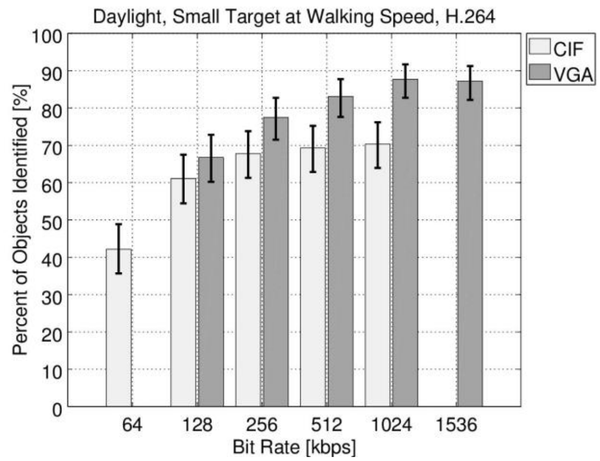
*These results imply the average viewer had worse performance, than if they simply guessed.

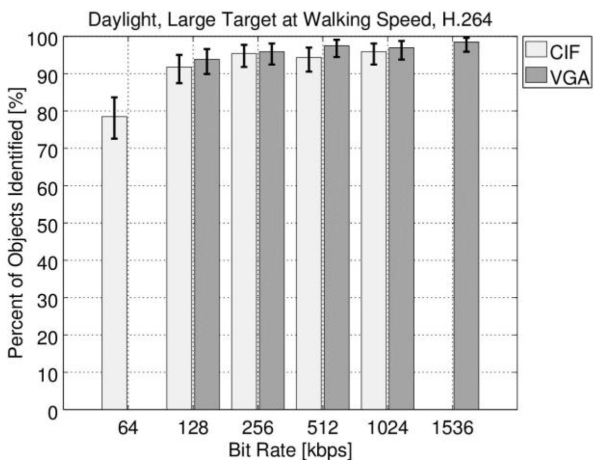
Note: In Figure 24 and Table 10, targets detected and percent correct have been adjusted to account for guesses made by participants in the study. Also target sizes such as “large” and “small” are used, and these descriptions correlate to target distances “close” and “small” respectively.

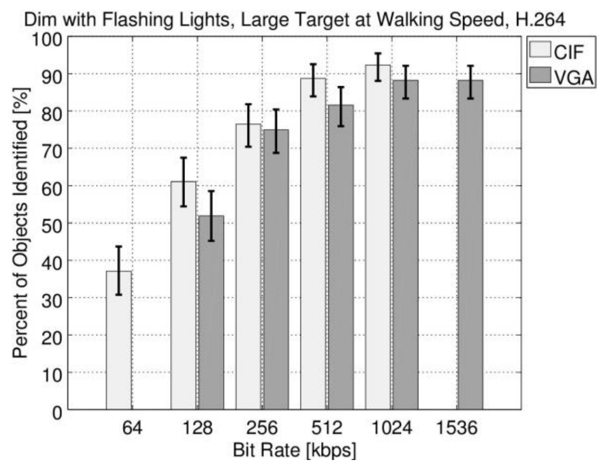
Figure 24. H.264 Data (9 Charts)




Daylight, Small Stationary Target, H.264
Percent of Objects Identified [%]
0 10 20 30 40 50 60 70 80 90 100
64 128 256 512 1024 1536
Bit Rate [kbps]
CIF
VGA


Daylight, Small Target at Walking Speed, H.264
Percent of Objects Identified [%]
0 10 20 30 40 50 60 70 80 90 100
64 128 256 512 1024 1536
Bit Rate [kbps]
CIF
VGA


Daylight, Large Target at Walking Speed, H.264
Percent of Objects Identified [%]
0 10 20 30 40 50 60 70 80 90 100
64 128 256 512 1024 1536
Bit Rate [kbps]
CIF
VGA


Dim with Flashing Lights, Large Target at Walking Speed, H.264
Percent of Objects Identified [%]
0 10 20 30 40 50 60 70 80 90 100
64 128 256 512 1024 1536
Bit Rate [kbps]
CIF
VGA

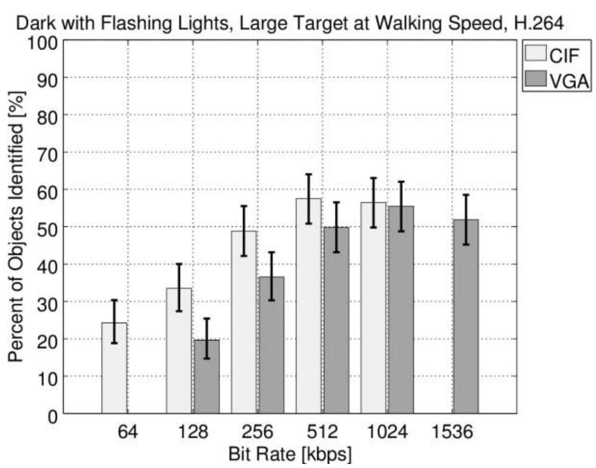

Dark with Flashing Lights, Large Target at Walking Speed, H.264
Percent of Objects Identified [%]
0 10 20 30 40 50 60 70 80 90 100
64 128 256 512 1024 1536
Bit Rate [kbps]
CIF
VGA

Table 10. H.264 Video Data

Scenario Groups	Bit Rate (kbps)	64	128		256		512		1024		1536
	Resolution	CIF	CIF	VGA	CIF	VGA	CIF	VGA	CIF	VGA	VGA
Daylight Stationary Large	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	101.16	101.16	108.16	109.33	111.66	110.50	112.83	111.66	110.50	112.82
	Percent Correct	88.74	88.74	94.88	95.90	97.95	96.92	98.97	97.95	96.92	98.97
Bright Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	211.66	226.83	217.50	226.83	224.50	226.83	226.83	228.00	226.83	226.83
	Percent Correct	92.83	99.48	95.39	99.48	98.46	99.48	99.48	100.00	99.48	99.48
Daylight Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	179.00	209.33	214.00	217.50	218.66	215.16	222.16	218.66	221.00	224.50
	Percent Correct	78.5	91.81	93.85	95.39	95.90	94.37	97.44	95.90	96.92	98.46
Dim Stationary Large	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	87.16	93.00	82.50	102.33	97.66	102.33	101.16	98.83	98.83	101.16
	Percent Correct	76.46	81.57	72.36	89.76	85.67	89.76	88.74	86.69	86.69	88.74
Dark Stationary Large	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	32.33	54.50	40.50	70.83	60.33	74.33	77.83	73.16	83.66	84.83

Scenario Groups	Bit Rate (kbps)	64	128		256		512		1024		1536
	Resolution	CIF	CIF	VGA	CIF	VGA	CIF	VGA	CIF	VGA	VGA
	Percent Correct	28.36	47.80	35.52	62.13	52.92	65.20	68.27	64.18	73.39	74.41
Daylight Stationary Small	Targets Present	114	114	114	114	114	114	114	114	114	114
	Targets Identified	63.83	83.66	97.66	93.00	103.50	100.00	105.83	98.83	108.16	105.83
	Percent Correct	55.99	73.39	85.67	81.57	90.78	97.71	92.83	86.69	9488	92.83
Daylight Walking Small	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	96.16	139.33	152.16	154.50	176.66	158.00	189.50	160.33	200.00	198.83
	Percent Correct	42.18	61.11	66.73	67.76	77.48	69.29	83.11	70.32	87.71	87.20
Dim Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	84.50	139.33	118.33	174.33	170.83	202.33	186.00	210.50	201.16	201.16
	Percent Correct	37.06	61.11	51.60	76.46	74.92	88.74	81.57	92.32	88.23	88.23
Dark Walking Large	Targets Present	228	228	228	228	228	228	228	228	228	228
	Targets Identified	55.33	76.33	44.83	111.33	83.33	131.16	113.66	128.83	126.50	118.33
	Percent Correct	24.26	33.47	19.66	48.83	36.54	57.52	49.85	56.50	55.48	51.90