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Luminance Metrics for Roadway Lighting

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EXECUTIVE SUMMARY

In nighttime driving, the visibility of a pedestrian or any object is dependent upon its physical characteristics. Such characteristics include the luminance of the object and the contrast between it and its surroundings. The luminance – that is, the light being reflected back to the observer – is a metric with little room for interpretation as to how it is derived. However, the concept of the contrast of an object has not been quite as clearly understood. The concept of contrast has been the focus of much investigation in past and current research.

The focus of the current study is the comparison of multiple contrast metrics, and the implementation of those which are determined to be most applicable as realistic measures. Specifically, the root sum of squares (RSS), power spectrum signature (PSS), Doyle, and line PSS methods of determining contrast are focused upon. These metrics are also used in conjunction with well-established metrics such as the Weber and Michelson contrast metrics, in order to make comparisons and inferences.

Methods

The images of pedestrians from a previous nighttime research study were used for analysis. The pedestrians were clothed in both denim and black-colored clothing under both high-pressure sodium (HPS) and metal halide (MH) overhead lights, and images were captured at multiple distances. The resulting images were analyzed through calculations of RSS, PSS, Doyle, Michelson, and other contrast metrics through the use of the MATLAB programming software.

Results

Calculations of the pedestrian wearing black clothing under HPS lighting resulted in higher contrast across all contrast metrics employed, and at the farther distances at which images were captured. One reason for this is because the background at such distances was the highly illuminated roadway. At closer distances, the pedestrian wearing denim clothing began to result in higher contrast than did the black-clothed pedestrian. This is due to the pedestrian being contrasted against the black sky at the closer distances. The RSS, PSS, and Doyle contrast metrics were instrumental in the investigation of the role of the variation in background and target luminance. The Weber contrast metric was valuable as a comparison to a more established, yet basic, calculation metric that takes negative and positive contrast into account.

Discussion

The RSS, PSS, line PSS, and Doyle contrast metrics were demonstrated to address the factors that play an important role in the visibility and contrast of pedestrians. These factors include the focus on localized parts of the pedestrian's body that increase their visibility and contrast to a driver, and what one would expect to see if the pedestrian were not there. The role of changes in background as distance increases and the polarity of contrast were also investigated.

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LIST OF ABBREVIATIONS AND SYMBOLS

CIE	International Commission on Illumination
HPS	high-pressure sodium
IESNA	Illuminating Engineering Society of North America
MH	metal halide
PSS	power spectrum signature
RMS	root-mean-square
RSS	root sum of squares

CHAPTER 1. INTRODUCTION

The visibility of an object on a roadway at night largely depends on the luminance of the object itself, as well its background. While the objects on the roadway may not, themselves, be emitting light, they are reflecting any light in the environment. The contrast of the object is the difference in its properties that make it distinguishable from the background or other objects. The luminance of an object can be defined as a measure of the intensity of light being reflected by an object back to an observer. While there is little contention regarding the means of measuring luminance, there are multiple methods of calculating the contrast. Some of these considerations include the question of whether to take the entire object into account or just local areas of it.

The current study is an investigation into contrast and a comparison of the emerging techniques for determining contrast. Specific local contrast metrics were chosen based on a review of literature and these metrics were implemented with the analysis of existing data of pedestrian images. Recommendations are made concerning the applicability of the chosen metrics.

Perhaps the most basic of contrast measures is the Weber contrast. This is the comparison of a target with uniform luminance compared to a background of uniform luminance.

Equation 1

$$Weber\ Contrast = \frac{\Delta L}{L_{bkg}}$$

Where:
ΔL = Luminance of a target – Luminance of the background
L_{bkg} = Luminance of the background

However, this makes the common assumption that many metrics make: uniform background luminance.(1) Therefore, an interest in a more varied background luminance must be taken into account.

The Michelson contrast also defines contrast using a summary of both background and target luminance, designated as maximum and minimum luminance values.

Equation 2

$$Michelson\ Contrast = \frac{(L_{max} - L_{min})}{(L_{max} + L_{min})}$$

Where:
L_{max} = Luminance of the target (for $L_{target} > L_{background}$)
L_{min} = Luminance of the background (for $L_{target} > L_{background}$)

The International Commission on Illumination (CIE)(2) and the Illuminating Engineering Society of North America (IESNA) define contrast similarly as:

Equation 3

$$CIE95\ Contrast = \left|\frac{L_{tgt} - L_{bkg}}{L_{bkg}}\right|$$

Equation 4

$$IESNA\ Contrast = \frac{L_{max} - L_{min}}{L_{min}}$$

However, these various definitions do not take into account the varied luminance values as well as complex distributions of luminance, where the mean luminance of a target and background alone do not accurately or sufficiently represent the visibility of the image or object. [3, 4]

It is also interesting to note that this concept of simply using the mean luminance in determining contrast was found to be unacceptable in studies of small target visibility and pavement luminous intensity. For example, it was found that drawing conclusions from an average measurement of luminance to explain highly varying luminous intensity on pavement leads to an inevitable error.[5]

The concept of a local metric to address contrast then needs to be considered. It is an effort to explain the full contrast of the object of interest, including features within the target, while maintaining the locally important features involving target and background. Based on the limitations discussed above, there were three contrast metrics that were investigated further for this research: the Doyle, root sum of squares (RSS), and power spectrum signature (PSS) contrast metrics.

The Doyle contrast metric begins to address the concept of variation in a target as it is based on the standard deviations and means of the target and background values.[6] It is calculated as follows:

Equation 5

$$Doyle\ Contrast = [(\mu_{tgt} - \mu_{bkg})^2 + (\sigma_{tgt} - \sigma_{bkg})^2]^{1/2}$$

Where:

= Mean luminance of the target pixel values
= Mean luminance of the background pixel values
= Standard deviation of target pixel values
= Standard deviation of background pixel values

It is because this metric addresses the variation within an object of interest that the concept of pixel analysis is introduced. A captured image of the object of interest may be analyzed pixel by pixel in order to determine an accurate mean luminance and standard deviation across the object.

The RSS and PSS contrast metrics similarly take into account the standard deviation of the target luminance in determining the contrast of an object. The metric is derived from the following equation:

Equation 6

$$RSS = [(\mu_{tgt} - \mu_{bkg})^2 + \sigma_{tgt}^2]^{1/2}$$

Where:

- Variance of the target pixel values.

This metric has been found to be effective for localized measurements and when a target's luminance is not uniformly distributed.[7,8] It is somewhat similar to the Doyle contrast metric, yet it does not take the standard deviation of the background into consideration.

Another metric considered is the PSS metric.[8] This PSS metric employs the normal target and background as well as an estimation of the expected background. The expected background is what one would expect to find if there were no target present. The metric is derived below:

Equation 7

$$PSS = [(\mu_{tgt} - \mu_{bkg})^2 + (\sigma_{tgt} - \sigma_{bkg})^2 + 2(1 - r)(\sigma_{tgt} * \sigma_{bkg})]^{1/2}$$

Where:
r = 2-D correlation coefficient

The estimation of the expected background is developed based on the local background surrounding the target. In the equation, the value of "r" is an approximation value based on when an actual image containing no object of interest is available, and thus an estimation of the expected background needs to be made. It should be mentioned that when the correlation coefficient is exactly 1, the derivation of this metric is identical to the Doyle metric.

Finally, an expansion upon the PSS metric's concept of an expected background is termed the "line PSS" contrast metric.[8] This metric builds upon the assumption that the human visual expectation is interpolated in a given direction. In the case of the study with a vertical pedestrian contrasted against the horizon, the direction of interpolation selected is horizontal in nature.

Essentially, this line PSS determines a contrast metric for each pixel within a selected target. This metric is based on the luminance of the target pixel, the total pixels in the target, and the expected background as if the target were not present. The calculation is as follows:

Equation 8

$$Line\ PSS = [\frac{1}{total\ pixels} * \sum_{i,j} (t_{i,j} - b_{i,j})^2]^{1/2}$$

Where:
total pixels = Total number of pixels in target

= Luminance at target pixel (*i*,*j*)
= Luminance of background for pixel (*i*,*j*)

Additionally, the background luminance is calculated as a function of the mean luminance both to the left and right of the target, for each target pixel. It is calculated as follows:

Equation 9

$$b_{i,j} = \left(1 - \frac{i`}{n(j)}\right) * \mu_L + \left(\frac{i`}{n(j)}\right) * \mu_R$$

Where:
= Distance along the horizontal from the left edge of target to pixel (*i*,*j*)
= Distance along the horizontal inside the target
= Mean luminance on horizontal in the local background to the left of the target
= Mean luminance on horizontal in the local background to the right of the target

The derivation of the values for the background is also presented below in Figure 1.

Figure 1. Photo. Line PSS calculation values.

The line PSS contrast metric attempts to consider a pixel-by-pixel comparison to the background rather than relying solely on the mean luminance of the target as a whole or the background as a whole. While a single line PSS value is the result of the calculation, there are individual values associated with each pixel and it is these values that give an indication of the localized areas within the target.

The contrast metrics selected as those to be used in the current study were the Weber, RSS, PSS, line PSS, Doyle, Michelson, and IESNA contrast metrics. The Weber contrast was selected as it is typically the most common measure of contrast. The RSS and PSS were selected based on previous research indicating their strength and their inclusion of the role of the standard deviations of target luminance. Additionally, the expanded line PSS was included in order to investigate the concept of the expected background and the role of localized areas of luminance within a target. The Doyle contrast metric was selected as a comparison due to its inclusion of background standard deviation of luminance as well as consideration of localized areas of luminance within a target. The Michelson contrast metric was included as a comparison to what may be considered a "basic" contrast of a target as was the IESNA contrast metric. It should be noted that the CIE95 contrast metric was not included in data analysis as it is simply the absolute value of the Weber contrast metric.

Research Objectives

The goals of the current study were to apply multiple contrast metrics to images in order to better understand the factors that play a role in the visibility of pedestrians in the roadway. Factors such as differences in background and the role of localized areas within a target are specifically addressed.

CHAPTER 2. METHODOLOGY

Equipment

Using the MATLAB Image Processing Toolbox, contrast metrics were employed to analyze a number of images. Previous luminance data were collected using a Radiant Imaging ProMetric photometer.

Procedure

Contrast metrics were calculated for an ongoing analysis of data collected from previous studies. Specifically, Weber, RSS, PSS, line PSS, Doyle, Michelson, and IESNA contrast metrics were included in analyses and related to detection distance. An example of the procedure for the derivation of the RSS contrast metric is completed for a single image and presented below. The following procedure was conducted through the MATLAB programming software. An original image is presented for the selection of a target (Figure 2).

Figure 2. Photo. Original image.

The region of interest (the pedestrian) was then selected by the user. These results are below (Figure 3).

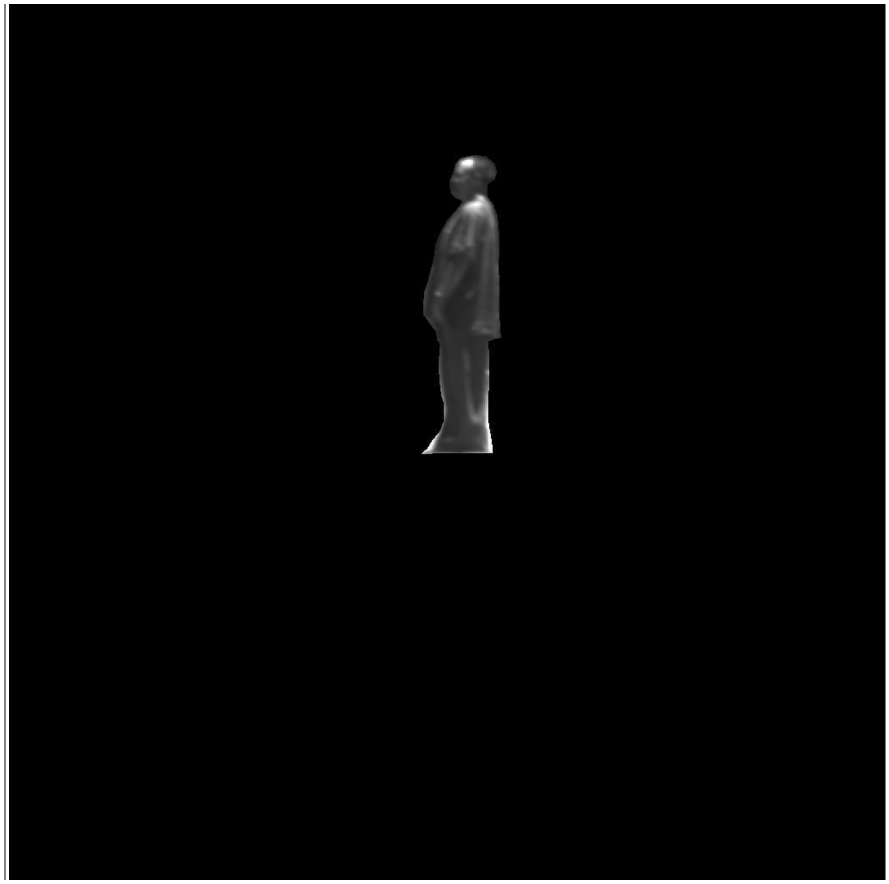

Figure 3. Photo. Final pedestrian image for analysis.

The background of the region of interest was then automatically selected based on the width of the object. This amount of background was selected in order to keep a constant target-to-background proportion for the changes with distance to the pedestrian. For example, a pedestrian 1000 ft. from an observer, appearing “x” pixels wide would have a surrounding background roughly “3x” pixels wide. The same pedestrian viewed 200 ft. away would appear larger to an observer and the same proportion of target-to-background was taken into account. This background was then used in multiple contrast metric calculations. An example of a selected background is presented below (Figure 4).

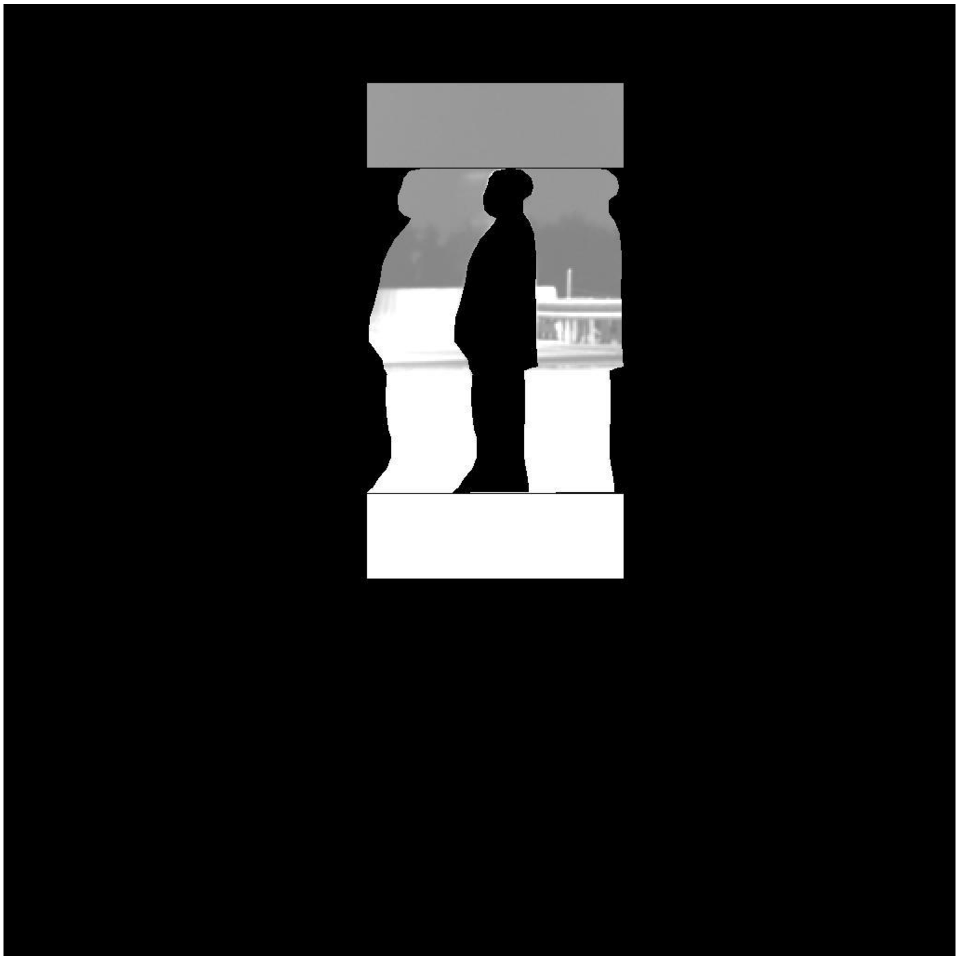

Figure 4. Illustration. Pedestrian background.

The multiple contrast metrics were then conducted based on the final target image.

This procedure was completed for 20 images of pedestrians from a research study (Information Report on Lighting Design for Midblock Crosswalks) previously conducted on the Virginia Smart Road.[9] This previous experiment was an investigation that considered the visibility of pedestrians in a crosswalk. The photometric condition of the pedestrians was measured using two methods. The first method used fixed distances and the second method used the mean detection distance of the pedestrians. The goal of applying these measurements to the current study was to determine the changes in the lighting condition as a vehicle approaches and to determine a visibility threshold for the pedestrian in the roadway. A specific description of the variables is in Table 1.

Table 1. Variables for analysis of existing photometric data at selected distances.

Variable	Levels
Distance (ft.)	200, 400, 600, 800, 1000
Clothing Color	Denim, Black
Overhead Lighting	High Pressure Sodium (HPS), Metal Halide (MH)

In order to compare objects at varying distances, the factor of the apparent size of the object was taken into account. For an object or pedestrian standing 1000 ft. from an observer, the size of the pedestrian appears much smaller than would the same pedestrian at 200 ft. In other words, while the pedestrian is wearing the same clothing, is presented under the same lighting scenario, and has the same height, the distance at which this pedestrian is viewed has changed and he/she will, therefore, appear smaller. Therefore, a light dosage factor was considered to account for the distance and difference in perception of the pedestrian. The concept of the light dosage factor is essentially an attempt to normalize the contrast data in order to draw conclusions across pedestrians of varying distances. For the current study, the dosage for each contrast metric was determined by this equation:

Equation 10

$$Contrast\ Dosage = Contrast * Object\ Size$$

The object size was the result of the following calculation:

Equation 11

$$Object\ Size = \frac{Object\ Height}{Distance}$$

The pedestrians for the study were males with an approximate height of 6 feet.

Finally, in order to relate the contrast metrics to pedestrian detection distance, an analysis of a second group of images was completed. This group of images was the result of a previous research study conducted on the Virginia Smart Road. The previous study concerned the detection of pedestrians wearing different clothing colors (denim, black, white) as well as a "surrogate" pedestrian in a crosswalk area under HPS lighting of varying intensity (6 lux, 10 lux, 20 lux, and 30 lux). Participants in the study were instructed to drive a vehicle at night on the Smart Road and verbally indicate when they could first see the pedestrian or surrogate. This verbal response was considered the moment of detection and recorded by an in-vehicle experimenter using the in-vehicle data acquisition system. A summary of all participant data resulted in a mean detection distance for each clothing type as well as lighting lux level. Images were collected using the same imaging photometer and recorded at the mean detection distances for each.

Table 2. Variables for analysis of crosswalk pedestrian detection distance data.

Variable	Levels
Distance (ft.)	Mean Detection Distances
Clothing Color	Denim, Black, White, Surrogate
Lighting Level (lux)	6, 10, 20, 30

Data Analysis

Through the use of the MATLAB Image Processing software, the PSS, line PSS, RSS, Doyle, Michelson, Weber, and IESNA contrast metrics were determined for images. An analysis of these contrast metrics as related to contrast dosage was also conducted. Metrics were then compared to existing detection distance data.

CHAPTER 3. RESULTS

The results are considered first in terms of the selected distances, then in terms of the threshold distance measured by the human subjects.

SELECTED DISTANCES

Contrast metrics were initially calculated for pedestrian images from the Crosswalk study.[9] The following results are based on the analysis of these pedestrian images that were captured in a static environment with a still photometer at the selected distances ranging from 200 ft. to 1000 ft. away from the photometer.

RSS Contrast Metric

The results in Figure 5 indicate a decrease in contrast dosage with an increase in distance from the target pedestrians. As can be expected, the contrast dosage is indirectly related to the distance at which the image was captured. This is due to the fact that, as distance increases, the relative size of the object decreases (through the derivation demonstrated in Equation 11). The contrast dosage of the denim- and black-clothed pedestrians under HPS lighting was found to be highest at the shorter distances and slightly higher across most distances from the observer/camera as compared to the MH lighting condition. The specific breakdown of the actual RSS contrast values is presented in Table 3.

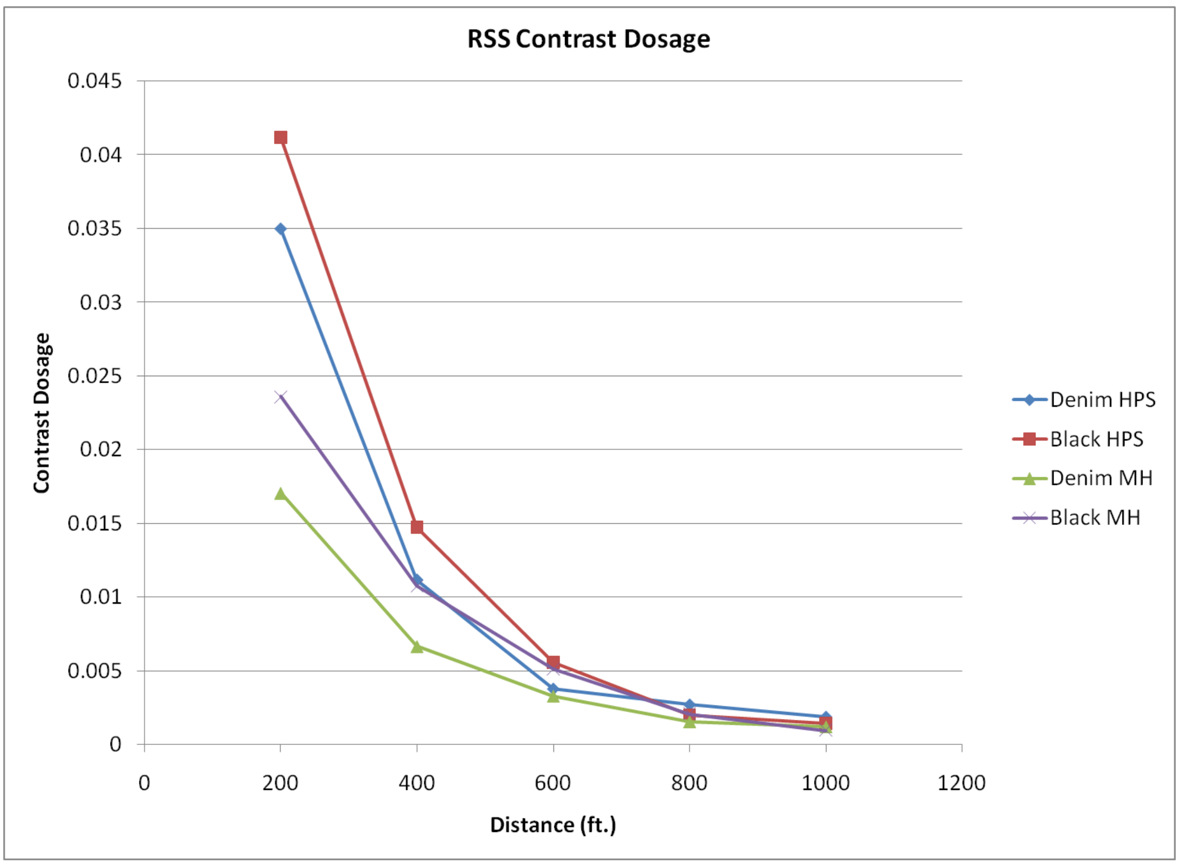

Figure 5. Graph. RSS contrast dosage.

Table 3. RSS contrast values.

	RSS Contrast			
	Light Source			
	HPS		*MH*	
	Pedestrian Clothing		Pedestrian Clothing	
Distance (ft.)	**Black**	**Denim**	**Black**	**Denim**
200	1.373108	1.166425	0.786625	0.568449
400	0.980955	0.744044	0.716098	0.443753
600	0.556204	0.375838	0.510812	0.330077
800	0.262847	0.357567	0.275759	0.207724
1000	0.232852	0.308018	0.157121	0.201758

As one can see from Table 3 and Figure 6 (below), similar to the contrast dosage results of Figure 5, there is a consistent decrease in RSS contrast values with the increasing distance. While this may be expected with the contrast dosage because its value is based on the relative object size, more of an explanation is needed for the decrease in actual RSS contrast. An example of the progression of such images across the increasing distances for the denim-clothed pedestrian under the HPS lighting condition is presented in Figure 7.

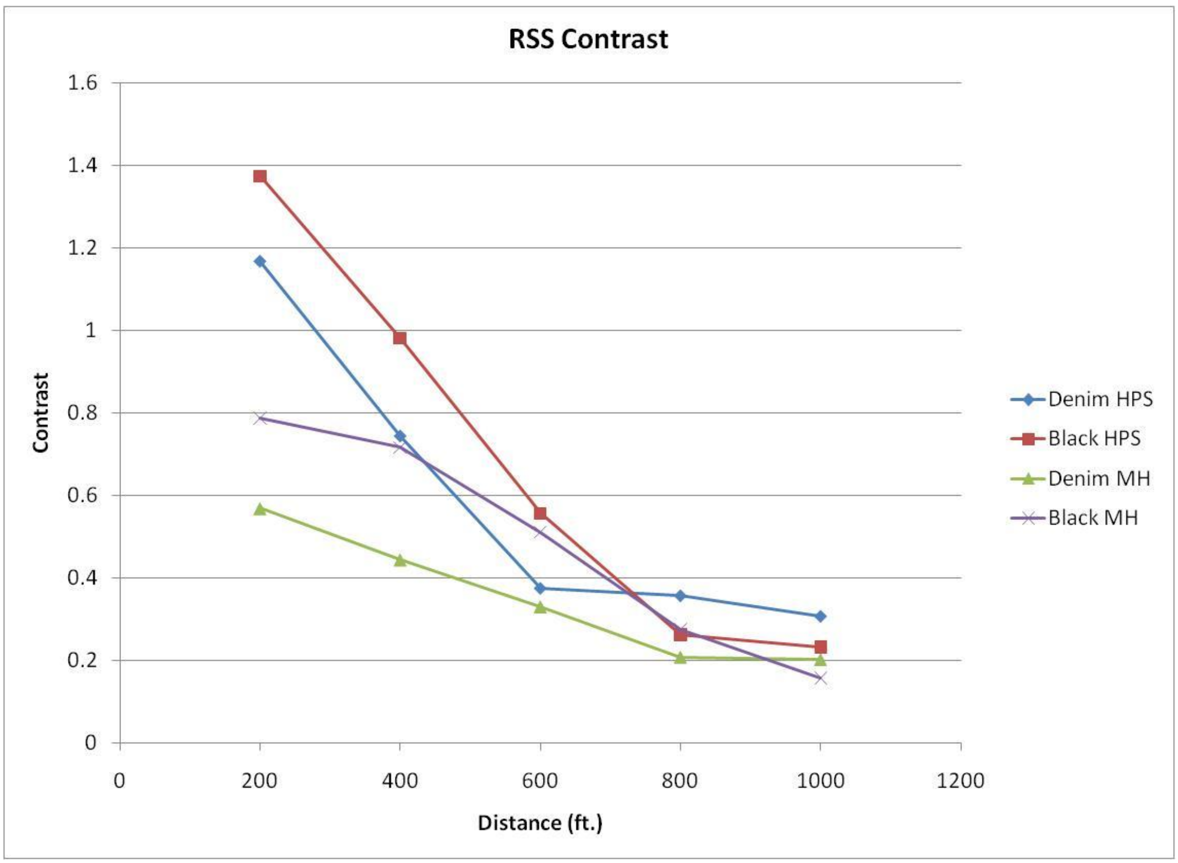

Figure 6. Graph. RSS contrast.

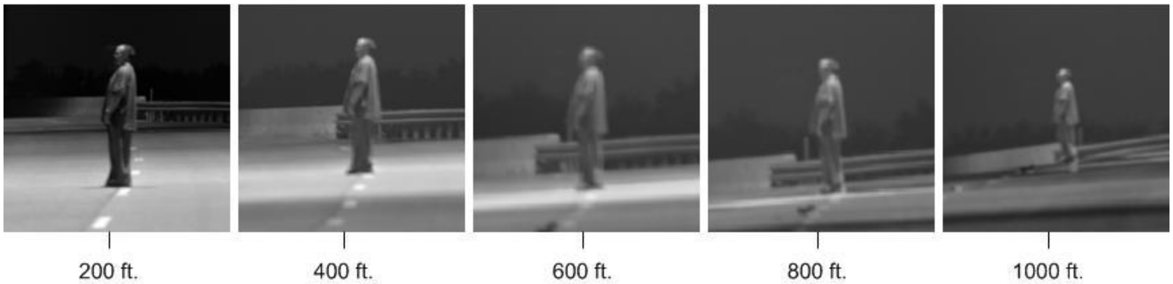

Figure 7. Photo. Background changes with increasing distance.

As one can see, as the distance from the observer/camera increases, there is also a change in the background of the pedestrian. At the closest distance of 200 ft., the majority of the background consists of the highly illuminated road surface. As the distance from the pedestrian increases, the background becomes composed less of the road surface and more of the dark night sky behind the pedestrian. Due to the RSS contrast metric being based on the luminance of the target (pedestrian) and the luminance of the background, it is important to understand how these values are changing over the distance. This is presented in Figure 8.

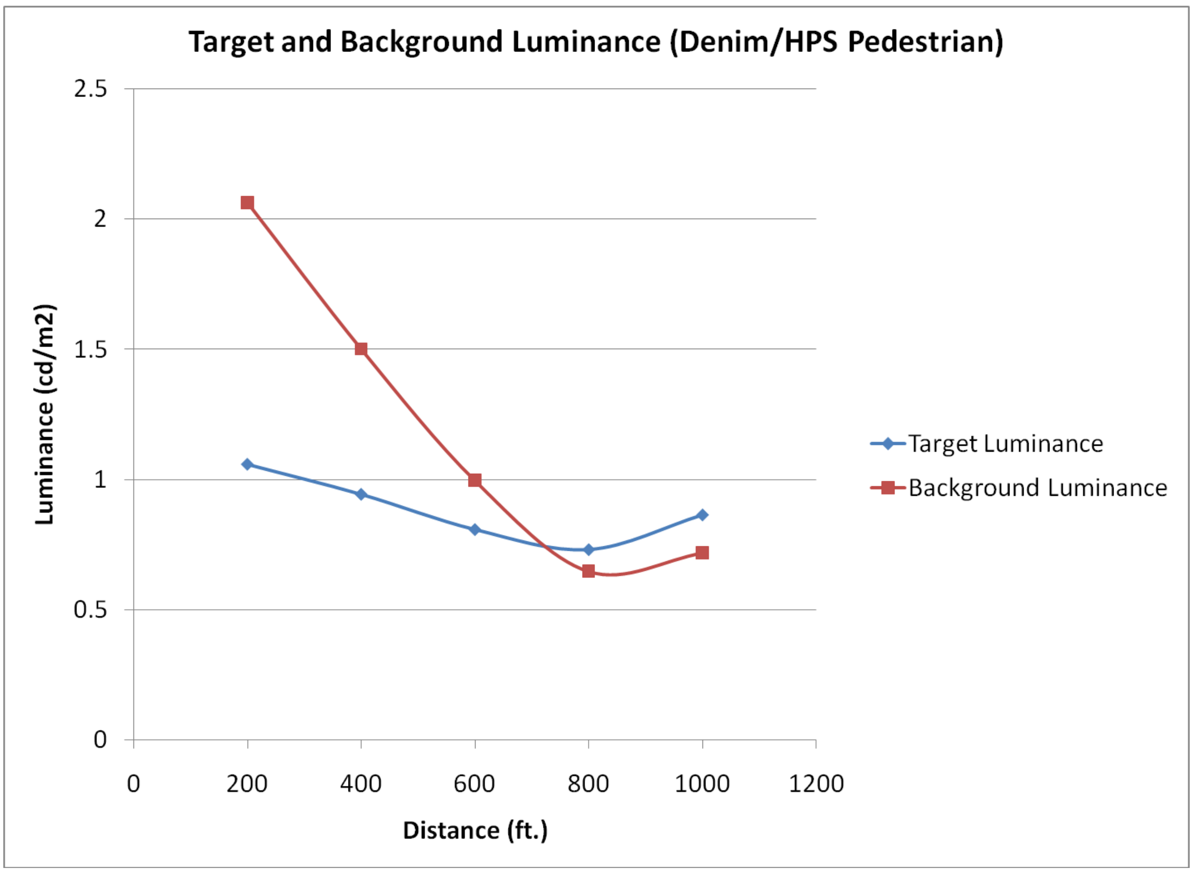

Figure 8. Graph. Comparison of target/background luminance.

As is displayed in the figure, as the target and background luminance values become similar over the increasing distance, the resulting contrast of a target against the background decreases. This is also evident in the RSS contrast metric results in Table 3 which show decreasing contrast values with increasing distances, indicating that the cause may be the darkening background with increasing distance. This could also be due to a change in the perspective with which the driver sees the object and the roadway. As was shown in Figure 7, the pavement that is typically considered the background is actually less and less influential the farther the object is from the observer.

Continuing the explanation of RSS contrast dosage (Figure 5), there also appears to be a higher RSS contrast dosage associated with the HPS lighting condition over the MH lighting condition. Once again, this is due to the higher luminance of both the pedestrian and the background in the HPS condition. This is presented in both Figure 9 and Figure 10, describing the denim-clothed pedestrian.

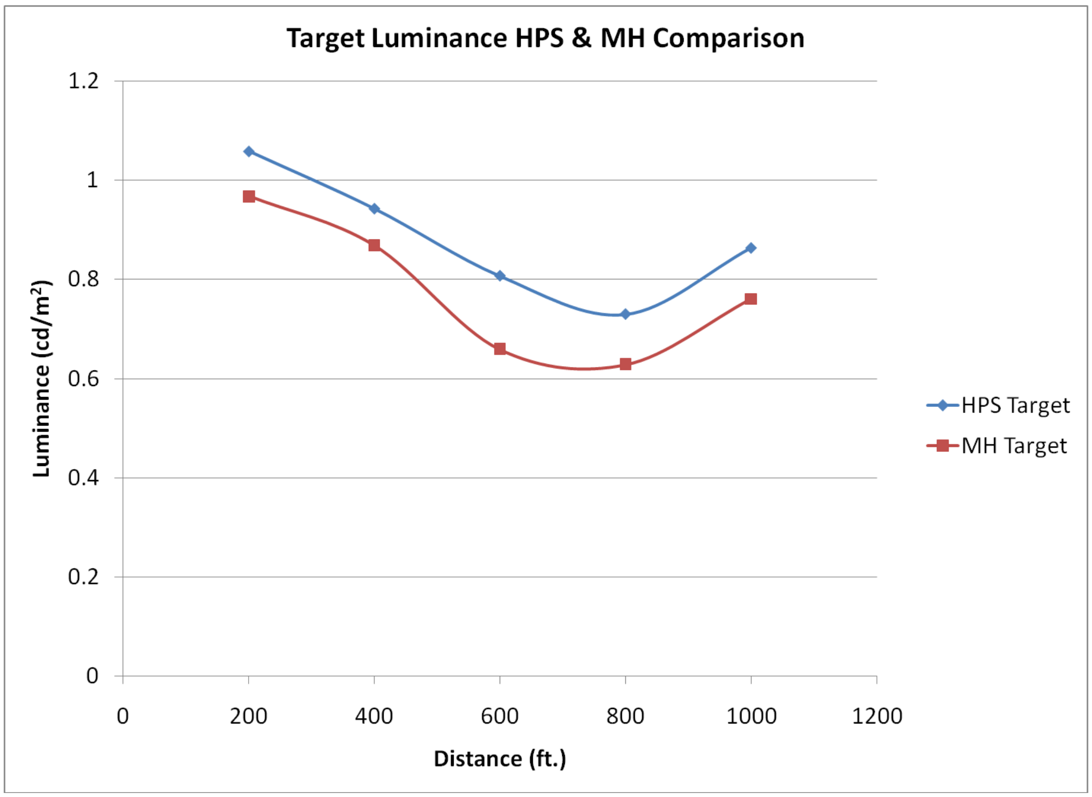

Figure 9. Graph. Target luminance HPS & MH comparison.

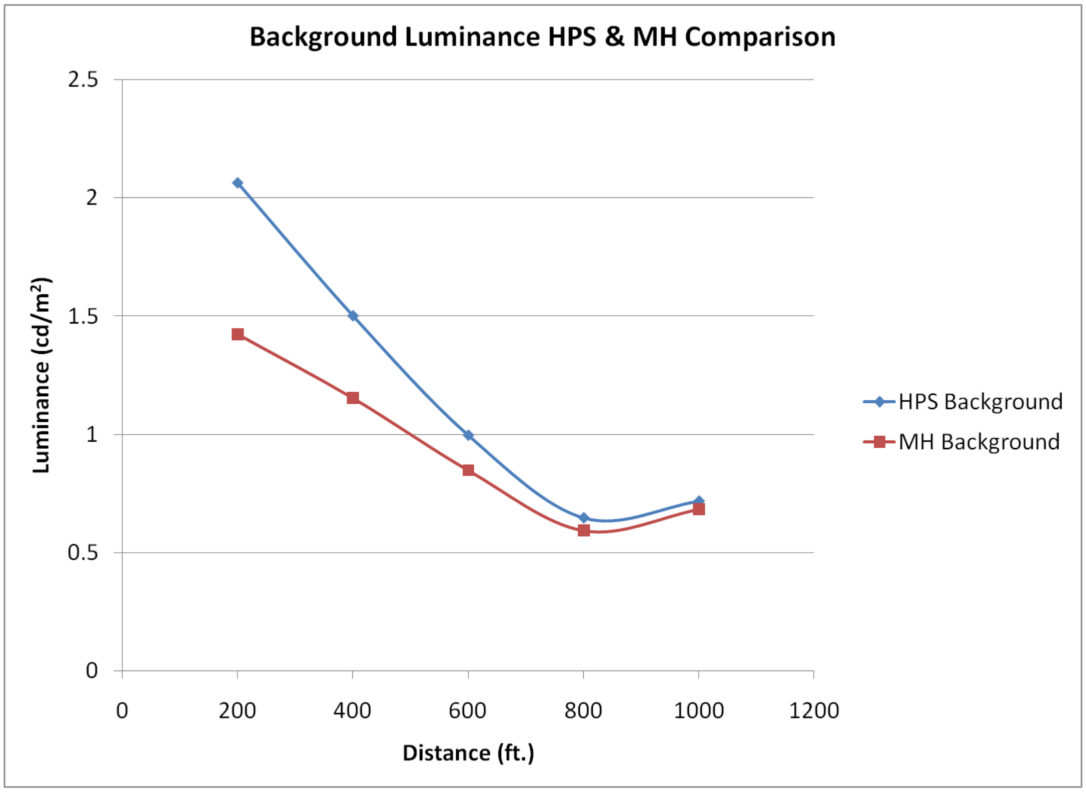

Figure 10. Graph. Background luminance HPS & MH comparison.

One can see from the above figures that the luminance results of both the target (pedestrian) and the background are higher in the HPS condition than in the MH lighting condition. Explaining the background luminance difference, one would assume that the background would remain constant between lighting conditions. However, it is because the background is composed of the illuminated pavement under the luminaire at the closer distances that the light source has such an impact on the background luminance. This is presented in Figure 11, with images of the black-clothed pedestrian being captured at the same distance under the HPS and MH lighting conditions.

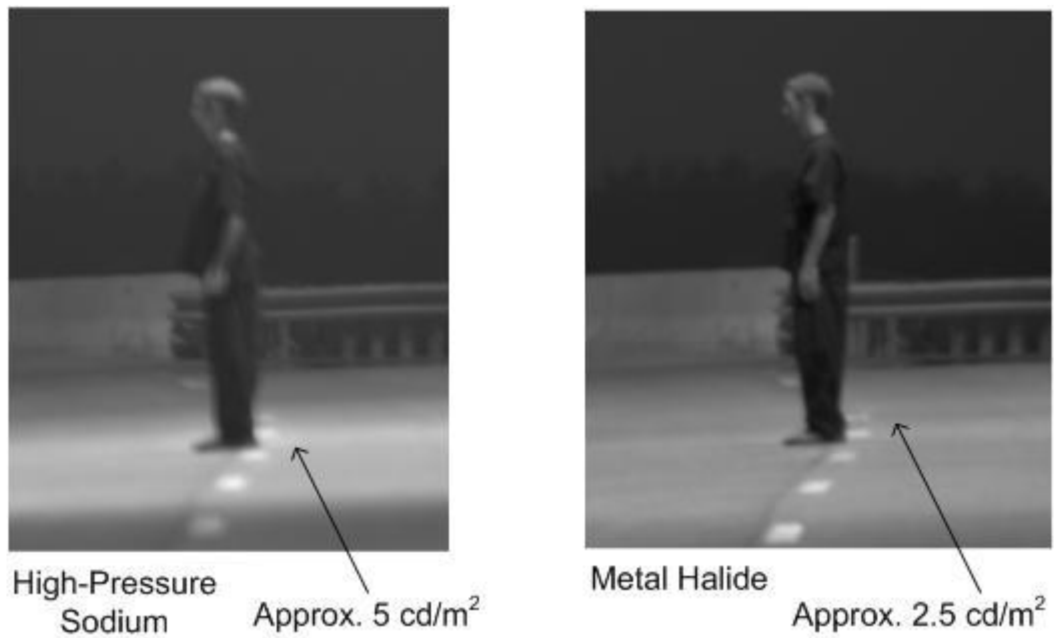

Figure 11. Photo. HPS and MH lighting on background roadway.

As one can see, the HPS lighting condition results in a slightly higher luminance on the roadway than does the MH condition. The difference in lighting conditions, while not affecting the sky background or the guardrail background, impacts the luminance of the roadway. In terms of the differences in target luminance between the HPS and MH conditions, an explanation would be the distribution of the intensity of the overhead lighting. Based on Figure 11, it is clear that the light is distributed somewhat uniformly on the pavement in the MH condition, while appearing more focused in the HPS condition. These differences in the distribution of light would also explain the differing luminances of the target pedestrians as well.

PSS Contrast Metric

The results of the PSS contrast metric indicate a somewhat similar trend as the RSS metric, with the black-clothed pedestrian contrast generating a higher calculation than the denim-clothed pedestrian in both lighting conditions (Figure 12). As previously mentioned, this can most likely be attributed to the roadway luminance background as compared to each clothing type. Data of actual PSS contrast values are shown in Table 4.

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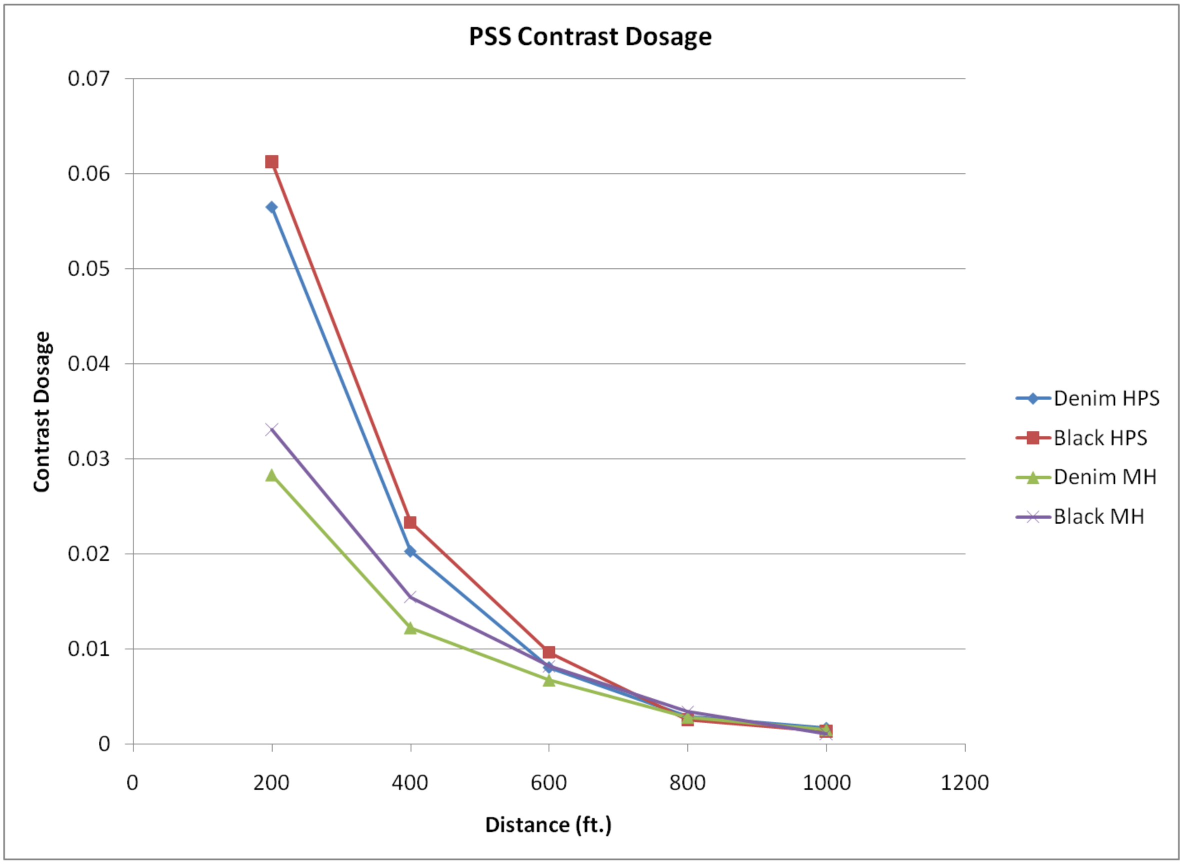


Figure 12. Graph. PSS contrast dosage.

Table 4. PSS contrast values.

	PSS Contrast			
	Light Source			
	HPS		*MH*	
	Pedestrian Clothing		Pedestrian Clothing	
Distance (ft.)	**Black**	**Denim**	**Black**	**Denim**
200	2.042595	1.883872	1.102715	0.944514
400	1.554187	1.352849	1.031109	0.816895
600	0.963765	0.806736	0.819003	0.675322
800	0.343058	0.381108	0.454259	0.379331
1000	0.221565	0.280148	0.179285	0.253981

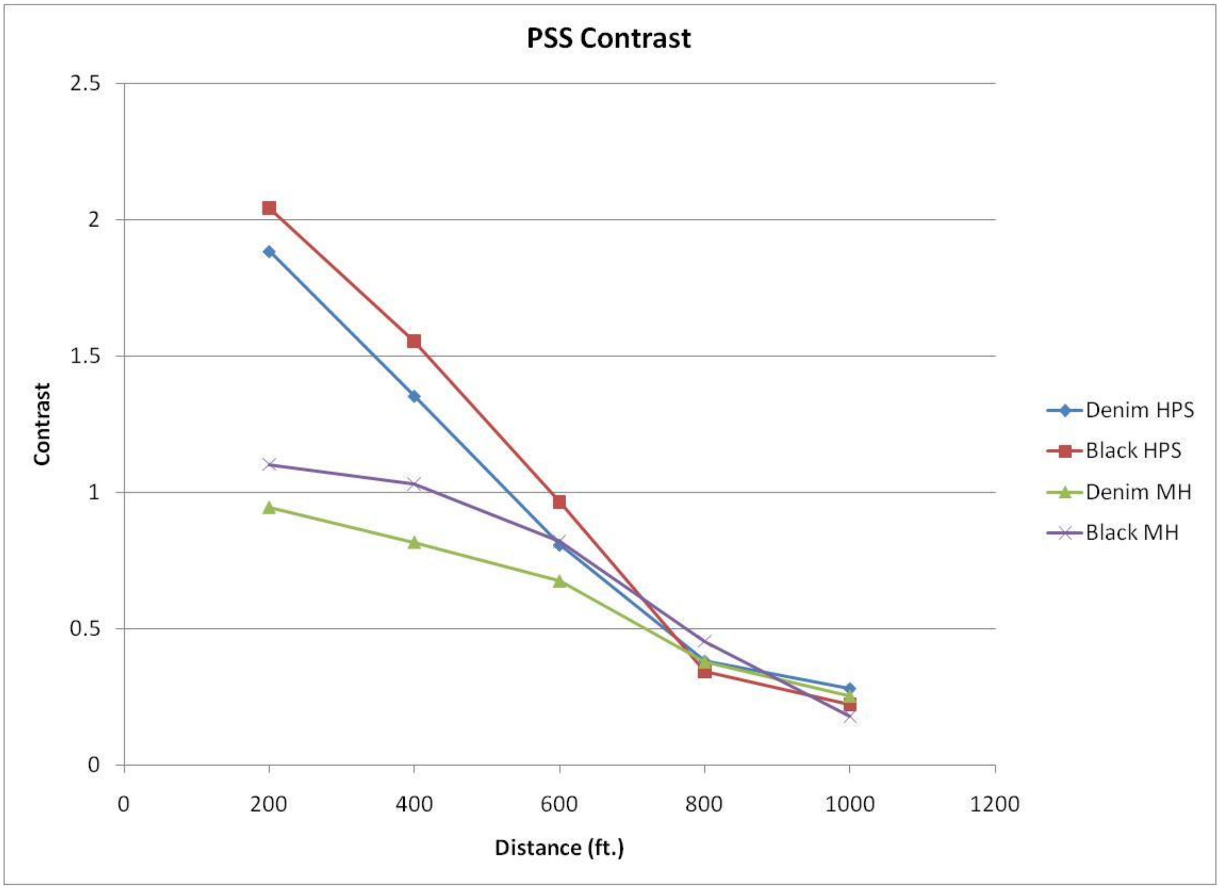


Figure 13. Graph. PSS contrast.

While the values themselves differ from resulting RSS contrast values, the trend remains the same; i.e., the black-clothed pedestrian resulted in higher contrast than the denim-clothed pedestrian for the close distances. Once the highly illuminated roadway composed less of the background (e.g., at distances further from the pedestrian), the denim-clothed condition indicates higher contrast to the now more prominent night sky.

Doyle Contrast Metric

As can be expected based on its derivation, the resulting Doyle metric is similar to both the RSS and PSS data (Figure 14).

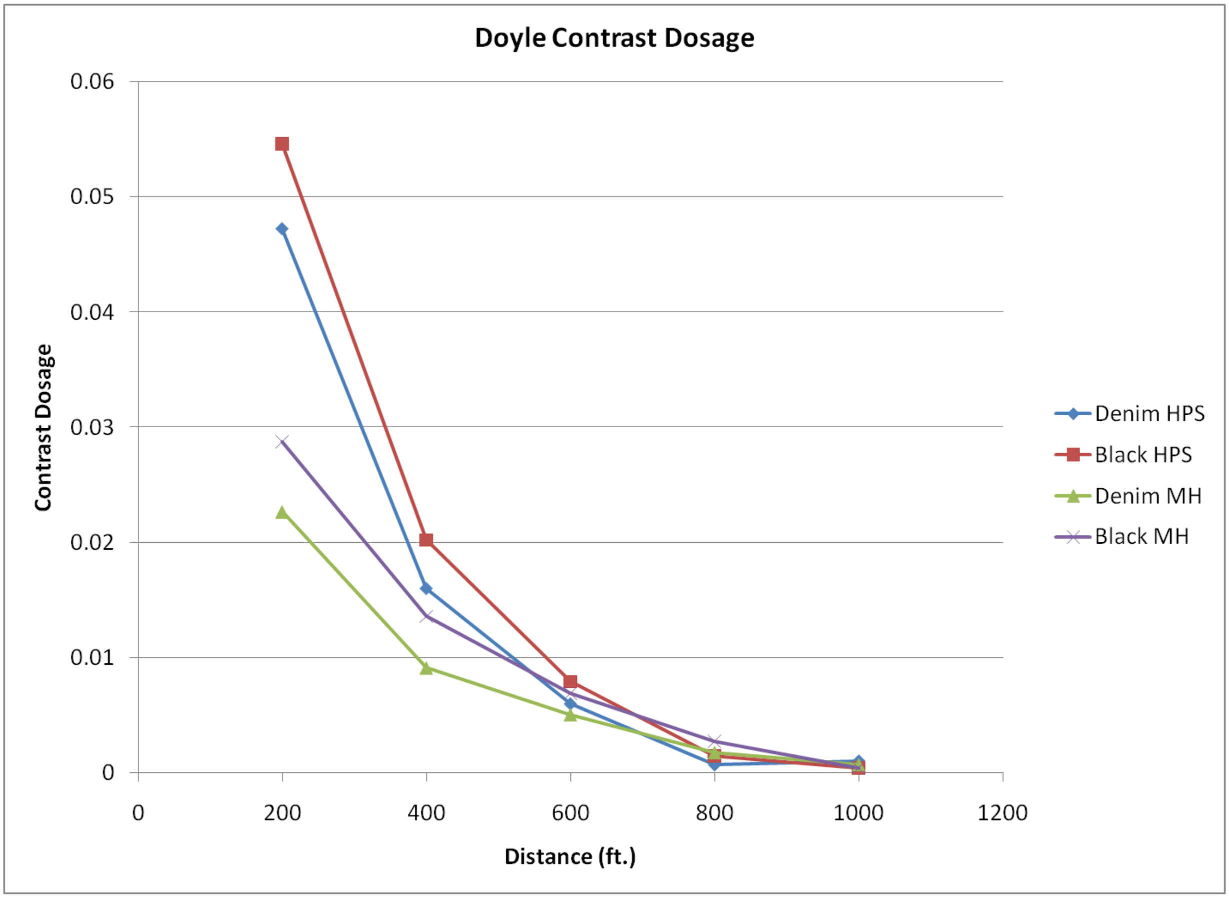


Figure 14. Graph. Doyle contrast dosage.

Line PSS Contrast Metric

The line PSS contrast metric calculation takes each pixel into account and compares it to the background to the left and right of the target. To summarize this metric with a single, average value for the entire target would defeat the purpose of the metric itself. Its strength lies in its ability to focus upon individual points within the target. An example of selected calculated values for a black-clothed pedestrian are therefore presented below (Figure 15) rather than as a summary chart.

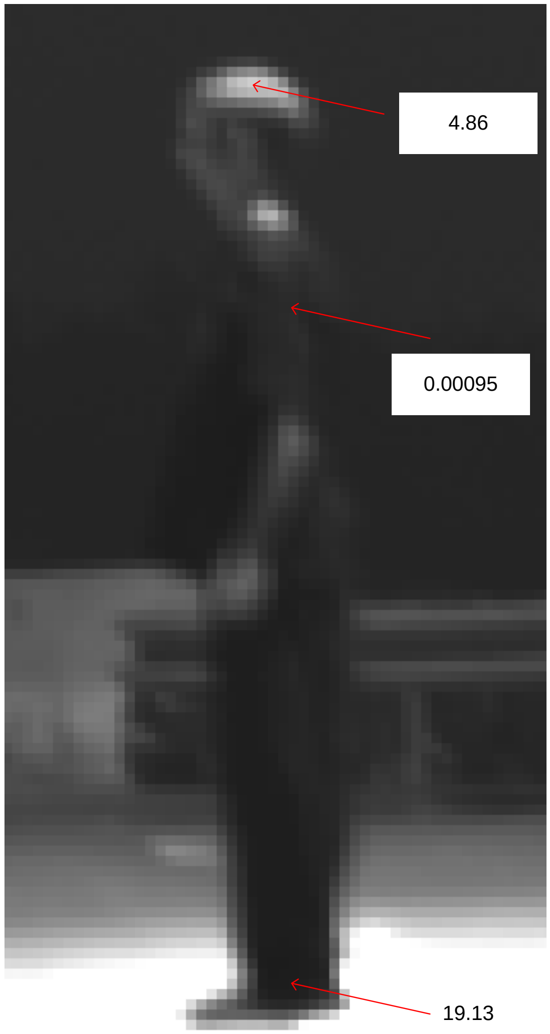


Figure 15. Photo. Line PSS example results.

One can see from Figure 15 that an area of higher luminance (such as the pedestrian's head), resulted in a higher contrast than did an area of lower luminance (such as the pedestrian's shoulder area). The highly illuminated portion of the pedestrian's head is contrasted against the dark sky and, therefore, may be more noticeable and visible to a driver or observer than the shoulder area of the pedestrian, which seems to blend in with its surroundings. Interesting to note, however, is a portion of very low luminance (such as the pedestrian's feet) and the much higher contrast value associated with it. Because it is being contrasted against the highly illuminated roadway, this low luminance area has a higher contrast than even the pedestrian's head. Based on the results of all the pixels within the target, the values associated with this section at the pedestrian's feet are actually of the highest line PSS contrast.

In order to give an indication of the line PSS contrast metric throughout the pedestrian image, the following figure displays the contrast values of a column of pixels within the pedestrian image (Figure 16).

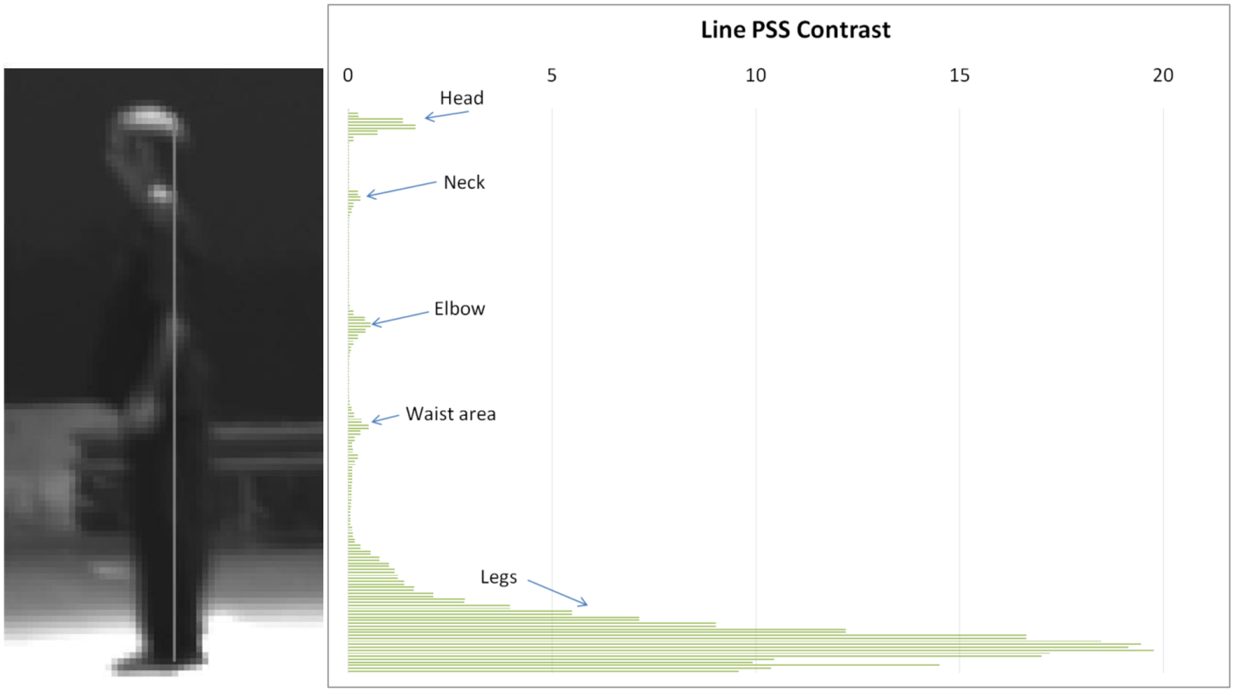


Figure 16. Photo and Graph. Line PSS example results detailed

As is shown in the figure above, the level of contrast within the pedestrian can vary greatly. As mentioned, while the head and neck of the pedestrian are highly illuminated, it is at the base of the pedestrian where the greatest contrast is taking place. Also interesting to note is the spike in contrast at the pedestrian's waist level. This is most likely due to the change in the pedestrian's background at this point, with a transition from the dark sky to the road's barrier and bridge.

Weber Contrast Metric

The Weber calculated contrast differs from the previously calculated metrics as it takes a polarity of contrast into account. Specifically, when the luminance of the background is greater than that of the target, the resulting contrast is negative. As has already been discussed (and is evident in Figure 17), there was a change in background that took place at the 800 ft. distance when the highly illuminated roadway comprised less of the background than it had at the closer distances. This would explain the sudden change in the resulting contrast from a negative to a positive for the denim-clothed pedestrian. Interestingly, for the 800 ft. and 1000 ft. distances, the contrast still remained negative for the black-clothed pedestrian. This would therefore mean that for all the distances taken into consideration, the mean luminance of the black-clothed pedestrian was always less than that of the background.

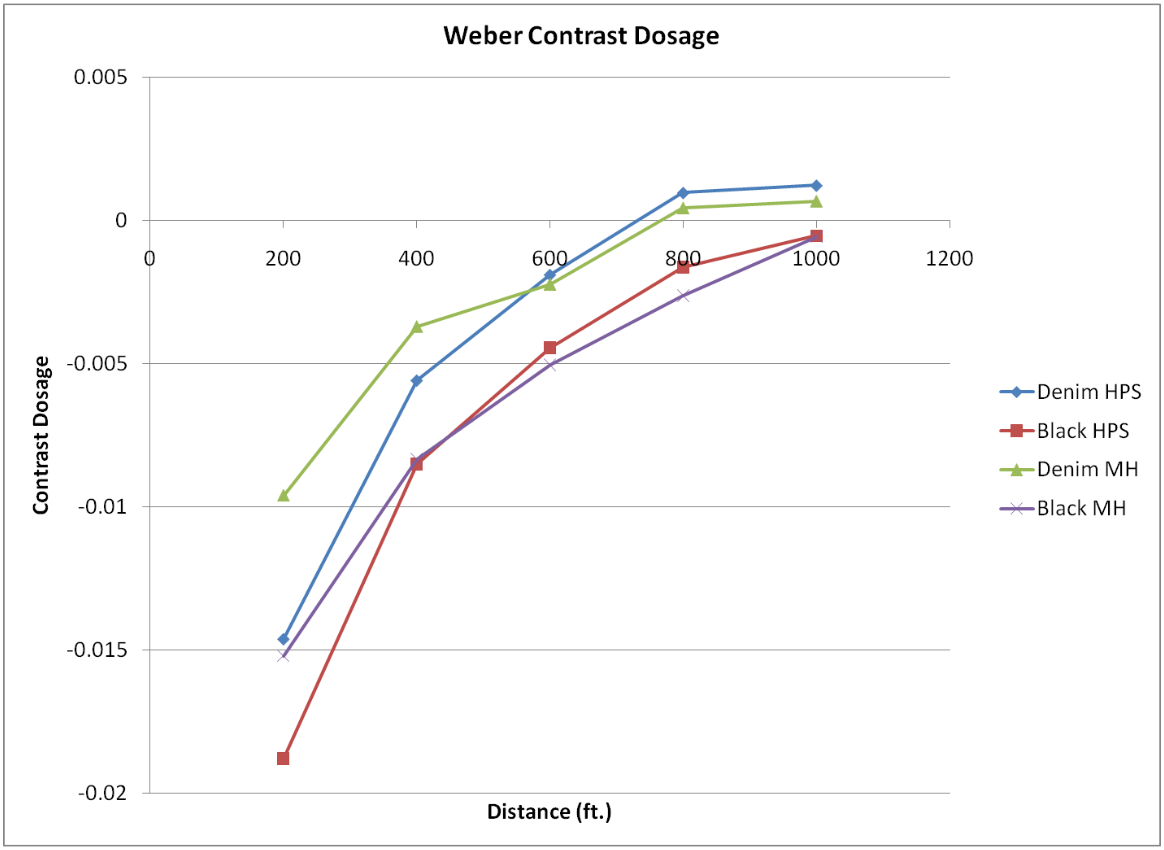


Figure 17. Graph. Weber contrast dosage.

Michelson Contrast Metric and IESNA Contrast Metric

The results of the Michelson and IESNA contrast metrics are indicated in Figure 18. While the actual values of the IESNA calculated contrast dosage differ from the Michelson contrast dosage, the trend appears the same and that is why they are grouped together here. Also similar are the resulting higher contrast dosages of the black-clothed pedestrian regardless of the overhead lighting type. This is understandable as both metrics are derived very similarly.

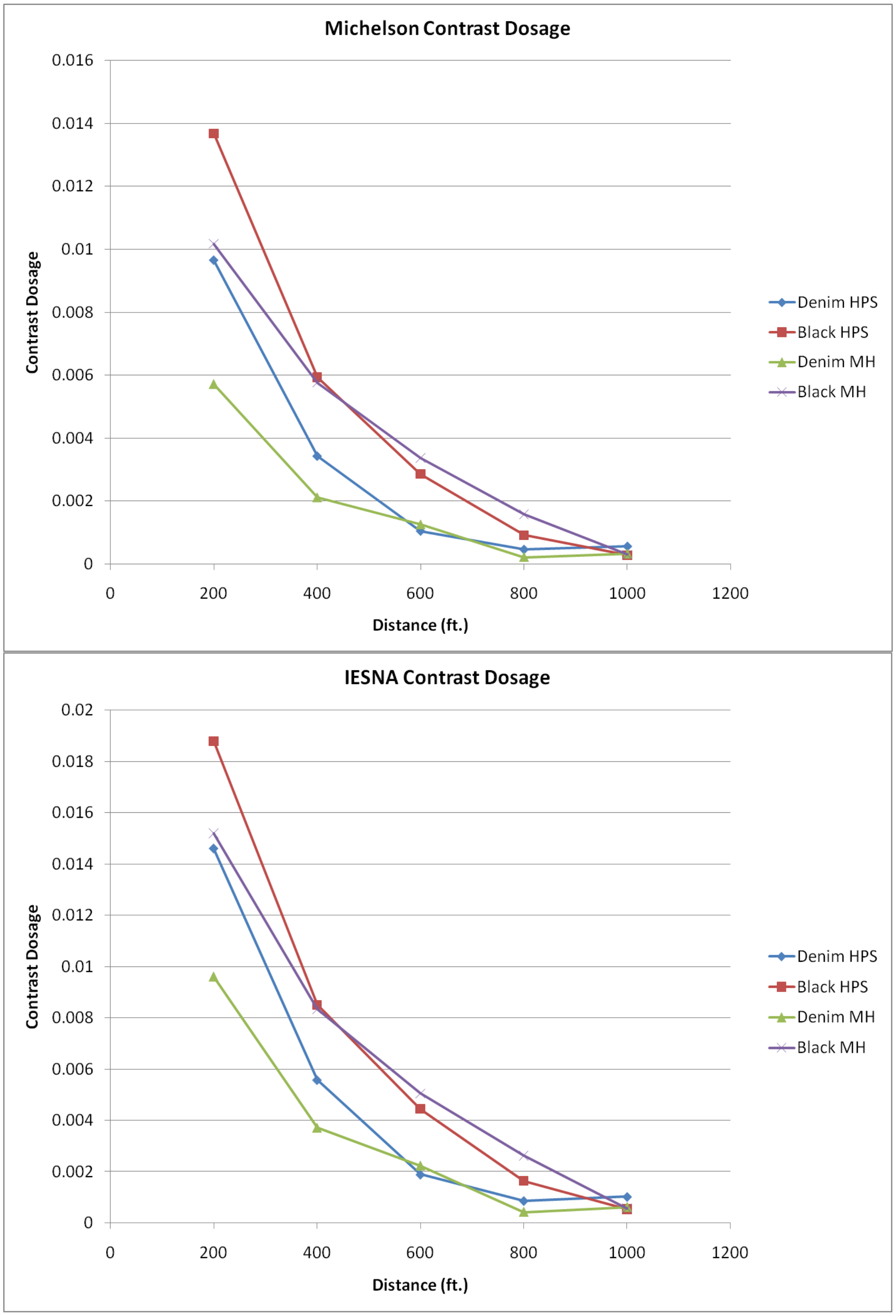


Figure 18. Graph. Michelson and IESNA contrast dosages.

These results are somewhat consistent with that of the Weber contrast, yet without a consideration of the polarity of contrast. One item of interest is the resulting contrast of the black-clothed pedestrian under both lighting conditions. The Michelson results indicate a consistently higher contrast dosage associated with the black-clothed pedestrian at the shorter distances. This conflicts with the results of the contrast metrics that consider more than just the mean luminance of the background, such as the RSS and PSS contrast metrics. A possible reason for this may be that a contrast metric such as the IESNA contrast metric does not take the standard deviation of the background into account. Therefore, differences between lighting conditions (such as the peak luminance of the focused light output demonstrated in Figure 11) would play less of a role in the calculation as the background and target are summarized by simple mean luminance values.

Among the contrast metrics employed for the analysis of pedestrian images at the selected distances, the RSS and PSS contrast metrics show their promising strengths of taking the variation of a pedestrian's background luminance into account when calculating contrast. Also, the characteristic of the Weber contrast calculation adds the dimension of the polarity of the contrast. This provides indication of the changes in the luminance of the pedestrian and the luminance of the background at different distances, and when these changes actually make the pedestrian either positively or negatively contrasted against his or her background.

DETECTION DISTANCES

Following the application of the contrast metrics at selected distances, an analysis was conducted on images captured at mean detection distances. As previously mentioned, these detection distances were established from the results of a participant detection task previously conducted on the Virginia Smart Road.

As a note, the line PSS is not considered in the following application to detection distance data. This is because the line PSS contrast metric places such an emphasis on the individual pixels within a pedestrian image. The images being used for the detection distance analysis are a result of a post-hoc capturing of images (i.e., the pedestrians in the images were not the same as those the participants actually viewed in the driving study); therefore, it would be misleading to draw conclusions using the line PSS contrast metric. For example, the line PSS contrast metric may give an indication of a high contrast value at certain parts of the pedestrian's body. However, because this pedestrian is different than what the majority of participants in the detection task study had viewed (and where the detection distance data are being derived from) it would be misleading to draw conclusions from such a metric.

RSS Contrast Metric

The results in Figure 19 reflect the RSS contrast of the four conditions (pedestrian clothing color and surrogate object) that were presented to participants. Within each condition are the four lighting intensity lux levels. As can be expected, the white-clothed pedestrian was detected from the furthest distance, on average, and also resulted in the highest RSS contrast value. What is interesting to note in a comparison between the black- and denim-clothed pedestrians is the shorter detection distance for the black-clothed pedestrian, despite having a higher RSS contrast. This is similar to the previously mentioned results from the selected distances, as the black-clothed pedestrian is contrasted greater than a denim-clothed pedestrian against the highly illuminated pavement at these short distances.

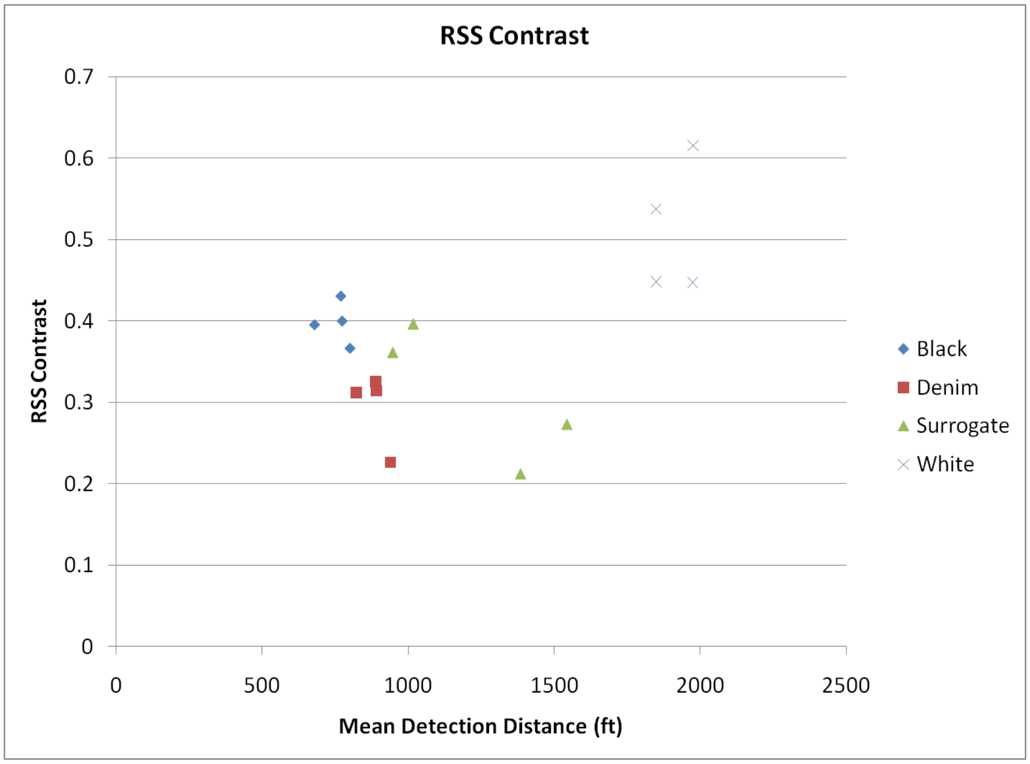


Figure 19. Graph. RSS contrast - detection distance data.

PSS Contrast Metric

The results of the application of the PSS contrast metric to images are presented below in Figure 20. What is interesting to note here is the existence of what appears to be a threshold at a PSS value of approximately 0.4. This may indicate that for a condition under HPS lighting, across all measured intensities of lighting, pedestrians in all clothing conditions need to have a PSS contrast value above 0.4 in order to be detected.

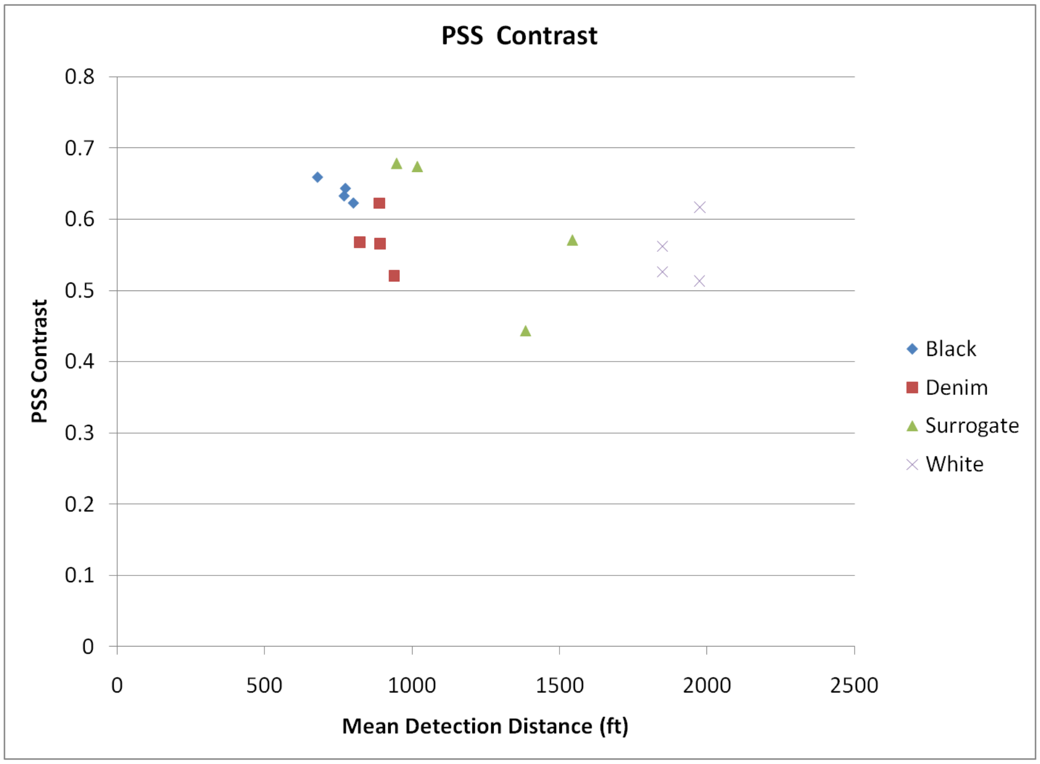


Figure 20. Graph. PSS contrast - detection distance data.

Doyle Contrast Metric

Results of the application of the Doyle contrast metric to the detection distance data are shown in Figure 21. The results appear very similar to those of the RSS contrast metric, with the obvious difference in the contrast values of the white-clothed pedestrian. This is most likely due to the Doyle contrast metric taking into account the standard deviation of the background luminance while the RSS contrast metric does not. There also appears to be a clear delineation in Doyle Contrast between the white-clothed pedestrian as compared to the other clothing conditions. It appears that the white-clothed pedestrian can be detected from the furthest distance and needs a Doyle Contrast value between 0.2 and 0.4, while the other pedestrian clothing needs to have a value of at least 0.4, similar to the PSS contrast metric.

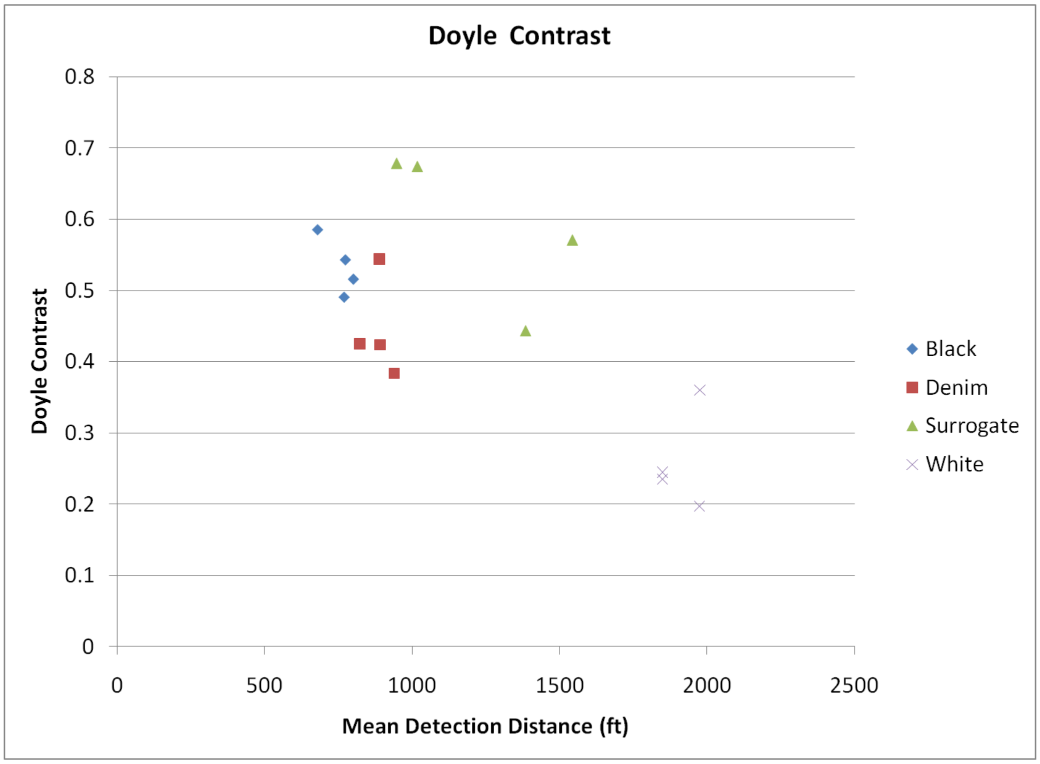


Figure 21. Graph. Doyle contrast - detection distance data.

Weber Contrast

The Weber contrast metric results indicate the strength of this particular metric's ability to indicate the positive or negative aspect of contrast. One can see a somewhat linear relationship forming with a correlation of short detection distance with high negative contrast of the black-clothed pedestrian, while a high detection distance is related to the high positive contrast of a white-clothed pedestrian.

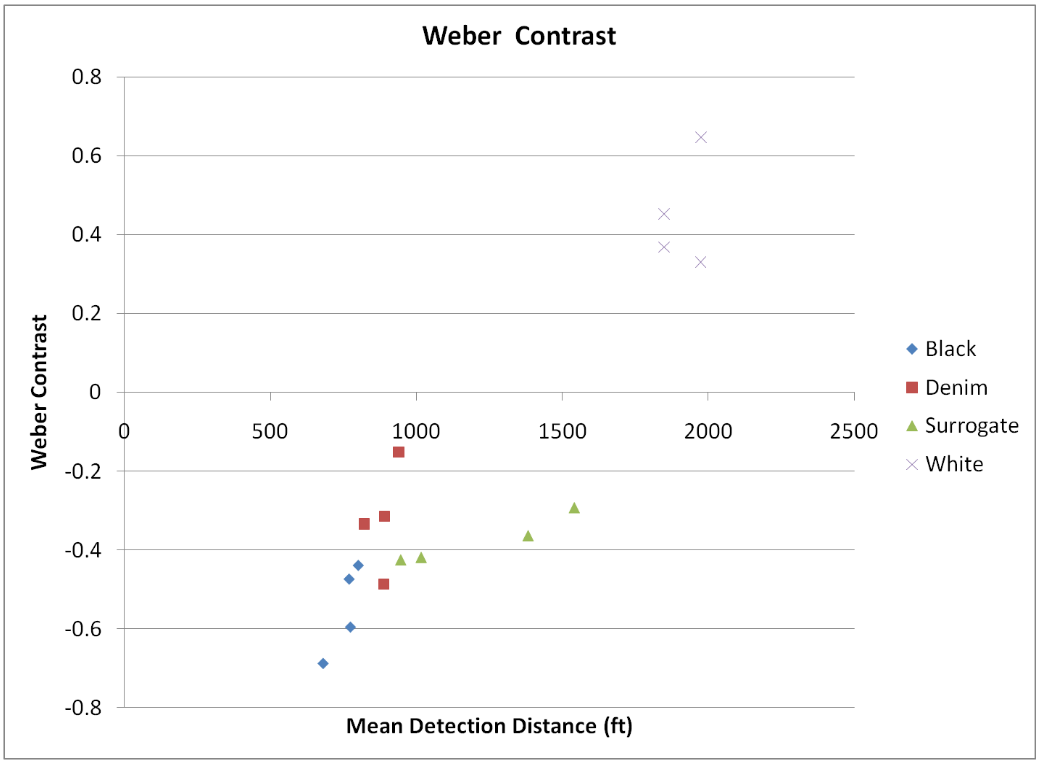
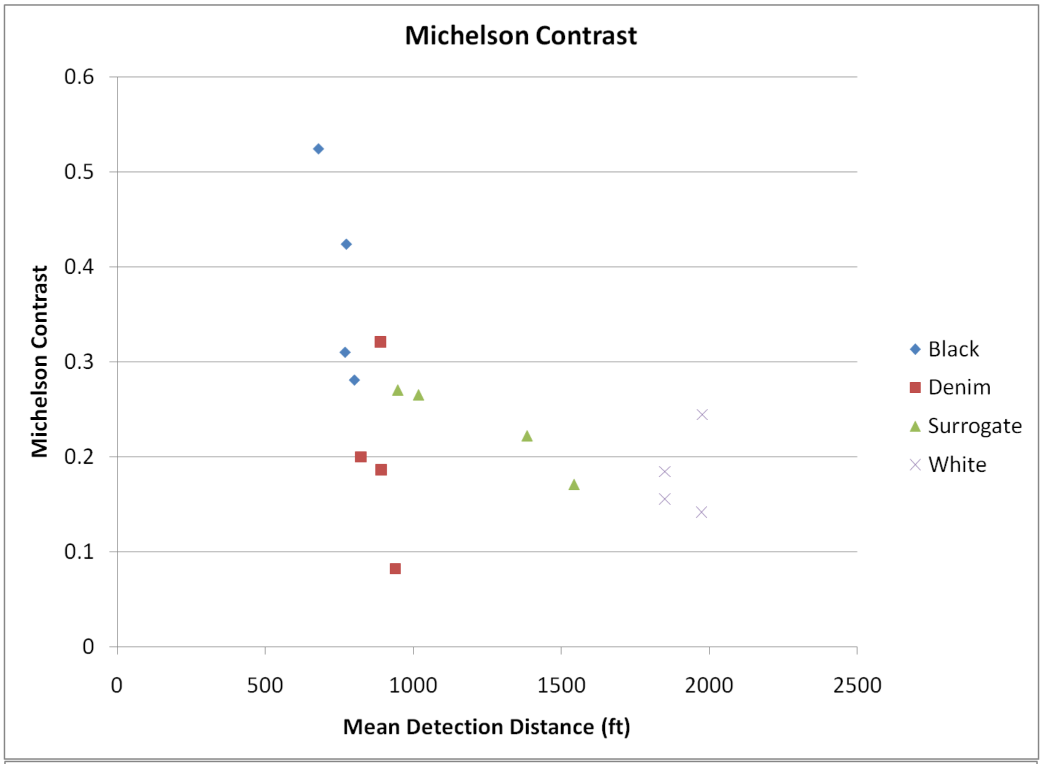


Figure 22. Graph. Weber contrast - detection distance data.

Michelson Contrast Metric and IESNA Contrast Metric

The Michelson and IESNA contrast metrics are the most basic calculations of contrast of the methods included in this study. The results of their application to the detection distance data indicate slightly higher contrast values associated with the black-clothed pedestrian as compared to all the pedestrian clothing scenarios. This may again be due to the sharp contrast that the black-clothed pedestrian has with the brightly illuminated pavement, but it is difficult to gather more information as these metrics only take the average luminance of the pedestrian and background into account.



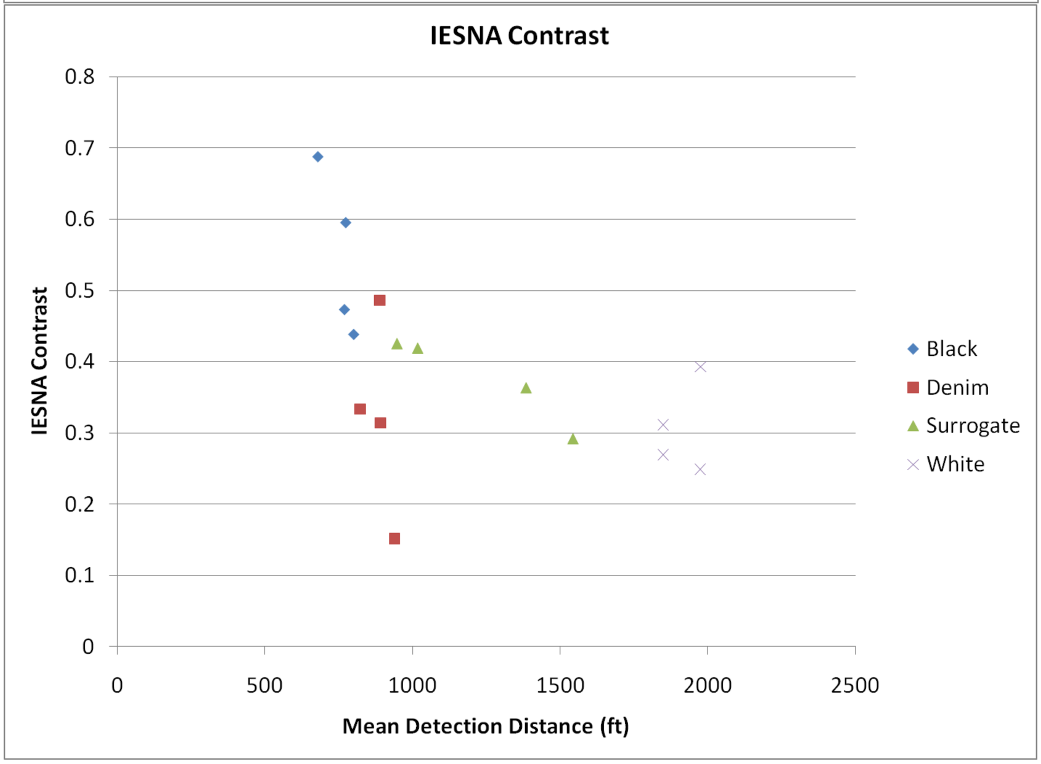


Figure 23. Graph. Michelson and IESNA contrast - detection distance data.

To summarize the analysis of the application of contrast metrics to detection distance data, the RSS and PSS contrast metrics provide important insight into factors that may have played a role in the detection of pedestrians from the crosswalk study.[9] Both of these contrast metrics seem to cluster at what seems to be a threshold PSS contrast value, where a pedestrian that exceeds this threshold may then become visible to an oncoming driver. An in-depth understanding of this threshold remains for future investigation.

CHAPTER 4. DISCUSSION

The objective of this study was to investigate the strengths and weaknesses of multiple contrast metrics for future application in determining pedestrian visibility. Of the many definitions for contrast that exist in the lighting and visibility community, a portion was selected for inclusion. These were the RSS, PSS, Doyle, line PSS, Weber, Michelson, and IESNA contrast metrics.

The results of the RSS, PSS, and Doyle contrast metrics explain contrast in similar ways as they consider the non-uniformity of luminance within a target pedestrian and the background luminance. The more traditional Weber, Michelson, and IESNA contrast metrics lack this characteristic of explaining the non-uniformity in a target as well as the background.

While the RSS metric ignores the standard deviation of the background luminance, results indicate that this had little impact on the resulting differences in contrast. This is shown as the PSS (which considers background standard deviation) resulted in a trend of contrast similar to the RSS metric. However, based on the different results of contrast metrics that focus solely on mean luminance value (such as the IESNA-defined contrast) there does appear to be a need for a deeper explanation of what constitutes the background to an observer.

The line PSS – which addresses an expected background – was shown as beneficial in identifying specific areas within the target that are of high contrast. This provides important information concerning visibility of pedestrians, as it is often localized areas and their contrast to the background that make objects visible on the roadway. However, all the images analyzed in the current study were captured in a static environment and are not a true indication of what drivers are actually experiencing on the roadway. A future application would be to employ the line PSS contrast metric to images captured in a more dynamic, realistic fashion.

The Weber contrast metric, while not considering localized areas of luminance or a non-uniform target or background, did convey helpful information in terms of the polarity given to a contrast value. There may be benefits to a metric that determines either a positive or negative value for a target compared to its background, in terms of its visibility to a driver. For example, in the case when a black-clothed pedestrian is actually darker than the background, the visibility of such a pedestrian may still remain high due to a high contrast. This would require further research and an analysis of more objects with both positive and negative Weber contrast values.

Both the Michelson and IESNA-defined contrast metrics lack considering the variation in the target luminance as well as the background luminance. As has been shown, the factors of localized areas within a target and a less-summarized description of a target need to be considered when understanding how visible a target may be to an observer.

Regarding the data collected from locations derived from detection distance data, there appears to be a threshold PSS contrast value that must be reached even before pedestrians in all conditions of clothing color, or the surrogate pedestrian, will be detected.

As all the contrast metrics investigated include some factor of the background, it is obvious one needs to consider the background when determining the contrast. However, it is interesting to note that there are times when even a black-clothed pedestrian will have a higher contrast than a denim-clothed pedestrian, if the background under consideration is a highly illuminated roadway. Therefore, there needs to be a greater understanding of the degree of impact such changes in background may have on the visibility of an object or pedestrian.

CHAPTER 5. CONCLUSIONS

The conclusions from this study are as follows:

- The background and its variation need to be considered in an accurate measure of object contrast. This is obtainable through the use of the RSS and PSS contrast metrics.
- The polarity (negative/positive) of contrast needs to be considered in determining how visible an object is to an observer. This can be accomplished with the Weber contrast.
- The future application of the line PSS contrast metric will be useful for addressing the localized areas within the target, using images reflecting what participants actually experienced.

Limitations

One example is the method with which the target or pedestrian is selected. Currently, the approach was allowing a single user to select the image and perform a type of manual cut of the pedestrian target. The cut of the pedestrian is based on users of the software. Future research would investigate the area of an object detection algorithm in order to minimize any differences among users and the selection of targets for analysis.

The comparisons for the current study were made between a pedestrian dressed in denim and a different pedestrian dressed in black, from a previous study. However, the variable of pedestrian physical differences was not considered in this analysis. In order to reduce extraneous variables, such as differences in hair color, physical build, and posture, further research would investigate the role of the contrast metrics among data of a constant pedestrian in variable clothing and overhead lighting scenarios.

Finally, there is the concept of what is considered the background of a target when determining contrast. For the current study, a background based on the width of the target was used. Future investigations would include forming a specific definition of what type of background is to be considered for a driver or observer when viewing objects in the roadway.

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