May 2021

# Conspicuity of Walkway Height Changes

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# CONSPICUITY OF WALKWAY HEIGHT CHANGES

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A Thesis
Presented to
the Graduate School of
Clemson University

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In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Human Factors Psychology

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by
Rachel Staats
May 2021

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Accepted by:
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**ABSTRACT**

Trip and fall events can be dangerous and result in injury. One-way trip events start is when an observer's minimum foot clearance (MFC) is smaller than the height change. One reason why the observer might not change their MFC in response to the height change is that the height change is not conspicuous. An important aspect of conspicuity is illuminance levels. In this study, we wish to explore an online method that uses digital manipulation of the amount of light in the photo to simulate illuminance levels (lightness levels). Previous studies with object detection suggest that the lower the illuminance levels the harder the object is to detect. This study found that people do indeed judge height changes as more conspicuous as the height change increases and as lightness levels increase. Major conclusions were that shadowing cues transfer well from in lab studies to pictures. Another conclusion is that there could be a danger to pedestrians at medium and low lightness levels.

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# INTRODUCTION

Trip and fall events are major public health concerns, especially in older adults. Tripping during walking can account for up to 53% of falls in older persons (Blake et al. 1988). Heijnen and Rietdyk (2016) found that among people aged 18-35, 58% of falls occurred during walking and 25% of those falls were caused by trips. Heihnen and Riedyk also pointed out that falls are the third leading cause of unintentional injuries in that age range. One common initiator of trip and fall events is an abrupt height change in an otherwise level walkway (Ayres and Kelker, 2006). Height changes in walkways are often observed at the expansion joint gaps between panels on sidewalks and are typically caused by tree roots growing under the sidewalk, settling or heaving of the sidewalk, or improper construction (Boodlal, 2003). A trip can occur when the swing foot's forward momentum is interrupted by an obstacle.  This interruption causes the toe to strike the vertical surface of the height change. This impediment causes the body to lose balance because of the forward momentum from walking and so may cause a trip and fall if balance is not regained in time (Barrett et al. 2010).

The smallest distance between the swing foot and the ground is known as minimum foot clearance (MFC). A trip may occur when the person does not notice the height change in time to adjust their MFC to clear the height change (An object smaller than MFC will allow the foot to pass over it uninterrupted). Barrett et al. (2010) argue that the average MFC is between 10-20 mm. Barrett et al. (2010) compared the results of many different studies that dealt with MFC characteristics in younger and older populations. They found that older populations have the same mean MFC as younger populations; however, older populations have greater variability in MFC than younger populations.

MFC estimates help inform guidelines for building and walkway construction. One such building code is ASTM F 1637-13 or Standard Practice for Safe Walking Surfaces. This code states that changes in height greater than 6.35 mm (¼ inch) are not acceptable. Height changes between 6.35 and 12.70 mm (¼ to ½ inch) must have a beveled edge with a slope less than a 1:2 ratios. The beveling allows the person to maintain enough swing foot momentum to minimize the likelihood of a trip-and-fall event. The minimum height required for beveling, 6.35 mm, is much smaller than the mean MFC because MFC is variable and the beveling height requirement should be on the conservative end to accommodate for the variability in MFC especially for older adults. All height changes greater than 12 mm must be replaced with a ramp or stairway that complies with building codes. Nemire (2016) notes that the change is because the codes only take into account healthy adults' gaits and variance in MFC and ignore older adults and adults with gait disabilities. There is also evidence that height changes less than 6 mm can also disrupt the gait and cause a trip and hazard event (Nemire, 2016). A study by Kwasniak et al. (2012) analyzed how pedestrians judge how hazardous the height changes were in walkways located in outside parks. They also measured how likely they were to report height change to the authorities. The study was conducted by the participants assessing differences that range from 0.10 inches to 1.1 inches in both the ascending and descending sides of the height change and then they were asked how likely they would be to report the height change. They found that height changes less than 0.75 inches (1.905cm, well over the mean MFC) are less likely to be perceived as a hazard and less likely to be reported to authorities. This would indicate that there are dangerous height changes not being reported and not being perceived as hazards.

Height changes in walkways have the potential to be extremely hazardous to the user. If the height change is larger than the observer's MFC and is not conspicuous to the user, then a trip event could occur. Also, the nature of the information specifying the height change may be important for conspicuity. Many cues may play a role in the conspicuity of a height change.

*Conspicuity*

Conspicuity in this context is referring to the ability to differentiate the target from the background. Wertheim (2010) and Porathe and Strand (2010) studied the use of conspicuity angle as a measure of conspicuity. Wertheim (2010) showed the reliability and validity of using the conspicuity angle as a measure of conspicuity. The naked eye method was one of the methods to measure conspicuity angle which had the participant divert their gaze away from the target until the target was not visible and measure a change in ocular angle with a disk. Previous research (Wertheim 2006) has shown that the conspicuity angles obtained are related to the mean search times which validates the method. The variability of the scores while using the device in the naked eye method should only be used by a trained individual. However, a similar method by Porathe and

Strand (2010) was much less variable. Wertheim (2010) originally used a device that measured the angle of the eye while Porathe and Strand (2010) created a new simple and practical technique to measure the conspicuity angle. Their technique involved the subject fixating on a point to the side of the target and moving the gaze until the target is detected. The gaze can also start at the target and the participant will move their gaze until the target is unable to be detected. Porathe and Strand showed that their method of measuring conspicuity is valid with low variability across participants which allows for a smaller sample size. These results from Porathe and Strand when compared to the results of Wertheim (2010) show that the Porathe method is better with naïve participants.

Toet et al. (1998) and Wertheim (2006) both validate the use of conspicuity angle as a measure of target conspicuity. Toet et al. (1998) wanted to see a relationship between mean search time and conspicuity. They found that as the conspicuity of an object increases, the mean search time of the object decreases. They did this by measuring the amount of time a participant took to find the target in a visual search and comparing those results to the conspicuity angle. The conspicuity measurement procedure used successive fixation points in the peripheral visual field. When the angular distance from the point where the target was first noted, and the center of the target was the conspicuity measurement. They discovered that target conspicuity and mean search time are strongly related. This study was later built upon by Wertheim (2006) which found that lateral masking is an important aspect of conspicuity. Lateral masking is when the lateral features can mask and reduce the visibility of target features. Wertheim (2006) conducted five experiments that test various visual search effects. Connecting this research and the research conducted by Toet et al. (1998), it can be concluded that lateral masking is connected to conspicuity.

Previous research on conspicuity conducted by Tutaj (2019) validated the use of conspicuity angle by correlating the results of the conspicuity of traffic signs to the magnitude estimation. Conspicuity angle is the angle at which the participant can distinguish the target from the background. The larger the angle, the more conspicuous the target. Magnitude estimation is a well-validated measure for estimating the strength of sensations. Tutaj validated the conspicuity angle method by asking participants to gauge the conspicuity of road signs and correlating this data to the measured conspicuity angle of the road signs. Tutaj (2019) had participants observe a picture with 1 of 10 different signs and asked for the participants to either rate the sign with a magnitude estimation or measure the conspicuity angle first then the participant completed the other technique. They measured the conspicuity angle by asking participants to move their eyes to the side until they could not distinguish the sign from the background and the angle was measured. Then they were asked to start to the side of the image and move their eyes to the point that they can distinguish the sign from the background. These two methods were averaged together to calculate the conspicuity angle. They indeed found that conspicuity angle and magnitude estimation are strongly correlated.

As an expansion of Tutaj's (2019) research, Staats et al. (2020) examined the conspicuity angle for trip hazards as a function of expansion joint gap width. The naive participants did not seem to be influenced by the ambiguity of the expansion joint gap when judging the conspicuity of the height change. The naive participants had similar conspicuity angles for each of the different expansion joint gaps for all of the different height changes as seen in Figure 1. The simulated walkway was a base of a Rubberific paver that was raised using linoleum tiles in combination with additional pavers. The pavers were simulated stone rubber and can be seen in Figure 2. They found in the first experiment that both the research assistants and naive participants saw that as height increased the conspicuity of the height change also increased (Figure 1).

Also in Staats et al.'s first experiment, it was found that the conspicuity range of the 7.6mm height change was between 2 and 6 degrees. They also found that the first group was possibly biased into using the shadow as a cue due to exposure to the stimuli as the first group saw that the zero expansion joint gap condition was less conspicuous than the other two expansion joint gap conditions. In other words, the expansion joint gap influenced the judged conspicuity of the height changes. It is more probable that the research assistants were using shadowing as a cue due to the results of experiment two where the effect of the expansion joint gap on the conspicuity of the height change was minimized by minimizing the shadowing on the vertical face of the height change. Experiment one was a 2 (participant type: research assistants and naive participants) x 3 (expansion joint gap: 0.0 cm, 0.32 cm, and 0.64 cm) x 5 (height change: 0.0 cm, 0.76 cm, 1.52 cm, 2.54 cm, and 5.08 cm) within-subjects factorial design. It was conducted by asking both groups of participants to report both magnitude estimation and conspicuity angle for all 15 trials. There was a similarly high correlation between the magnitude estimation and conspicuity angle that Tutaj (2019) found in their study.

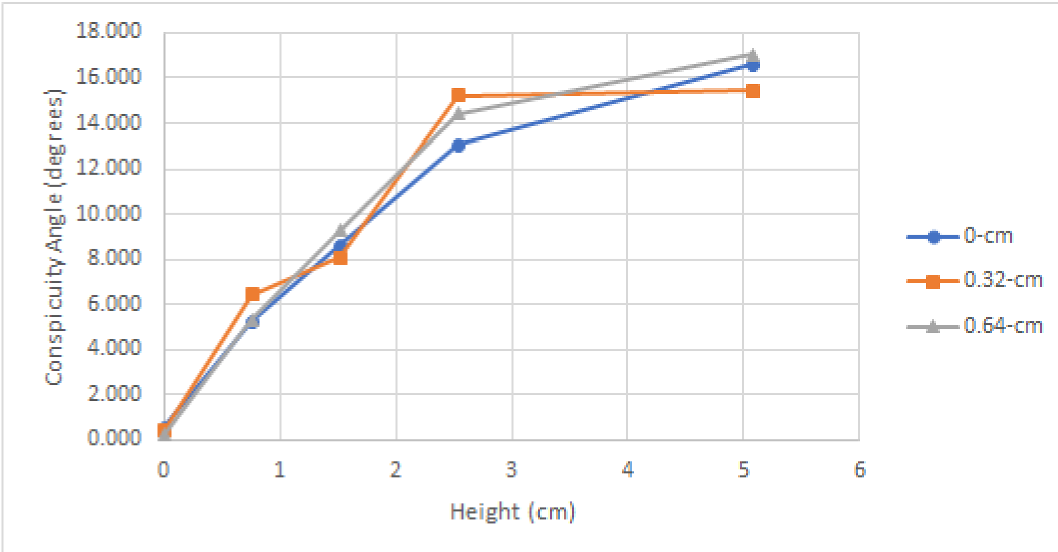

Figure 1: Staats et al. (2020) Naive participants' conspicuity angle data.


Figure 2: Mock sidewalks with the fourth paver raised 1.19 cm and gap size set to 0.64 cm.

*Visual Cues in Detecting Height Changes*

One visual cue for detecting trip hazards is shadows. Specifically, the shadow on the vertical surface of the height change. Fotios and Cheal (2009) stated that they thought their observers were using a shadowing cue to assess an object's height. However, there is little research on the effect of shadowing in predicting height changes. Mamassian et al. (1998) would argue that shadows are a very salient cue to the spatial layout of objects but not useful when determining surface shape. They also found that this phenomenon is repeated in both stationary and active conditions. Yonas, Goldsmith, and Hallstrom (1977) that showed the location of the cast shadow influenced depth perception and height change of objects of adults, three-, and four-year-old children. Each of the children involved in the experiment was pretested to assess their judgment abilities of real objects. After the pretest, the children were asked to make the various distance, size, and height judgments by answering a forced-choice question of which object in a picture were "close", "fat", or "high" respectively. On the display cards used in the pretest, the shadow-location and object-position displays were intermixed. There was not a pretest for adult participants. The results showed that height judgments were the most accurate type of judgment over distance and size and that performance was better when there was a gap between the object and the shadow. In addition to the stationary condition, Mamassian et al. (1998) posit that shadows are also a salient cue to spatial layout in the active condition. In their experiment, moving just the shadow of a static object made the participants perceive the motion of the object. In the current study and previous research, the shadowing cue occurs in the dark band on the vertical surface of the height change. A static view of the shadow could be used to reveal the magnitude of the height change.

In depth perception, many other monocular cues can be used to perceive depth including occlusion, texture gradients, and size familiarity. However, Cohen and Sloan (2016) specifically mentioned visual cues for pedestrian walking surfaces including contrast. According to Cohen and Sloan (2016), high contrast is particularly useful and cited in multiple other sources for grabbing attention. The higher the contrast the more attention-grabbing obstacles. This is supported by an article by Foster et al. (2014) which showed that adding a high contrast stair highlighter reduces misstep. They also found that the highlighter should be placed flushed to the nosing. This makes a high contrast edge allows the user to more easily perceive the edge of the stair.

*Light Levels*

Human vision is sensitive to 14 log units of light however no species can see in complete darkness. As the light approaches complete darkness from a bright light the visual mode changes from photopic where the cones are active to mesopic where both cones and rods are active to finally scotopic where only the rods are active. The difference between photopic and scotopic vision is what type of cells are active. The cones mostly occupy the fovea and allow for color vision. Rods on the other hand occupy 98% of the visual field except in the fovea and are much more numerous (about 90 million cells per eye) than cones (about 5 million cells per eye). Another important difference between rods and cones is that rods have poor spatial resolution. As luminance decreases human acuity, contrast sensitivity, accommodation response, and circular section also decrease (Owens, Francis, and Leibowitz; 1989). The decrease in contrast sensitivity is important to think about for the current study as shown in the next studies.

Lighting is an important aspect of the conspicuity of objects. A pedestrian who notices a height change in the walkway can adjust swing foot height to clear the obstacle, but height changes may vary in visibility and conspicuity. Fotios and Cheal (2009) found illuminance influenced object detection. The height change was created by raising a small pedestal embedded in the 1.20 x 1.08-meter floor of a small enclosed box-like “booth” viewed monocularly through an aperture in the wall and illuminated from the booth’s “ceiling” (Figure 3). The pedestal was at one of four locations, each of which was roughly equidistant from the viewing aperture and roughly 14 degrees to the right and below the fixation point (Figure 4). Viewing was monocular, and a fixation point was provided on the far wall at a distance of 1.08 meters. The authors posited that observers were using shading cues to detect height changes in this simulated walking environment. In particular, the vertical surface of the pedestal was darker than the horizontal surfaces when the pedestal was raised, providing a cue to the height change. The observer's head was constrained[?] to negate head movements. They found that the change between 0.2 lux and 2 lux had a higher change in object change detection than the change between 2 lux and 20 lux. They also found that the height change detection threshold at 0.2 lux was between 2 to 3 mm.

Uttley, Fotios, and Cheal (2015) completed a similar study later that focused on the effect of illuminance on peripheral obstacle detection. They found that their results were reasonably similar to the 2009 study by Fotios and Cheal. In this study, the height change was created by raising a small pedestal embedded in the 2.4 x 3.8-meter floor of a booth similar to the 2009 experiment. However, in this study participants were placed on a treadmill, to simulate walking, rather than standing still. The viewing was binocular, and a fixation point was provided on the far wall 3.8 meters away from the participant.

The object was placed 2.6 meters away from the participant. Similar to the original Fotios and Cheal (2009) article, Uttley, Fotios, and Cheal (2015) stated that detection was mainly determined by contrast or the darker of the vertical surface in comparison to the horizontal surface of the pedestal when raised the higher contrast and the higher the detection.

From previous research (Fostios and Cheal, 2015; Ayres and Kelker, 2006), the high contrast attached shadowing cue could lead to the height change being more conspicuous at higher height changes. Due to various methodological differences in viewing distance, eccentricity, and dependent measure, it is difficult to compare the Fostios and Cheal assessment of visibility and the Staats et al measure of conspicuity. Nonetheless, we can try to adjust for target size and viewing distance across the two studies. In the Fostios and Cheal (2015) study the ratio of height change to view distance is 0.0028. While the Staats et al. (2020) study had ratios of 0, 0.003, 0.006, 0.010, 0.021. When the Staats et al. (2020) viewing distance is converted to mimic Fostios and Cheal (2015), as shown by the ratios, it appears that only the 0.76cm height change is similar to the 3 mm detection threshold measure of Fostios and Cheal (2015). All of the other height changes are above the detection threshold.

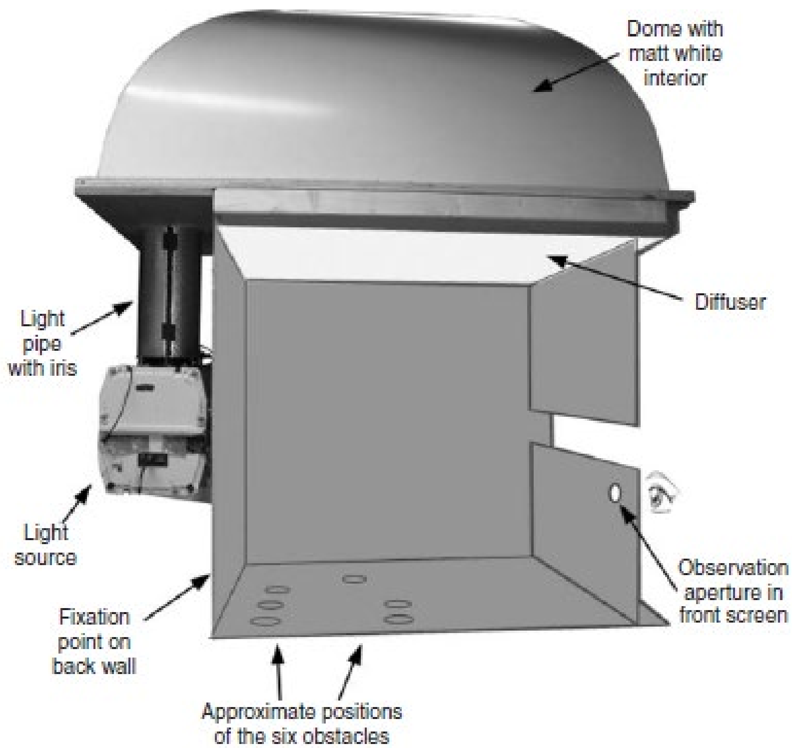


Figure 3: Illustration of the apparatus used in Fotios and Cheal (2009) pilot study.

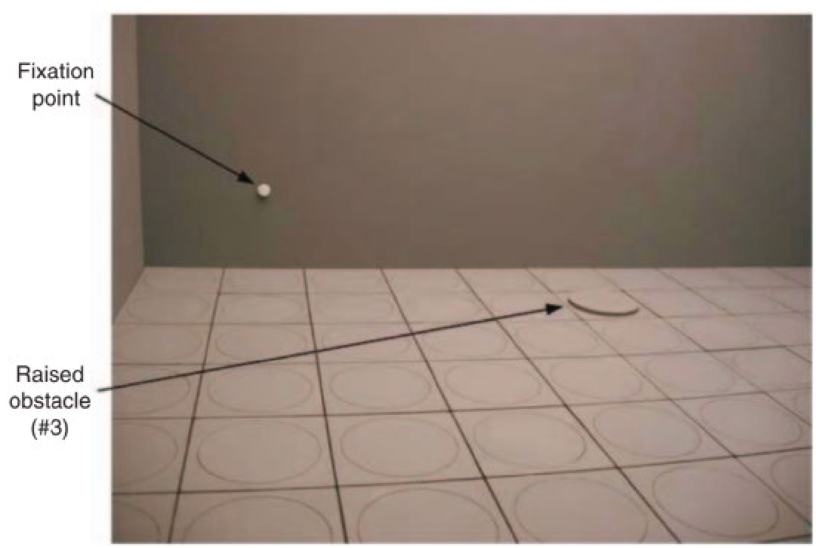


Figure 4: Fotios and Cheal (2009) shadow box with a fixation point and raised platform

The current proposal aims to show the relationship of trip hazard conspicuity as a function of height and digitally manipulated illuminance for online methods. There are a few limitations in conducting this experiment remotely. One limitation is that all the depth cues are now monocular. However monocular cues can give some of the same information as binocular cues as seen in Rogers and Graham's (1978) study about motion parallax. Motion parallax is when the movement of the observer or movement of an object across the visual field causes relative movement of images across the retina. Rogers and Graham (1978) found that motion parallax can only provide depth information. In Rogers and Graham's experiment, they showed that when both the observer and the computer-generator random-dot stereograms were stationary, then all the observers reported that the stereograms were flat. In both the self-produced motion and external motion conditions, all the observers reported that the stereogram appeared to be in three dimensions. The self-produced motion condition was when the participant moved their head side to side, and the external motion condition was the apparatus moving side-to-side while the participant was still. An important aspect of this experiment was that all the participants were viewing the stereogram monocularly so the depth perception only being provided by the motion parallax rather than binocular disparity.

The current study will take place via an online (Qualtrics) survey using pictures of the stimuli. Using static pictures of an environment causes a monocular view versus the binocular view that is achieved during an in-lab experiment. The issue is that when the experiment is viewed on a screen it eliminates the perceptual value of stereopsis due to the absence of retinal disparity. This problem is emphasized by Gomez et al. (2018) who found that graspable objects have a more powerful influence on attention and manual response than both 2-D and 3-D images. The authors conducted three experiments where they used flanking tests comparing the response time and error rates between the three conditions. The authors further posit that images might not be suitable proxies for psychological research. This current study will allow the researchers to compare the differences between the judged conspicuity of the height change in pictures versus how conspicuity is judged in laboratory settings.

### *The Current Study*

The purpose of the current study is to see the influence of lightness levels on the conspicuity of height changes in walkways. The independent variables of this study are height change and lightness levels. The dependent variable is the judged conspicuity of the height change. Due to the simulated nature of the illuminance levels here I will define the digitally manipulated illuminance levels using the exposure tool in Adobe Photoshop 2020 as lightness levels. Since Tutaj (2019) showed that magnitude estimation is highly correlated with conspicuity angle it can be said that magnitude estimation is a valid measure to measure conspicuity in this experiment. We hope to understand the effect of different digitally manipulated illuminance levels on the conspicuity of height changes.

#### *Hypotheses*

1.) As lightness levels increase the more conspicuous the height change will be judged to be.

2.) As height change increases the more conspicuous the height change will be judged to be.

3.) There should be an interaction between the conspicuity of light exposure levels and height change. The expected interaction is that at the higher height changes the difference between the judged conspicuity at the different lightness levels will be larger than the lower height changes.

## METHOD

*Participants*

The sample had normal or corrected to normal vision which can be verified by requiring the participants to have a driver's license. Of a total of 97 participants 55 participants were included in the study. The first round of eliminations where 32 participants were eliminated because they did not complete the survey. Then the most recent data from 7 participants were deleted if it came from the same IP address to eliminate participants' second attempt at the survey. Two participants were deleted due to typos in their responses. The final elimination was to delete 7 participants whose data had one answer that was 3 standard deviations from the mean. Of the remaining 55 participants 20 failed the attention check question. We did not delete the people who failed the attention check because there was no significant difference between the people who passed and failed the attention check, $F(1, 50) = 0.196$, $p = 0.66$. After analysis of the data without the participants who failed the attention check the only difference is that the interaction becomes non-significant. Participants were chosen from a pool of undergraduates who received credit for a course.

*Apparatus and Materials*

Data collection was in an online survey setting with pictures of a mock sidewalk that is in the lab with existing overhead room fluorescent lighting. The photographs of the scene were created as follows. The picture is constructed using the Sony Handycam AX53. The camera was placed at 152 cm to simulate an eye height. The camera has a resolution of 3840 x 2160 and a focal length of 26.8 mm with no degree of zoom. The camera lens was kept at a consistent 2.44 meters away from the target and held there by a tripod. The camera was also at a consistent 56-degree downward pitch which was monitored by an electronic level (Figure 5). The simulated walkway consists of 2 wooden pieces that were 40.64 cm high, 40.64 cm wide, and 2.54 cm tall. The third wooden piece was a variable with the 7 different levels of height change (0.0 cm, 0.3175 cm, 0.635 cm, 1.27 cm, 2.54 cm, 5.08 cm, and 10.16 cm)) (Figure 6). The height changes were created by adding a combination of wooden pieces and linoleum tiles under the variable piece. There was also an expansion joint gap of 0.64 cm in between the second and third piece and an expansion joint gap of 0.32 cm in between the second and first piece to better simulate a real-life sidewalk (Figure 7). The expansion joint gaps are unequal because in the real-life scenario the gaps are expanded at the height change.

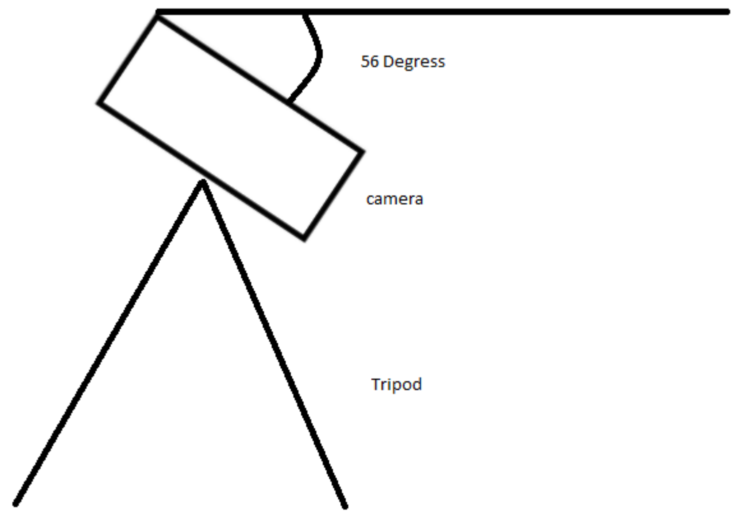


Figure 5: Pictorial representation of the camera set up

Figure 6: High, Medium, and Low Lightness Levels at the 10.16 cm height change.

The photos exposure was digitally manipulated using Adobe Photoshop 2020. The exposure level defined by Adobe Photoshop is the amount of light in the photo. Zero indicates that the amount of light is the same as the original picture. While negative numbers indicate that there is less light than the original picture and positive numbers indicate more light than the original picture. There were three different lightness levels of low (-4.5), medium (-2.75), and high (0). We took luminance measurements of the vertical surface of the height change as well as the horizontal surface of the variable slab to compare the contrast ratios of each of the different conditions and the real world. These exposure levels were chosen because they closely match the luminance ratio (contrast ratio = vertical luminance/horizontal luminance) of the vertical surface to the horizontal surface of the physical world mock walkway is 0.648. High lightness had a contrast ratio of 0.650, medium lightness had a contrast ratio of 0.655, and low lightness had a contrast ratio of 0.657. This ensured that the ratio of light radiating from the simulated walkway is the contrast decreases from low lightness to high lightness over all three lightness levels and it is also relatively consistent with the real-life simulated walkway. The higher contrast at the low lightness ensures that participants will not change the results.

Photos were presented within a survey using a Qualtrics platform. The participants used their laptop or PC as a viewing apparatus. The participants viewed all 21 pictures in a Qualtrics survey in a random order to help control for possible order effects. There was also a practice photo at the beginning of the survey to show the participants what is meant by height change. The photos in Qualtrics will appear in the center of the participants' screen and are surrounded by a dark screen. The photo was also the same size for all of the participants. Each of the 21 conditions appeared as separate questions. Finally, the participants emailed the researcher a passcode to finish the survey.

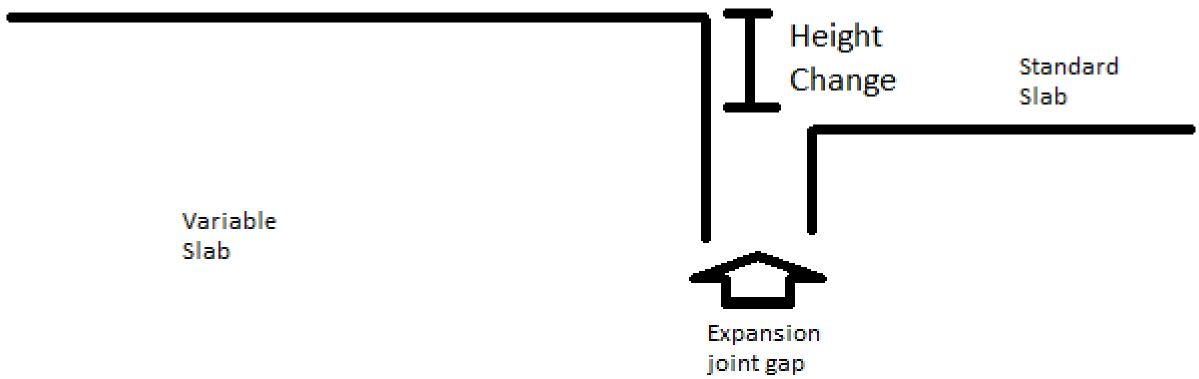


Figure 7: Sketch of the variable piece and standard piece with the parts standardized.

*Procedure*

This experiment was a 3x7 within-participant factorial design. The participants filled out a survey via Qualtrics on their laptops or desktops. The participants were chosen through SONA and given course credit.  First, the participants were asked to read an informed consent. Then the participants were asked in the instructions if they have normal or corrected to normal vision. They were asked to wear their corrected lens if needed will be in the SONA instructions as a requirement. The next step is for the participant to calibrate their computer to the best brightness and contrast for the individual participant who was asked to place their brightness of 100% by opening the control panel or by using buttons on the keyboard to increase the brightness.

After setting up the computer the participants started the experiment with the questions in random order. Each of the 21 conditions was in a new random order for each of the participants. The participants indicated the numeric value that they judged best represents the conspicuity of the height change in the picture. Below is an example of the script for each of the questions which have been pilot tested by 5 people for understanding.

*"Please indicate with a number how likely you are to notice the height change in the photo. Please use a 10-point scale however if you feel that it is appropriate you can go over 10. Low numbers indicate that you do not notice a height change and high numbers indicate you are more likely to notice a height change. PLEASE DO NOT INDICATE HOW HIGH IS THE HEIGHT CHANGE."*

## RESULTS

A 3(lightness) x 7 (height change) repeated measures ANOVA was performed to test the main effects and interactions on conspicuity judgments. The sphericity assumption of the repeated measures ANOVA was violated f due to Mauchly's test being significant for the main effect of height change, lightness, and the interaction (□2 (20) = 237.7, $p <0.001$, □2 (2) = 32.9, $p < 0.001$, □2 (77) = 154.6, $p < 0.001$, respectively) which was corrected by using adjusted degrees by the Huynh–Feldt correction ($\varepsilon = 0.397$, $\varepsilon = 0.696$, $\varepsilon = 0.796$, respectively). The ANOVA revealed that both the main effects of Height Change and Lightness were both significant, $F$ (2.4, 128.5) = 135.21, $p < 0.0001$, $\eta^2 = 0.715$, $F$ (1.4, 75.2) = 34.29, $p < 0.0001$, $\eta^2 = 0.388$, respectively. On average as the height change increases the judged conspicuity also increased. In post hoc LSD testing, it was revealed that 5 of 7 height changes were significantly different from each other. The 1.27 cm and 2.54 cm height changes were not significantly different from each other. On average, the higher the lightness level the higher the judged conspicuity. In post hoc testing of the main effect of lightness levels; all the different lightness levels were also significantly different from each other.

The ANOVA also showed that the interaction between Lightness and Height Change was statistically significant, $F(9.5, 515.7) = 2.98$, $p < 0.001$, $\eta^2 = 0.052$. The interaction can be seen in Figure 8 as indicated by the standard error bars. The high lightness level's standard error bars consistently never overlap with either the medium or low lightness levels. However, the medium and low lightness levels standard error bars are nearly always overlapping excluding the 0.445 cm and 10.16 cm height change conditions. For the 0.445 cm height change the medium lightness level is at least one standard error below the low lightness level. For the 10.16 cm height change the medium lightness level is at least one standard error above the low lightness level.

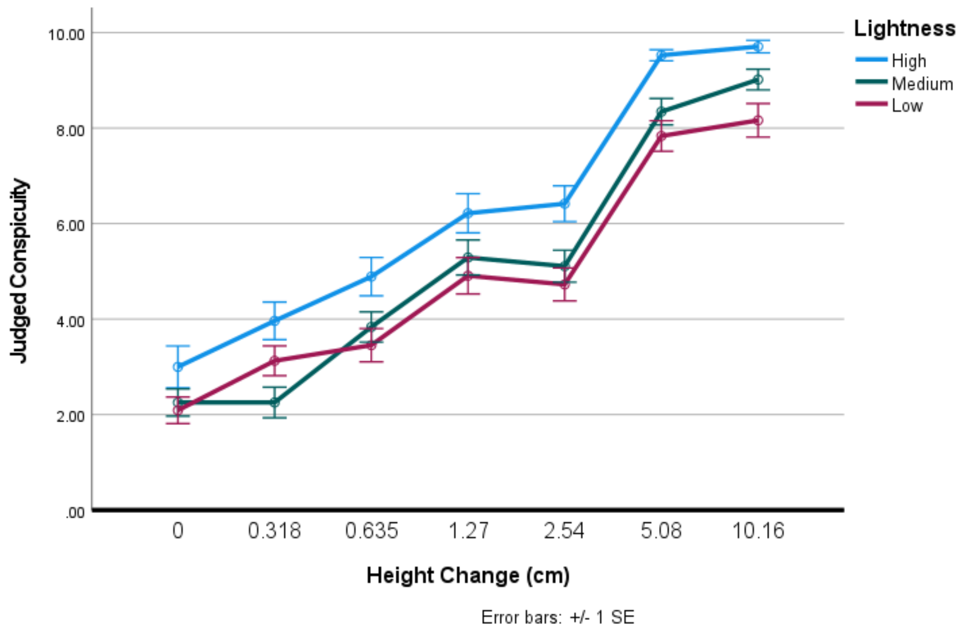


Figure 8: Average judged height changes over 7 height changes and 3 lightness levels including standard error bars.

Now we will examine the three different lightness conditions in different best fit logarithmic functions. We used a linear logarithmic scale because when box plots of the data showed that the height change was positively skewed while the judged conspicuity of the height change was normally distributed. Another reason why the logarithmic scale was used was because it improved the R2 value. For example, the R2 of the high lightness model increased from 0.369 to 0.443 when the log base 10 transformation was applied to the height change.  Due to the 0 height change condition, a 0.1 in constant was added to all the height changes in the logarithmic function. The constant should not have a larger effect at lower heights

A logarithmic function was used to model the relation between Height Change and Judged Conspicuity at high lightness levels.  The model was used to explore and predict the relationship between height change, lightness level and conspicuity. The model's homoscedasticity was also examined by using a score test to see if the variance in the residuals is changing with height change, $\chi^2$ (1) = 40.86, $p < 0.001$. In this case the test found that the homoscedasticity was violated which was addressed by using the HCCM method and HC4 modifier. The overall model was statistically significant, F (1,383) = 304.10, $p < .001$, and $R^2 = .44$. Thus, the logarithm of the height change explains about 44.25% of the variance in Judged Conspicuity at high lightness levels. The estimated slope, b = 4.57, was statistically significant from zero, t (383) = 17.44, $p < .001$ as shown in Figure 9. The equation for the model of best fit is $y= 7.07+ 4.57 \log(x)$. The model's residuals were tested with a Q-Q plot (Figure 10) and the Shapiro test. While the Shapiro test was significant (W= 0.98816, $p < 0.003$), it was influenced by the large sample size. It was determined that the model's residuals were normally distributed by graphical means.

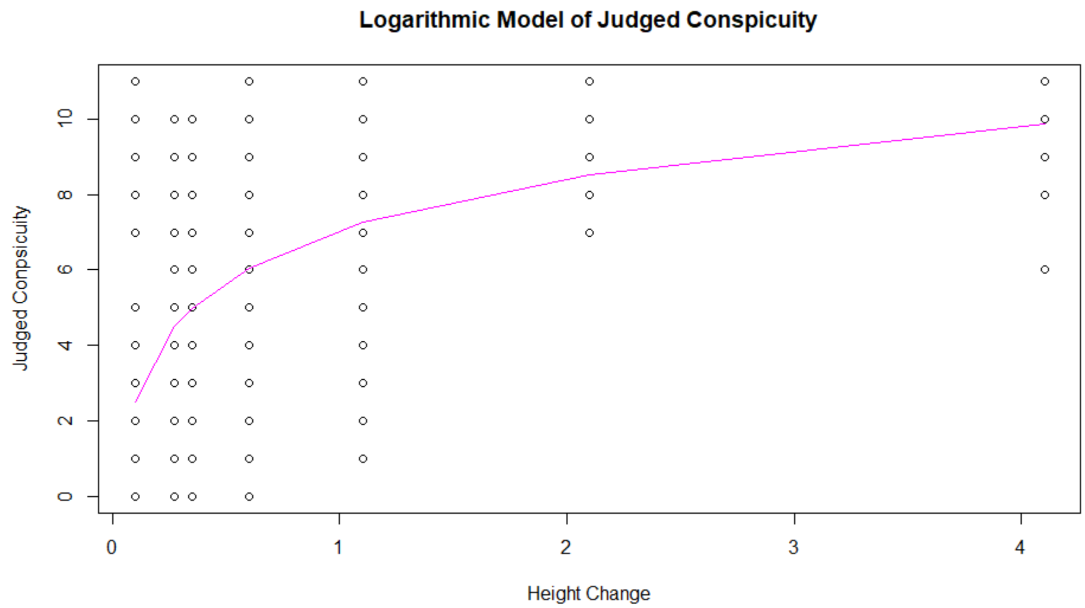


Figure 9: Logarithmic Model of Judge Conspicuity at High Lightness

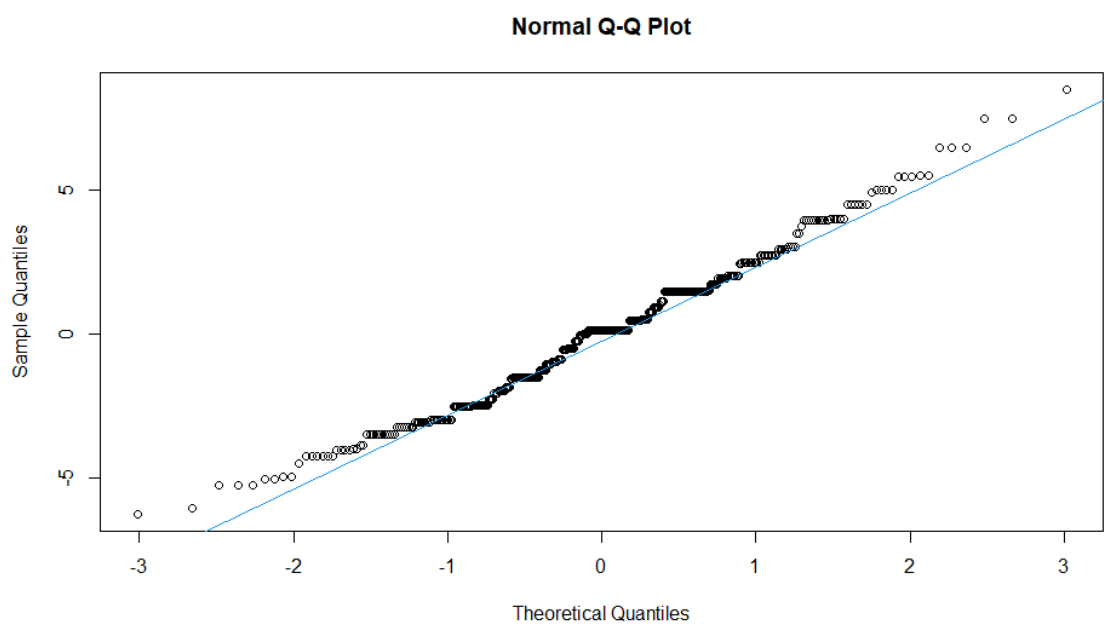


Figure 10: Q-Q Plot of the High Lightness model

A logarithmic function was used to model the relation between Height Change and Perceived Conspicuity at medium lightness levels. The model's homoscedasticity was also examined by using a score test to see if the variance in the residuals is changing with height change, □2 (1) = 3.30, p = 0.07. The homoscedasticity assumption was satisfied. The overall model was statistically significant, F (1,383) = 383.5, $p < .001$, and $R^2 = .50$. Thus, the logarithm of the height change explains about 50.03% of the variance in perceived conspicuity at medium lightness levels. The estimated slope, b = 4.66, was statistically significant from zero, t (383) = 19.58, $p < .001$ as shown in Figure 11. The equation for the model of best fit is $y= 6.00 + 4.66 \log(x)$. The model's residuals were tested with a Q-Q plot (Figure 12) and the Shapiro test. While the Shapiro test was significant (W= 0.98882, $p < 0.004$), it was influenced by the large sample size. It was determined that the model's residuals were normally distributed by graphical means.

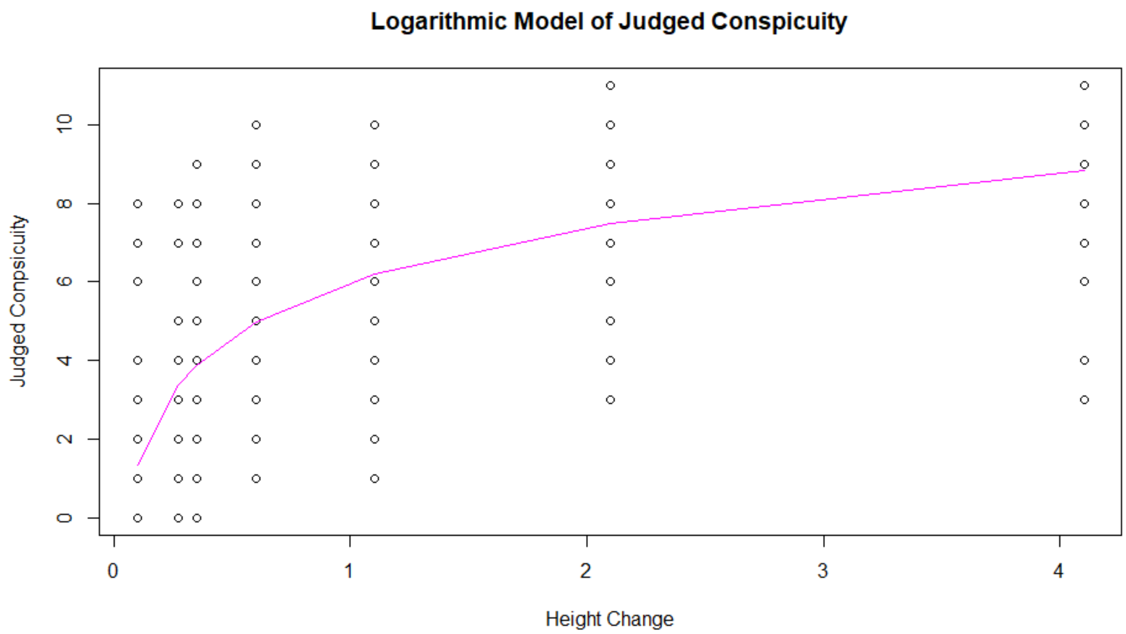


Figure 11: Logarithmic Model of Judge Conspicuity at Medium Lightness

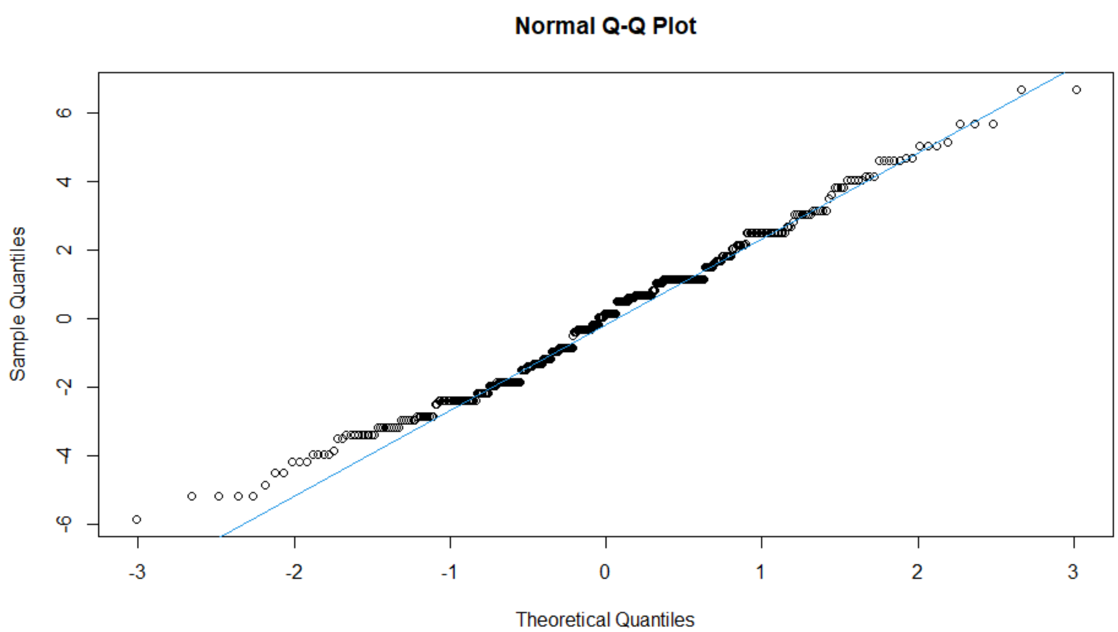

Figure 12: Q-Q Plot of the Medium Lightness model

A logarithmic function was used to model the relation between Height Change and Perceived Conspicuity at low lightness levels. The model’s homoscedasticity was also examined by using a score test to see if the variance in the residuals is changing with height change, □2 (1) = 2.00, p = 0.16. The homoscedasticity assumption was satisfied. The overall model was statistically significant, F (1,383) = 256.40, p < .001, and $R^2$ = .401. Thus, the logarithm of the height change explains about 40.1% of the variance in perceived conspicuity at low lightness levels. The estimated slope, b = 4.06 was statistically significant from zero, t (383) = 16.01, p < .001 as shown in Figure 13. The equation for the model of best fit is y= 5.63+ 4.06 log(x). The model's residuals were tested with a Q-Q plot (Figure 14) and the Shapiro test. While the Shapiro test was significant (W= 0.98923, p < 0.006), it was influenced by a large sample size. It was determined that model’s residuals were normally distributed by graphical means. The overall results of the three fitted curves was that there was a robust power function to explain the relationship between height change, lightness and conspicuity which is consistent with the literature.

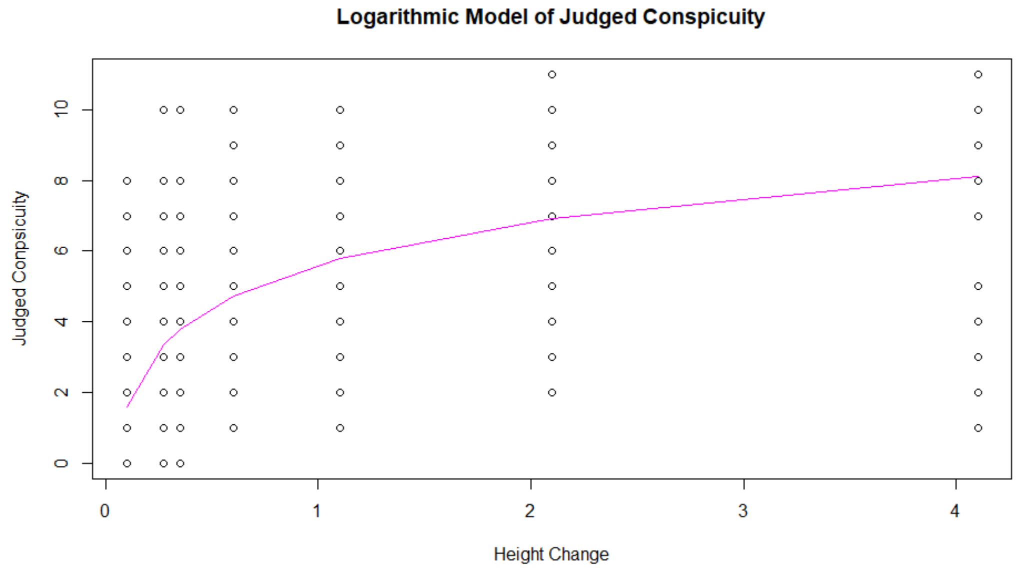


Figure 13: Logarithmic Model of Judged Conspicuity at Low Lightness

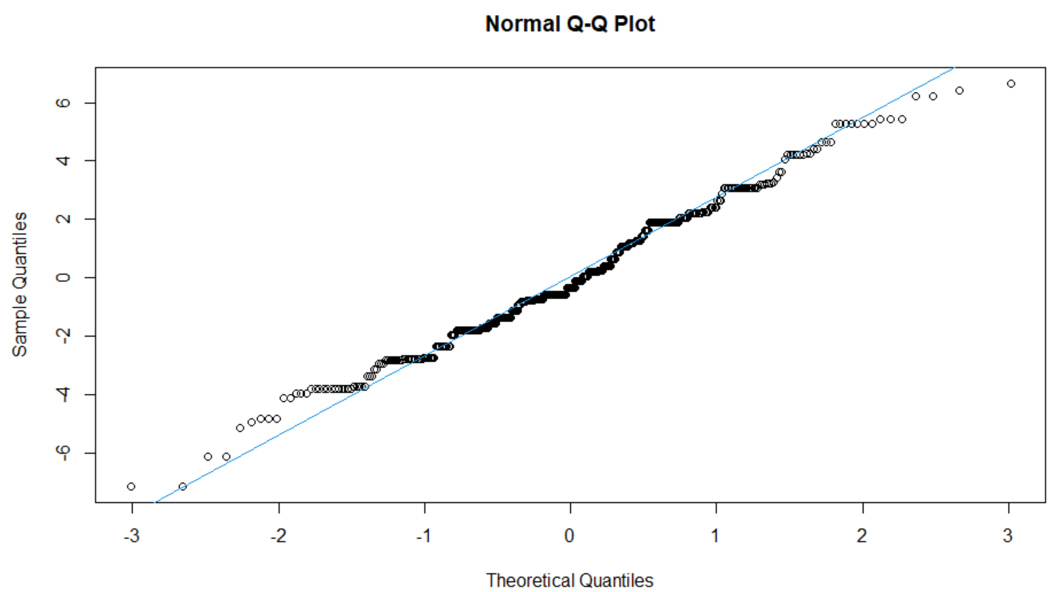


Figure 14: Q-Q Plot of the Low Lightness model

## DISCUSSION

The first hypothesis was that participants would judge height changes to be more conspicuous as the height change increases. The significant repeated measures ANOVA main effect showed that this was supported with a large effect size of 0.715. The significant ANOVA and large effect size confirm that participants judge height changes to be more conspicuous as the height change increases. Fotios and Cheal (2009) also pointed out the importance of the shadowing cue. They posited that the shadowing cue is one of the major cues that people use to judge heights in general. In this study as well, the shadowing of the height change is a prominent cue that participants are using the width of the shadow to judge the conspicuity of the height change. As the shadow's width-contrast sensitively and size increased the participants were cued that the height change was also increasing and the participants indicated the height change as more conspicuous accordingly. An interesting finding was that the significant main effect of height and the strong effect size was similar to that of the Staats et al. (2020) study. The similarity of these two studies indicates that people can judge the conspicuity of height change just as well in a picture as in real life due to shadowing being a monocular cue. From the first evidence of hypothesis one alone it is possible that the participants were just ranking the height of the height change. However, with the evidence from hypothesis two it was shown that the participants were not just ranking the height of the height change.

The post hoc testing also showed a nonsignificant difference between the 1.27 cm and 2.54 cm. After looking at the stimuli in Appendix B a reason for the anomaly could not be determined.

There are several implications for real-world scenarios, for example, the 6.35 mm height change. The 6.35 mm is the maximum height change that should exist without any changes as indicated by building code ASTM F1637. However, from looking at the results (Figure 8) it is possible to conclude that participants judged the 6.35 mm height change condition on the lower end of the scale. This information can be extrapolated to the real world. If the in the real world user does not notice the 6.35 mm height change that could cause a trip and fall event. Given the tendency to fixate the horizon when walking in urban areas (Foulsham et.al. (2011), the need for following the ASTM code is clear. Because it is more likely that pedestrians would not notice the height change. Another important height change was 12.7 mm which is in the mean range of the MFC (10-20 mm). If the information is not conspicuous enough and could likely cause a trip and fall event.

The second hypothesis was that participants will judge higher lightness levels to be more conspicuous. Again this was supported by the significant main effect of lightness in the repeated measures ANOVA with a medium effect size of 0.388. All of the different lightness levels were significantly different from each other. This ANOVA result indicates that the lightness of the photo is an important factor in determining the conspicuity of the simulated walkway. These findings are consistent with Owens, Francis, and Leibowitz (1989) which found as luminance decreases human acuity and contrast sensitivity also decrease. Our participants judged that the lower the lightness levels the less conspicuous the height change because the lower luminance values of the pictures decreased the participants' acuity. Therefore, the higher lightness levels had a higher luminance so the participants had better acuity while viewing the stimuli and so they judged the height change as more conspicuous. As mentioned at the end of hypothesis one this effect of lightness indicates that the participants were not just judging the height of the height change. If the participants were just judging the height change then there would be no effect of lightness. Since there is an effect then it can be concluded that the participants were judging the conspicuity of the height change.

These ANOVA findings can also be understood using the logarithmic models shown in Figure 9, Figure 11, and Figure 13 to predict judged conspicuity for each of the different lightness levels. The estimated slopes of each showed that both the high ($b = 4.57$) and medium ($b = 4.66$) lightness levels are closer together while the low ($b = 4.06$) lightness level was relatively farther apart from both of them. The low lightness level has the most compressed slope while the other two lightness levels were relatively similar. These numbers could indicate that the judged conspicuity is affected the most by the low lightness level. The ANOVA plus the logarithmic models imply that as the lightness levels decrease the more likely the user is to not notice the height change and cause a trip and fall event.

The third and last hypothesis was that there would be an interaction between height change and lightness levels. The hypothesis was supported by the significant repeated measures ANOVA interaction with a small effect size of 0.052. The interaction that we predicted was that at the higher height changes the difference between the judged conspicuity at the different lightness levels will be larger than at the lower height changes. This pattern is due to all of the lightness levels converging at 0 on the y axis at the 0 height change. However, while there was an interaction between height change and lightness levels the shape of the interaction was different. The reason for this change in the pattern is that the medium lightness level was more similar to the low lightness level than expected. As indicated by Figure 8 the high lightness level is overall was judged as more conspicuous over both the medium lightness and low lightness levels. The medium lightness and low lightness level are however where the interaction happens. However, due to the small effect size and no external reason for the interaction I believe that this interaction is not important.

As stated previously, high lightness level consistently had a higher judged conspicuity over all height changes than both the medium and low lightness levels at all height changes. However, Figure 8 shows a different picture for the medium and low lightness levels. Both of these different lightness levels are closer together and the medium lightness level was judged to be less conspicuous than the low lightness levels at the 4.45 mm height change on average. When the height change is around 10.16 cm the medium lightness level is on trend to be more conspicuous at higher height changes than the low lightness level. The interaction implies that it is harder for users to judge the difference in the conspicuity of the lower height changes at medium and low lightness levels. Also, the interaction implies that only at high height changes do the medium lightness levels change to be a greater slope than low lightness levels. In the real world, this shows that even medium lightness levels are a danger to users when the height change is smaller because they are on a very similar trend to the low lightness levels. The reason why this is a potential danger is that the change in slope does not occur until the 10.16 cm mark which is well above people's mean MFC. However, since the interaction had such a small effect size this interaction needs further study before any conclusions can be drawn.

*Limitations*

There are multiple limitations of the current study. One limitation is the lack of control the experimenter has over the participant's behavior. For example, it is difficult to ensure that participants are consistently at the same distance from the screen. The implications for the results are that some of the participants could have been in different viewing environments which could have been a confounding variable. If the participants were farther away from the screen that could have made the lower height change to be less conspicuous. It would have also made all height changes and lightness levels to be smaller due to the distance.  While it is likely that participants were at different viewing distances. However, we believe that the process of deleting the participants that answered greater or less than three standard deviations away from the mean will catch these people. If the experimenter had the time and resources to observe each of the participants' behavior and environment this could further mitigate confounding variables.

Another limitation of the experiment was that the picture was taken in monocular conditions. In real life, people may enhance depth perception with binocular vision. This can imply that these results cannot be generalized to three-dimensional environments. However, in this case, shadowing may have been the dominant cue in both laboratory and picture displays.

The final limitation of the study is that the lines that appear on the vertical surface of the simulated walkway could have given the participants another cue to judge the conspicuity of the height change. The extra cue could have allowed the higher height conditions to be more conspicuous because there are more lines visible. The lightness main effect would likely have not changed. This will make the higher height changes to be more conspicuous which would compress the graph if the experiment was repeated without the vertical lines. The lines on the height change could have added a texture which is another depth cue. The texture makes the higher height change conditions more conspicuity to the observer which provides a confound. There was also a similar texture cue in the Staats et al. (2020) paper.

## CONCLUSIONS

In conclusion, the participants tended to judge greater height changes and greater lightness to be more conspicuous. The medium and low have similar slopes of judged conspicuity at the lower height changes while they have different slopes at higher height changes in Figure 8. There could be a real danger for pedestrians at medium and low lightness levels on a path with a lower height change. Another danger to pedestrians is the 6.35 mm and 12.7 mm height changes because both of those height changes have a relatively low judged conspicuity. 6.35 mm is the maximum height change before ASTM F1637 requires a beveled edge on the height change and 12.7mm is in the mean MFC. 6.35mm is well below or in the bottom the mean range of the MFC however the lack of conspicuity especially at low lightness level there is a higher possibility that particularly older adults which have greater variability in their MFC that a trip and fall event can occur.

For future studies, I would like to compare the data gathered from digitally manipulated lightness levels and compare it to data gathered from a traditional study with varying illuminance levels. This would provide valuable information about the differences between using pictures as a model for a three-dimensional object. Likely, the results between pictures and the real world are not significantly different. The only exception if the experiment requires only binocular cues due to photos only captures the monocular cues.

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APPENDIX A

Information about Being in a Research Study
Clemson University

## A Study of the Conspicuity of Height Change

**KEY INFORMATION ABOUT THE RESEARCH STUDY**

**Voluntary Consent:** Dr. Ben Stephens is inviting you to volunteer for a research study.

Dr. Ben Stephens is a Professor at Clemson University conducting the study with Rachel Staats

You may choose not to take part and you may choose to stop taking part at any time. You will not be punished in any way if you decide not to be in the study or to stop taking part in the study.

If you decide not to take part or to stop taking part in this study, it will not affect your grade in any way.

**Study Purpose:** The purpose of this research is to understand how conspicuous a height change is in walkways.

**Activities and Procedures:** Your part in the study will be to provide a magnitude estimation distance of how conspicuous a height change is in a walkway.

**Participation Time:** It will take you about an hour to be in this study.

**Risks and Discomforts:**

We do not know of any risks or discomforts to you in this research study. OR

**Possible Benefits:**

The potential benefits to the study is to increase the safety of walkways.

**EXCLUSION/INCLUSION REQUIREMENTS**

All participants must have natural or corrected 20/20 vision

For Clemson University employees:

As responsible employees under Clemson University Title IX policies, we are required to report incidents of discrimination based on sex, sexual harassment, or sexual violence involving a member of the Clemson University community. Nothing you say in this study will be associated with your name at any point in the process unless you disclose information that may be reportable under Clemson's policies.

**PROTECTION OF PRIVACY AND CONFIDENTIALITY**

The results of this study may be published in scientific journals, professional publications, or educational presentations.

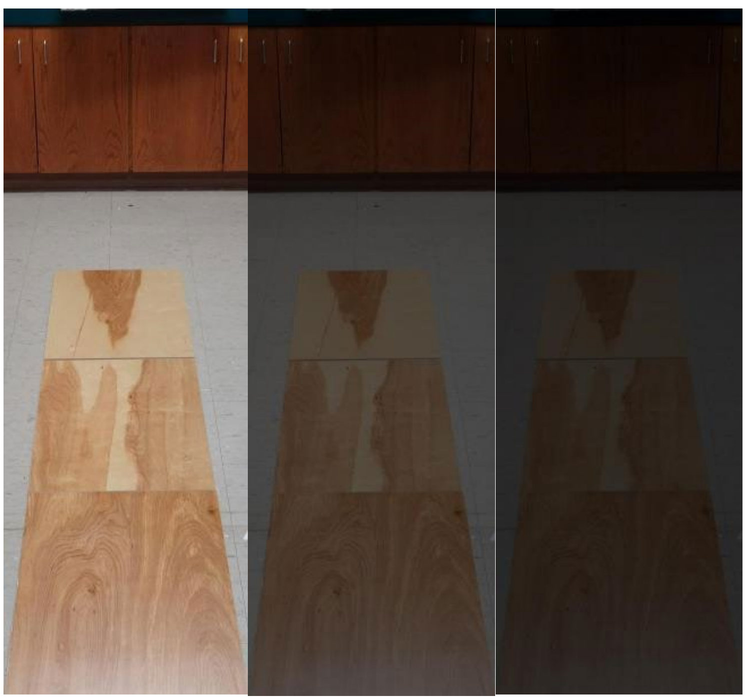
The information collected during the study could be used for future research studies or distributed to another investigator for future research studies without additional informed consent from the participants or legally authorized representative.

**CONTACT INFORMATION**

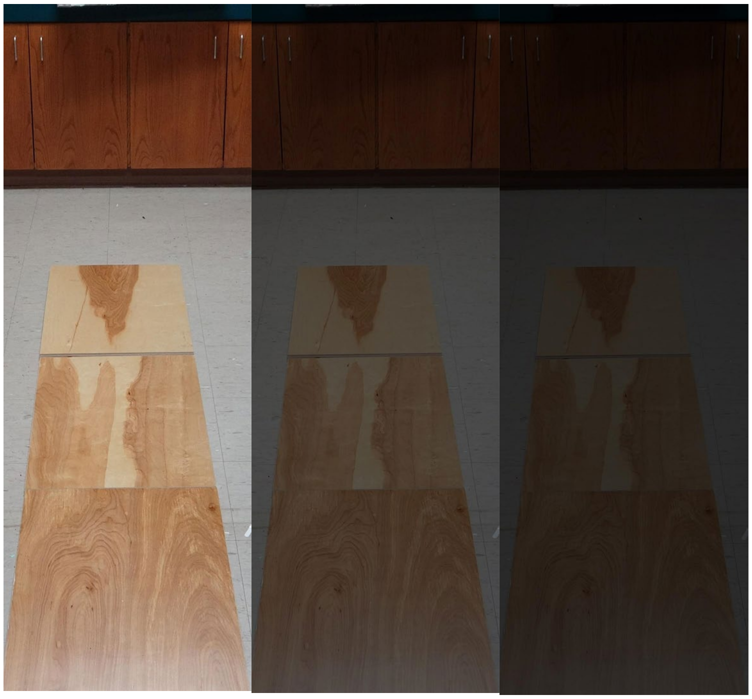
If you have any questions or concerns about your rights in this research study, please contact the Clemson University Office of Research Compliance (ORC) at 864-656-0636 or irb@clemson.edu. If you are outside of the Upstate South Carolina area, please use the ORC's toll-free number, 866-297-3071. The Clemson IRB will not be able to answer some study-specific questions. However, you may contact the Clemson IRB if the research staff cannot be reached or if you wish to speak with someone other than the research staff.

If you have any study-related questions or if any problems arise, please contact Rachel Staats at Clemson University rstaats@clemson.edu.

**APPENDIX B**



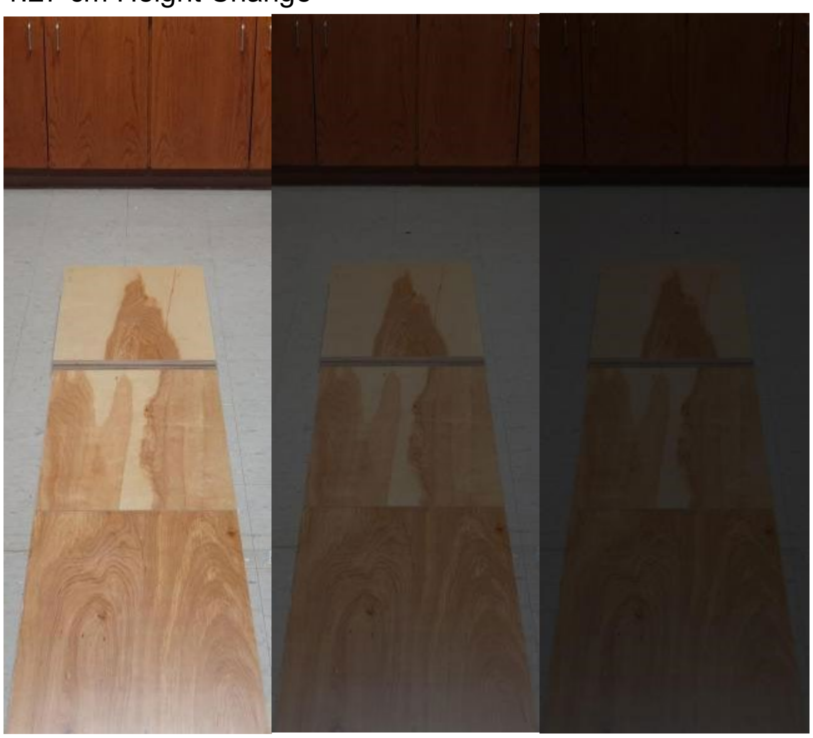
0 cm Height Change



0.445 cm Height Change

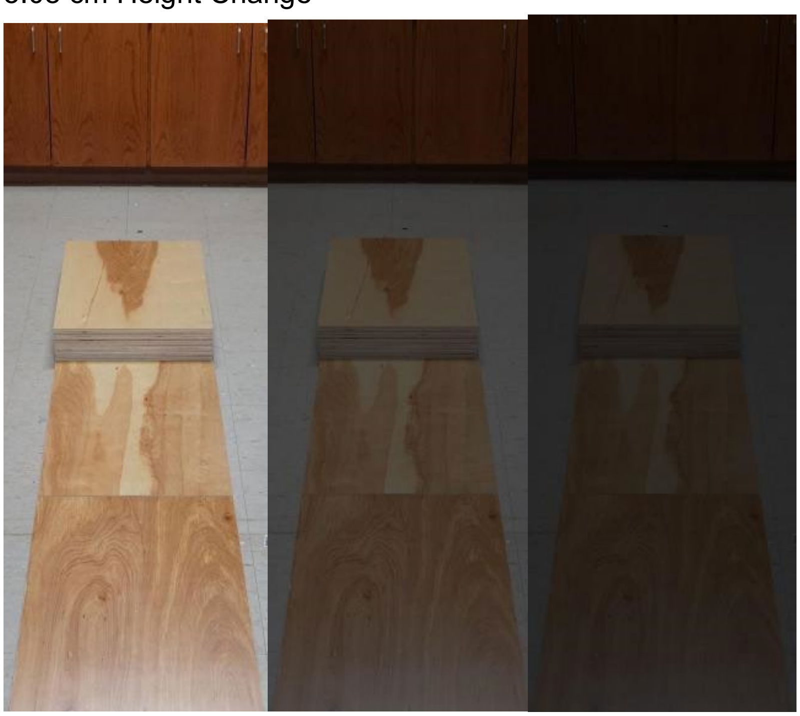
0.635 cm Height Change

1.27 cm Height Change



2.54 cm Height Change

5.08 cm Height Change



10.16 cm Height Change