Technische Universität Berlin

Computational Psychology
Fakultät IV
Marchstr. 23
10587 Berlin
https://www.psyco.tu-berlin.de

Bachelor Thesis

Visual perception of depth through different illuminations of 3D generated scenes on the computer screen

Karol Rogoza

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Supervised by
Prof. Dr. Marianne Maertens
Prof. Dr. Guillermo Gallego

Hereby I declare that I wrote this thesis myself with the help of no more than the mentioned literature and auxiliary means.

Berlin, 27.11.2023

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Abstract

This study explores the significance of human visual depth perception in computer-generated imagery, with a specific focus on monocular cues, particularly shadows. It aims to investigate how different illuminations of 3D scenes on a computer screen influence the perception of depth and whether directional lighting and its shadows, compared to diffuse lighting, positively impact recognizing greater relief and depth in 3D images.

The experiment conducted, utilizing the MLCM method, involved presenting specially created stimuli. These stimuli represented various elevations, such as hills and valleys, each assigned random depths, heights, and frequencies. The presented stimuli aimed to minimize unintended visual cues, concentrating solely on lighting and shadows to convey depth-related information to the observer.

The results suggest a potential positive impact of utilizing directional light on depth recognition compared to diffuse light. However, due to the small scale of the experiment, it remains unclear whether these results occur or are the exception. Further research is necessary for conclusive findings.

Zusammenfassung

Diese Studie untersucht die Bedeutung der menschlichen visuellen Tiefenwahrnehmung in computererzeugten Bildern mit einem spezifischen Fokus auf monokulare Hinweise, insbesondere Schatten. Ziel ist es, zu untersuchen, wie unterschiedliche Beleuchtungen von 3D-Szenen auf einem Computerbildschirm die Tiefenwahrnehmung beeinflussen und ob gerichtetes Licht und seine Schatten im Vergleich zu diffuser Beleuchtung dazu beitragen, ein größeres Relief und mehr Tiefe in 3D-Bildern besser zu erkennen.

Das durchgeführte Experiment, das die MLCM-Methode verwendete, umfasste die Präsentation speziell erstellter Reize. Diese Reize repräsentierten verschiedene Erhebungen wie Hügel und Täler, denen jeweils zufällige Tiefen, Höhen und Frequenzen zugewiesen wurden. Die präsentierten Reize hatten zum Ziel, unbeabsichtigte visuelle Hinweise zu minimieren und sich ausschließlich auf Beleuchtung und Schatten zu konzentrieren, um dem Beobachter tiefenbezogene Informationen zu übermitteln.

Die Ergebnisse deuten auf einen potenziell positiven Einfluss der Verwendung gerichteten Lichts auf die Tiefenerkennung im Vergleich zu diffuser Beleuchtung hin. Aufgrund des kleinen Umfangs des Experiments bleibt jedoch unklar, ob diese Ergebnisse auftreten oder die Ausnahme sind. Weitere Forschung ist für abschließende Erkenntnisse notwendig.

Contents

1 Introduction

Human vision plays a crucial role in our daily lives, enabling us to perceive colors, shapes, and spatial relationships. It allows us to navigate curved roads while driving or accurately throw a ball to a desired location. By using these examples, Snowden et al. 2012 highlight in their book the significance of human vision and depth perception in spatial localization of objects. Nowadays, developments in computer-generated imagery have revolutionised the way we experience visual content. As our dependence on digital representations continues to grow, we spend an increasing amount of time in front of screens, understanding how people perceive depth in computer-generated scenes is becoming more important. Through this work, I would like to arouse curiosity about this fascinating area of research and application.

1.1 An Overview of Human visual depth perception

Human visual depth perception refers to the ability of the visual system to perceive and interpret the spatial relationships between objects in the three-dimensional world. It allows us to perceive depth, distance, and the relative positions of objects, which is crucial for interacting with our environment and navigating the world around us. Depth perception relies on the integration of visual cues and the processing of visual information by the brain. After Kalloniatis and Luu (2011, 1) these cues can be classified into two broad categories: monocular cues and binocular cues. Monocular cues provide depth information based on the visual input from a single eye. Binocular cues, on the other hand, rely on the coordination of both eyes and provide depth information based on the differences in the images received by each eye. I would like to focus on monocular cues, especially shadows. To show the importance of shadows, I would like to present the illustration that first caught my attention and prompted me to study further. Figure 1.1 presents 7 spheres that are positioned on a chessboard board. For most observers the spheres on the left seem to be farther away from the observer. The spheres on the right seem to be pending in the mid air above the checkerboard. However, if we look at the spheres themselves and ignore the grey ovals under the spheres, representing the shadows, we see that the spheres form a "u" shape on the chessboard. The spheres on the right do not seem to be pending in the mid air, but are farther away from the observer, like on the left side. This shows how important shadows are and what effect they can have, on the perceived position of an object in space.

Recognizing the significant role shadows play and can completely change how we see objects in the image, I would like to focus on the more specialised experiments, examples that have influenced this work.

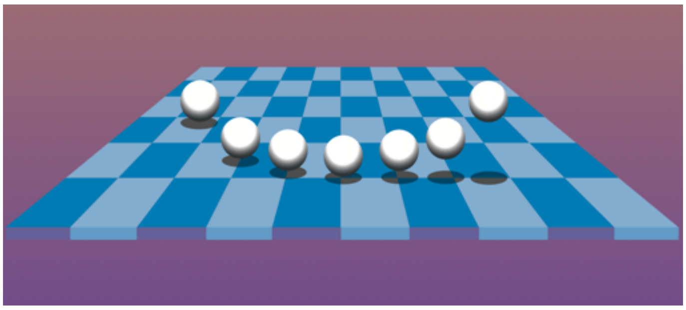

Figure 1.1: Changing the position of the shadows changes the perceived position of the spheres. (Adopted from Snowden et al. 2012, 226)

1.2 Shape from shading introduction

Shape from shading is the process by which our visual system infers the three-dimensional shape and orientation of an object's surface based on patterns of light and shadow observed in a two-dimensional image 1.2. This concept is based on the understanding that the interaction between light sources, surfaces and the viewer's perspective leads to shadow variations that carry valuable information about an object's geometry.

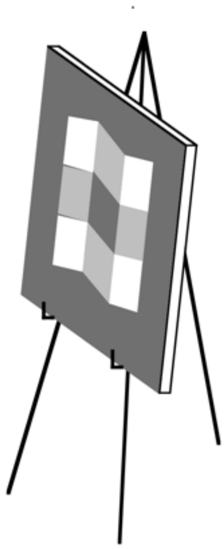

Figure 1.2: The scene consists of a flat surface, evenly lit. All the image information is taken into account by changes in the gray shade (reflectance) of the paint. (Adopted from Adelson and Pentland 1996, 226)

Adelson and Pentland (1996, 1), in their paper "Perception of Shading and Reflection" study the topic of how we perceive the shape and characteristics of a material based on shading cues. They show the correlation between light, surface reflection and our perceptual mechanisms that allow us to decode the structure of objects. The main concept of this work revolves around the idea that our visual system is able to separate the contributions of illumination and material properties from the observed shading patterns. Adelson and

Pentland (1996, 1) introduce the concept of "lightness", which refers to our perception of the apparent brightness of a surface. They emphasize that our perception of lightness does not depend solely on the physical intensity of light incident on surfaces, but also on the underlying mechanisms that account for differences in shading due to surface geometry and reflectance. The authors propose a computational model that mimics the human perceptual process. This model takes into account the intricate interplay between illumination, reflectance, and viewer perspective, enabling it to simulate the observed shading patterns. By analyzing these simulated shading patterns, the model then attempts to recover the underlying three-dimensional shape of the depicted object. Their model underscores the remarkable complexity of the shape from shading problem and highlights the importance of considering multiple factors – including light direction, surface orientation, and material properties – when interpreting shading cues. Their pioneering work not only provides valuable insights into the mechanisms of human perception but also helps make the way for advancements in computer vision algorithms aimed at recovering object shape and structure from images through the analysis of shading patterns.

1.3 Shape from shading under diffuse illumination

Langer and Bülthoff (2000, 649) conducted experiments to investigate shape-from-shading perception under a uniform diffuse-lighting condition. The traditional model of shape-from-shading assumes that the surface irradiance varies with the angle between the local surface normal and a collimated light source. However, that model is not applicable in scenarios with diffuse lighting, such as on a cloudy day. They have proposed a perceptual model called "dark means deep" to explain shape perception under diffuse lighting conditions. Three experiments were conducted during which participants performed depth-discrimination and brightness-discrimination tasks using identical stimuli. Observers were asked to judge whether isolated marked points on a surface were "on a hill" or "in a valley" Langer and Bülthoff (2000, 650)

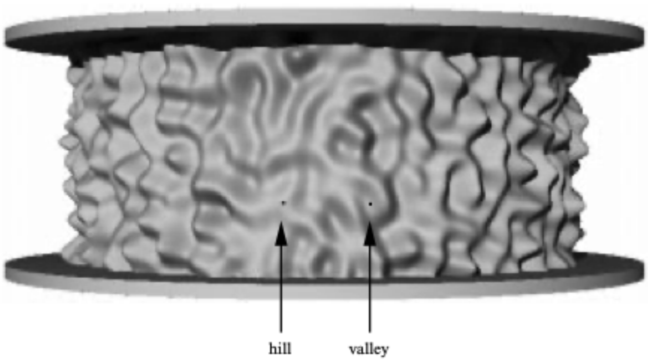

Figure 1.3: Altering the position of the shadows alters the perceived position of the points. (Adopted from Langer and Bülthoff 2000, 2)

The results revealed a significant correlation between the participants' responses in both tasks, supporting the dark-means-deep model. The overall performance in the depth-discrimination task exceeded the predictions of the dark-means-deep model. This suggests that humans employ a more accurate model than dark-means-deep when perceiving shape-from-shading under diffuse lighting. The experiments demonstrated that while there is a relationship between dark colour and perceived depth, humans use a more complex model than dark-means-deep to perceive shape-from-shading under diffuse lighting conditions.

1.4 The depth perception due to realistic and unrealistic shading

Another experiment investigating the effect of shadows and lighting on depth perception is "The influence of realistic and unrealistic shading on human depth perception", performed by Zinke 2023. He tried to answer the question of what impact realistic and unrealistic shading has on human depth perception. The experiment was based on the MLCM method and investigated 3 different light conditions and accordingly shadows conditions, illuminating the same terrain differing in scaling. Scaling can be described by the difference between no hill or a valley and a hill. Terrain used in this experiment was similar to the terrain used in the previously described experiment 1.3.

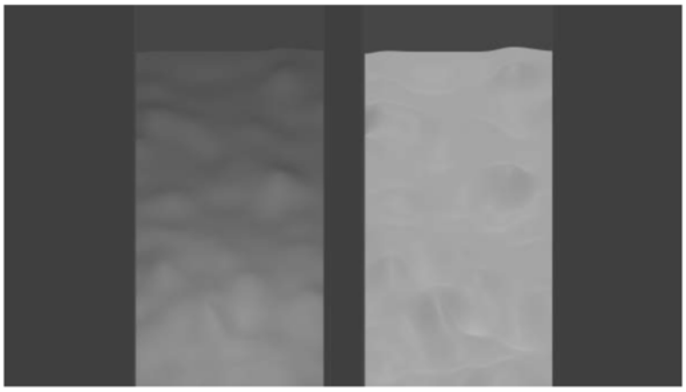

Figure 1.4: Setup of the MLCM experiment by Zinke (2023, 15). The stimuli shown in this comparison have the same terrain scale and are illuminated with different types of light. The stimulus on the left is illuminated by direct light and stimulus on the right is illuminated by direct light.

Test subjects were shown two stimuli placed next to each other on the screen, with one image on the left and another image on the right 1.4. They had to answer the question on which image represented area has a greater scaling. It was observed that the terrain illuminated by direct light was preferred over the area illuminated by diffuse light. However, in the experiment few issues of the stimuli have been identified and should be changed in order to confirm these findings. The stimuli used in the experiment showed too much information about the height of relief. On Figure 1.5 we can see that the upper part made it possible to directly compare the relief and therefore made the experiment too simple .

The other aspect that was suggested for improvement was the change of the diffuse light. Diffuse lighting condition was too strong and made it look unrealistic and confusing for the test subjects. The test subject could have the impression that illuminated terrain is another terrain. In my experiment I would like to address these issues.

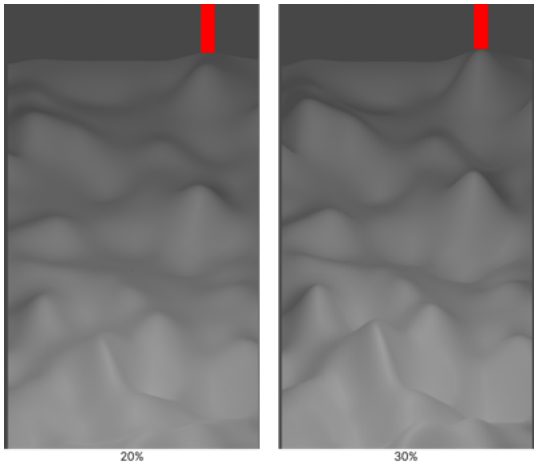

Figure 1.5: This figure shows a possible comparison of two stimuli by looking only at the upper part of each stimulus. In the upper right part of each stimulus we can notice a difference in the distance of the highest elevation from the end of the image.

1.5 Hypothesis

The main purpose of this work is to test the visual perception of depth influenced by different illuminations of 3D generated scenes on the computer screen. I have considered the following hypothesis that I hope to confirm or falsify. I believe that directional lighting and its shadows, compared to diffuse lighting, has a positive effect on recognizing greater relief, therefore depth in a 3D generated scene on a computer screen.
In order to test this hypothesis, I have prepared an experiment that I will describe in the following sections.

2 Experiment

2.1 Stimuli

The experiment preparation began with the creation of stimuli, which was divided into several chronological stages as described below.

2.1.1 Terrain

The initial phase involved the creation and scaling of a terrain. My terrain featured a variety of elevations, including hills and valleys, each assigned random depths, heights, and frequencies. To ensure compliance with the recommendations outlined by Zinke 2023, the following steps were taken to avoid unintended visual cues, particularly in the upper portion of the image, which could potentially provide excessive depth cues beyond lighting and shadows. The scene was conceptually divided into three distinct zones: bottom, middle, and top. The primary elevation features were concentrated in the lower and middle sections. In contrast, the upper part of the stimulus featured smaller hills designed to introduce background blurring, thereby directing focus towards the middle and lower segments of the visual stimulus.

After successfully generating an initial scene that met the specified criteria, the next phase involved scaling up. A series of 21 distinct landscapes were generated, ranging from 100 percent to 200 percent scale, with each successive landscape exhibiting a 5 percent difference in the scaling of height for each hill and valley. All landscapes adhered to a uniform shape and format. Notably, measures were taken to prevent the creation of overly tall hills that might encroach upon the upper portion of the image and thereby exacerbate the addressed issue.

2.1.2 Illumination

In order to choose a satisfying way of illumination, I took into account the following points:

1. Type of light source
2. Angle of incidence of the light to the center of the scene
3. Light colour
4. Size of the light source
5. Power of the light
6. Distance of the light source from the center of the scene

The first and most important choice was to determine the type of lighting. I have considered in the experiment two light sources. The first type is an ambient light source that illuminates the whole scene with the same intensity. The second type of light is directional light, which illuminates the scene from one direction and its size is limited. The scene is only fully illuminated in a limited area. To render the illuminated scene I have chosen *Blender* 2023 and *Cycles Renderer* 2023 graphic engine . These tools have given me the ability to easily test multiple configurations and quickly evaluate the results. I selected ambient occlusion as a shading technique. It simulates the way that light interacts with objects in a scene and creates the illusion of depth and volume through shadows. After selecting the editor and engine, I checked how to represent the diffuse and directional light source. Diffuse light was generated with an already available type of light called: *Sun-Light* 2023 in *Blender* 2023. A *Sun-Light* 2023 provides light of constant intensity emitted from a single direction from infinitely far away. I chose *Area-Light* 2023 as the directional light. This light simulates light originating from a surface or surface-like emitter. In both cases I decided to choose the white ($\#FFFFFF$) colour of light. In order to compare the two different types of lighting, I focused on the common features and the settings that I need to adjust. The first setting was the distance and angle of incidence of the light to the centre of the scene. I have tested 90 degrees and 65 degrees angle with the same distance from the middle of the scene. With the sunlight from infinitely far away with an angle of 90 degrees, I got an almost non-realistic illumination of the scene. The 90 degree angle of incidence was rejected. The 65 degree created realistic illumination and was selected. The next parameter was the power of the light. I have started with sunlight and adjusted directional light so that both images are illuminated in a similar way, only the shadows are different. The value for sunlight was chosen according to the Blender's documentation 1000 W / m2 which means a sunny day with a clear sky. Due to the fact that the directional light illuminates my scene in a relatively different way, I had to decide on a criteria for selecting the power and size of the directional light.

I tested 2 different parameters:
- The standard deviation that provides a measure of the dispersion of image grey level intensities is similar with both illuminations.
- The brightest pixels of the rendered scene are the same.

The image illuminated with direct light, which had a similar standard deviation compared to the image illuminated with diffuse light, appeared excessively bright. Realising that comparing two images based on standard deviation values wasn't appropriate, I decided to use the value of brightest pixels as a criterion for selection instead. While choosing the appropriate lighting power for direct light, I also assessed the impact of the light source size. I have tested three different values: a square area light with dimensions of 1x1m, 10x10m, and 20x20m. Ultimately, I settled on the 10x10m area light source as it produced the most realistic shadows.

2.1.3 Final selection of stimuli

The final step was to pick the final set of prepared images for the experiment. I assumed that the final images needed to be distinguishable under the same illumination. I created a presentation where 2 images were displayed side by side on the test monitor and the test subject needed to select the image with a bigger relief. Having as many as 21 images varying 5 percent in scaling, I started to compare them with 2 different scaling steps: 5% and 10%. With a 10 percent difference, I noticed that it was almost too easy to select an image representing higher relief. On the other hand, the pictures with a difference of only 5 percent, were hard to distinguish. I decided to generate new images with the same lighting conditions, but different scaling. New images were generated, where the difference in scaling is 7.5 percent. I repeated the selection process and picked 8 scales for the final experiment ranging from 125 percent to 177.5 percent. After rendering the images, I focused on the presentation format. I chose the side by side format, which was used in a previously described experiment by Zinke 2023. This variant did not cause any problems, but the form of presentation required me to crop the generated 1920 x 1080 images to 580 x 800 to fit in the center of the monitor. During modification, I did not observe any changes affecting their quality. Therefore, I ran another test presentation to prove that scaling is still recognisable.

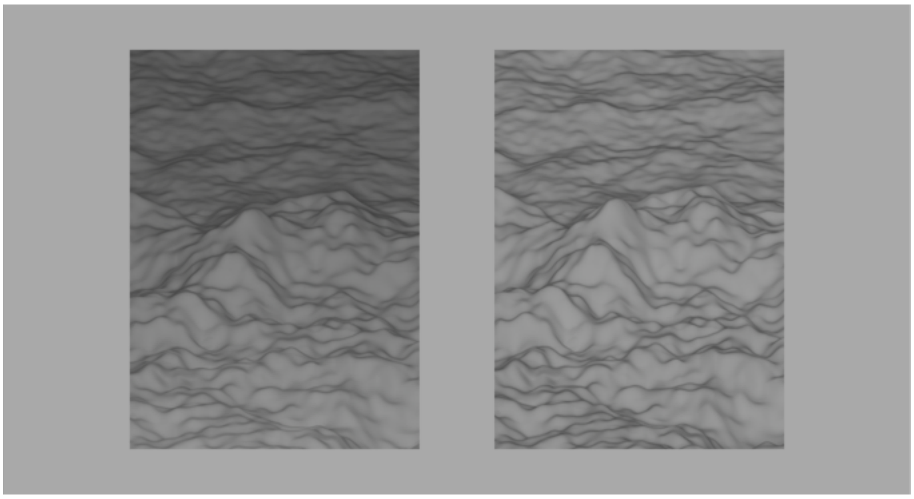

Figure 2.1: Setup of the MLCM experiment. The stimuli shown in this comparison have the different terrain scale. The left stimulus is illuminated with direct light source and the stimulus on the right is illuminated by diffuse light source.

2.2 Methode

When considering the approach for conducting the experiment, I opted for the Maximum Likelihood Conjoint Measurement (MLCM). Developed by Knoblauch and Maloney 2012, this method has demonstrated its robustness and reliability in various research contexts. Notably, it had been successfully employed by Zinke 2023 in a previous experiment, which laid a strong foundation for my decision to utilize MLCM for my own study.

2.3 Procedure and Task

The experiment was designed with MLCM. There are two stimuli presented side by side for 0.5s in Figure: 2.1. The test subjects were given a task to choose the image that has a higher relief. Decisions were made with the left or right arrow key. There were 16 stimuli in total and each one of them were compared to the other ones but not to themselves. Each pair of images was compared only once per run. One run had 120 comparisons (16*15/2 = 120). There were 10 runs in total. The order in which the image pairs were shown was random. So was the arrangement of the images. I implemented the experiment with *HRL* 2023. After a run, there was always a break and the test person could decide to start again.

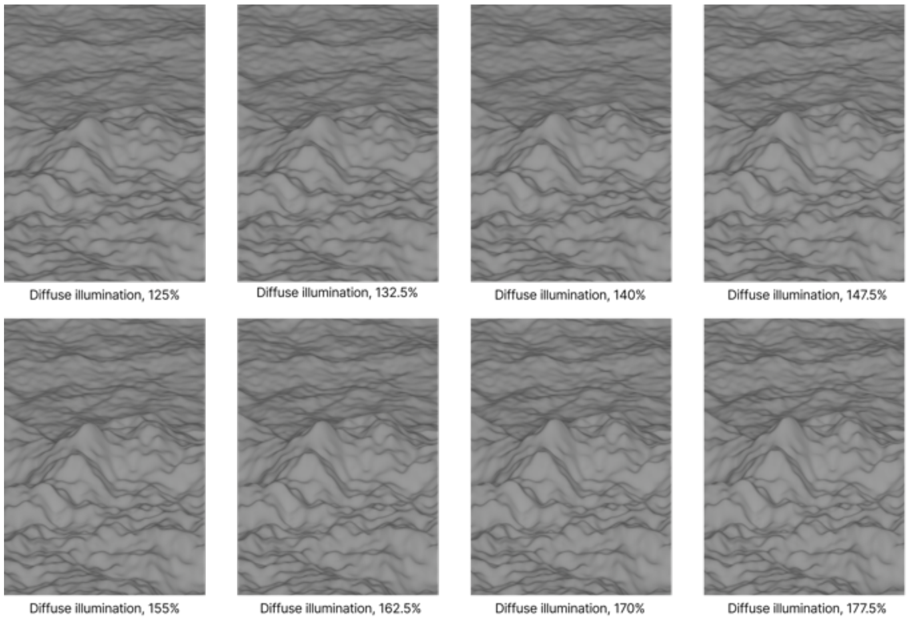

Figure 2.2: Images used in the experiment, diffuse illumination from the smallest scaling to the largest (from 125% to 177.5%).

2.4 Apparatus

The experiment was performed in a dark room. The test subjects were at a distance of one meter from the monitor. A headrest was set, to ensure an upright sitting posture and always the same distance. The monitor is the View- Pixx 3D/Lite. The resolution of the monitor is 1920 x 1080 pixels. The screen diagonal is 24 inches and the monitor has a pixel pitch of 0.2715mm x 0.2715mm. The refresh rate of the monitor is 120 Hertz and the brightness is 250 cd/m2 in the monitor's standard backlight mode.

2.5 Participants

The test was conducted by 5 participants. The test subjects were my friends who had no prior information about the experiment. Both men and women between the ages of 22 and 27 took part in the experiment. All the subjects spend a minimum of 3 hours in front of a computer, phone screen during a day.

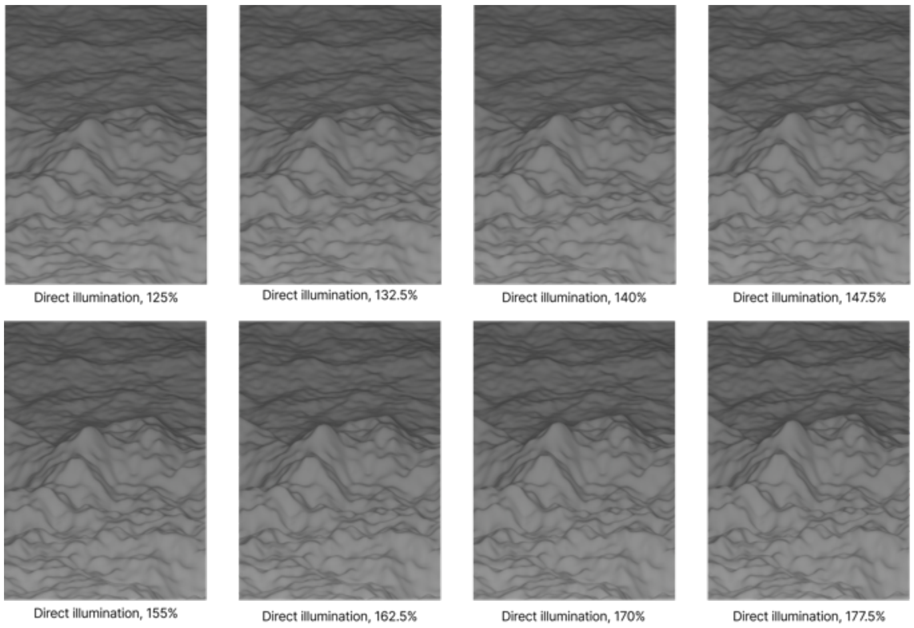

Figure 2.3: Images used in the experiment, direct illumination from the smallest scaling to the largest (from 125% to 177.5%).

3 Results

The data from the experiment was analyzed in R as an MLCM experiment and visually represented using Python.

3.1 MLCM Graphs

To generate the graphs presented in 3.1, I used the MLCM implementation available in the R programming language. These graphs display perceptual scales of perceived depth across various landscape scales used in the experiment. Each graph is created based on the answers collected from a single participant. The x-axis represents the scaling of terrain as a percentage of the original image, while the y-axis indicates the distinguishability between terrain scaling. A higher function value at a point suggests better estimations of depth at that scale. The blue line represents the direct light source, and the red line represents the diffuse light source. Additionally, error bars are plotted, indicating the standard error.

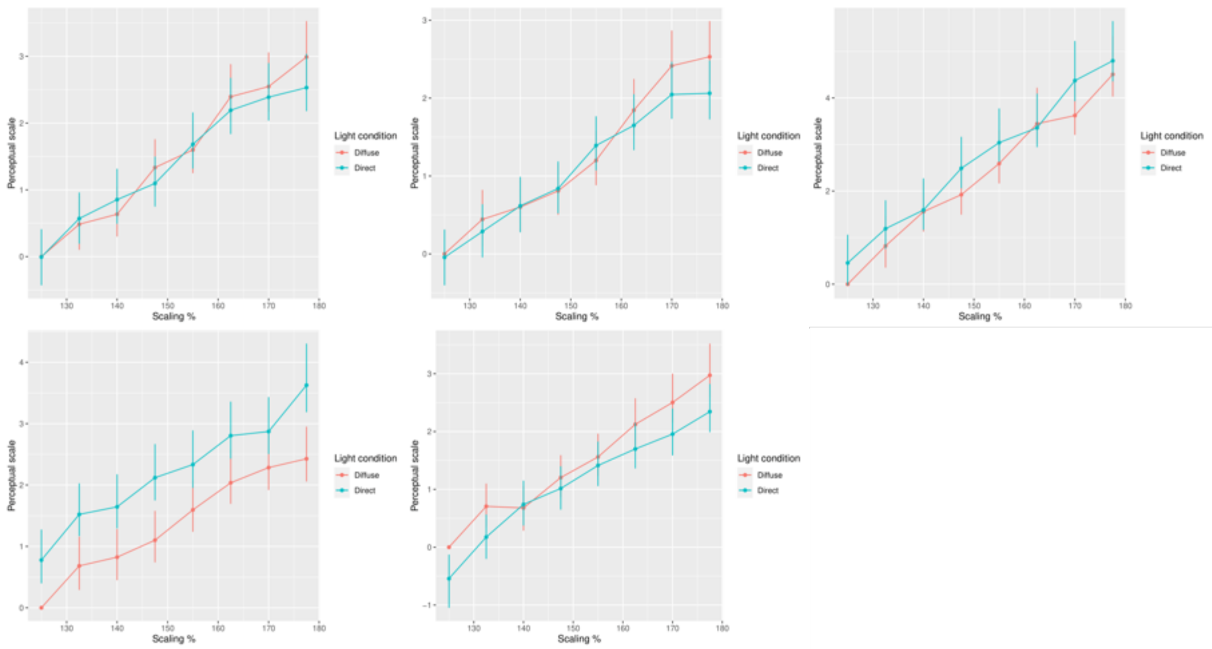

Figure 3.1: Each MLCM chart reflects the results collected during the experiment for each test participant.

All study participants consistently showed an increasing trend in their ability to distinguish changes in elevation. It should be noted that the results did not apply uniformly to every test person. Some patterns appeared significant for specific subgroups of participants. For three out of the five participants, an immediate discrepancy in the perception of initial values was observed.

Four out of the five graphs displayed similar trends, suggesting that differences between diffuse and direct lighting conditions do not significantly affect depth recognition. However, one participant showed better depth perception in directly illuminated scenes over diffuse illuminated scenes. Considering those who rated both types of lighting similarly, a trend can be seen. The discrepancy in ratings is small, mainly favoring diffused light at higher scales. To better understand the individual responses and validate the observed trends, I created heatmaps.

3.2 Heatmaps

The illustration 3.2 shows heatmaps created with Python. They display all the responses given by the test subjects during the experiment. These heat maps show the results of comparisons between the stimuli placed on the left and those on the bottom. The value in each cell describes how often the left image was perceived to have higher terrain, a greater scale. By dividing the heatmap into 4 parts, we observe that the top left segment represents the comparison of the stimulus illuminated with diffuse light. The top right segment showcases how frequently diffuse light was chosen over directional light. The bottom left segment displays the results of choosing directional light over diffuse light, and the bottom right part represents the comparison of directional light with itself.

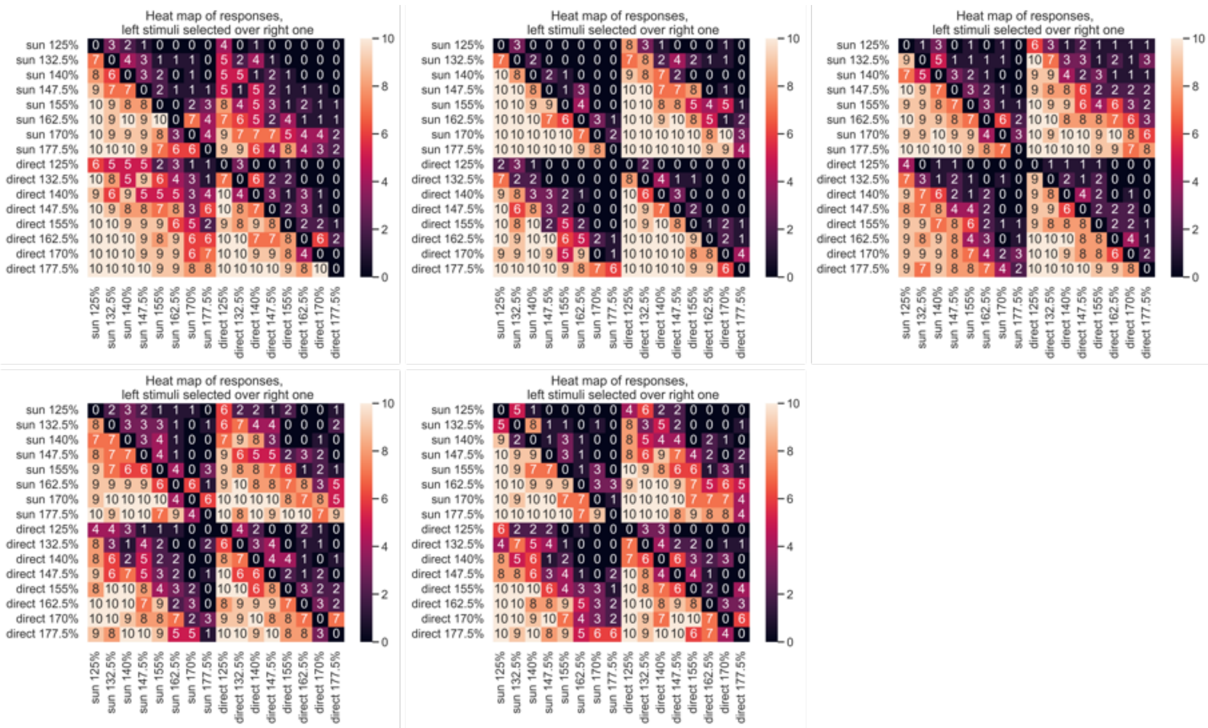

Figure 3.2: Each heatmap displays results collected during the experiment for each test subject. Direct xx% represents stimulus illuminated by direct light source and Sun xx% represents stimulus illuminated by diffuse light source.

Each heatmap has a diagonal line with cells having a value of 0. This line signifies comparisons of the same stimuli not included in the experiment. Other values of 0 represent valid results from the experiment. The maximum cell value is 10, indicating that in 10 comparisons, the left stimuli on the heatmap were consistently chosen over the ones at the bottom.

To gain a better understanding of the results, I intended to analyze the heatmap 3.3 of a person who frequently chose directional light over diffused light. This analysis aims to compare it with other heatmaps to identify similarities and differences.

The upper left part of each heatmap displays a comparison between diffuse and diffuse illumination. I have noticed 2 trends. Figure 3.4 shows comparison where all test subjects faced difficulties; terrain at a scaling of 162.5 percent, illuminated by diffuse light, was often chosen over terrain illuminated by diffuse light with a scaling of 170 percent. Identifying the reason why this comparison caused more issues than others remains unknown.

The upper right sections illustrate how frequently diffuse lightning conditions were selected over direct illumination. The first heatmap in the top row appears much darker compared to the other heatmaps. This particular heatmap 3.3 represents the results of a person who frequently selected direct light over diffuse light.

Similarly, the bottom left sections indicate how often directional light was chosen over diffused light. The first heatmap in the top row is notably brighter this time. I didn't observe any particular comparisons that stood out in the results of other test subjects.

However, when examining the comparisons of the same lighting conditions in the heatmap, it becomes apparent that there were difficulties in distinguishing between adjacent scales, such as 125 with 132.5 or 132.5 with 140, etc. Interestingly, a more substantial difference between the scaling values might indicate fewer incorrect selections between the stimuli.

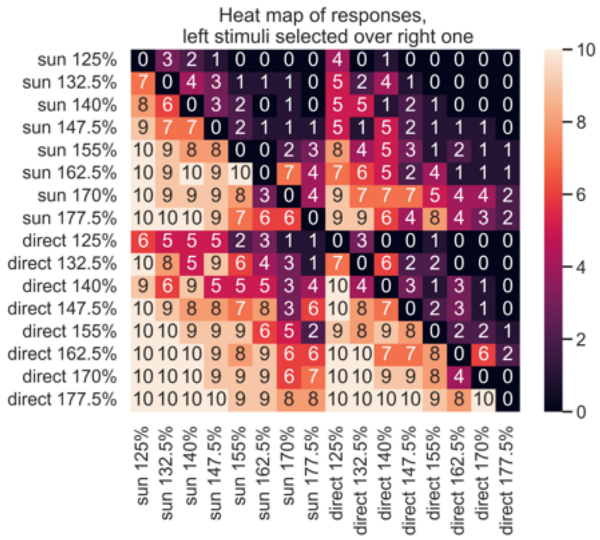

Figure 3.3: This heatmap shows results of a person who frequently chose directional light over diffused light.

3.3 Response time

To better understand the outcomes from heatmaps and MLCM graphs, I also analyzed response times. Illustration 3.5 displays response times as histograms for each tested

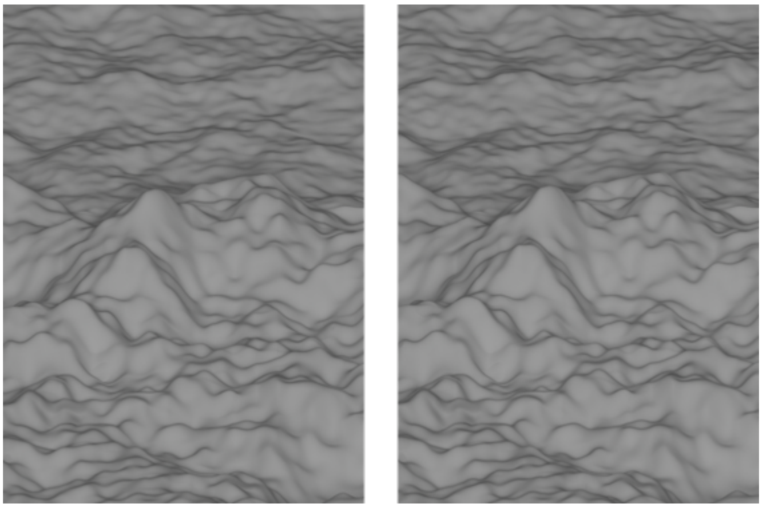

Figure 3.4: The figure illustrates comparison between diffuse illuminations. The left stimulus shows a scaling of 162.5%, while the right one shows 170%.

individual. It is evident that the majority of responses occurred within the first second after the stimulus presentation ended, and nearly all responses fall below 2 seconds. These results suggest that the stimuli were appropriately selected, and the test subjects did not have significant issues, as evidenced by their prompt responses. Otherwise, the response times would likely have been considerably longer.

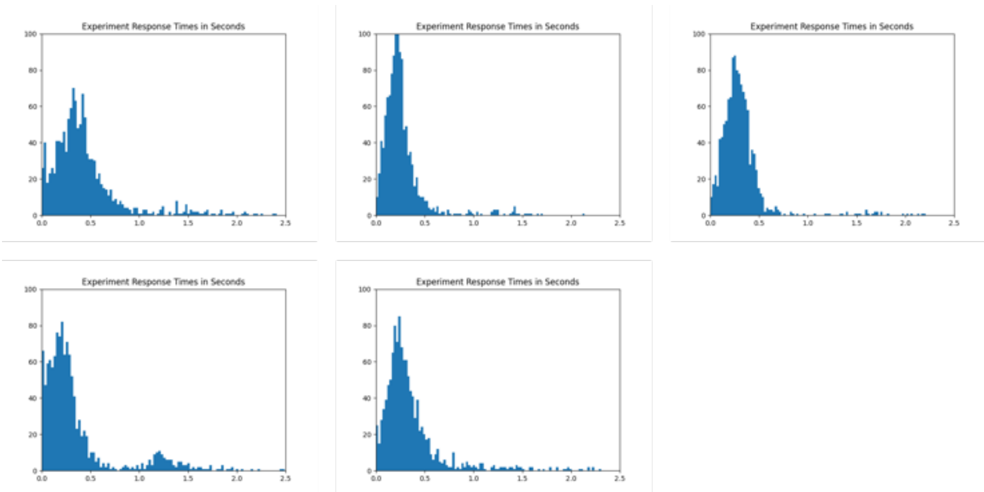

Figure 3.5: Distribution of response times among test subjects.

4 Conclusion and discussion

4.1 Conclusion

After analyzing the results, I am unable to fully confirm my hypothesis. The MLCM graphs indicate that for the majority of participants in the experiment, there is no difference between diffused light and directional light. However, it is possible that directional light better represents depth, as confirmed by the results of one of the tested individuals. The small scale of the experiment does not allow me to determine whether this behavior occurs within small percent of the population or if it is just an exception. It's essential to note that the experiment was conducted on a small group, resulting in low external validity. The results do not indicate such an exception for diffused light, which leads me to the following conclusion: To better represent depth in an image, the use of directional light may have a positive effect on depth recognition compared to diffuse light, but results are not conclusive and further research is required.

4.2 Possible changes related to terrain

In creating the experiment, I made several decisions regarding the scope and characteristics of the experiment. Only one terrain pattern was presented in the experiment, consisting of hills and valleys. Additionally, the scaling and differences between elevations were established uniformly from the top rather than individually tailored to the tested individual. Setting these values as constant made it easier to create and conduct the experiment, but limits the scope and influence received results. One potential extension or continuation could involve adjusting the scaling levels individually for each tested individual. Such an approach would make it more difficult to compare results, but if appropriately scaled, might be more precise than selecting scaling uniformly for all test subjects. Introducing several terrain patterns into the experiment would also have a positive effect on the accuracy of the received results. However, it would lengthen the experiment and make more difficult the creation of each stimulus. It would be difficult to create many stimuli that would not reveal any information about the depth beyond the shadows themselves.

4.3 Possible changes related to illumination

In choosing the type and parameters of lighting, I aimed to achieve scene illumination as close to reality as possible. I had to predefine numerous parameters to meet the set goal. Altering just one of these parameters could positively or negatively affect the results. If I were to conduct this experiment again and expand it, I would add another type of lighting conditions. For example, 2 additional light sources with different angle at which the light falls onto the center of the scene. Increasing the angle by 10 degrees or setting the light to fall almost perpendicularly (close to 90 degree) to the surface could entirely change the perception of depth in the created image and maybe change the results of the experiment. The type, size, and intensity of the light were consciously chosen to be realistic, but each parameter could be slightly modified. The results I obtained are a consequence of my lighting choices. While the multitude of parameters allowed me to create a 'realistic scene', changing one parameter could completely alter the experiment's outcomes. If I were to continue this experiment, one interesting change in lighting parameters that could be explored is comparing diffused, intense light, similar to the light used in the Zinke 2023 experiment, to equally strong directional light. I believe that having results with very strong lights creating weak shadows could either confirm or falsify my hypothesis.

4.4 Summary

This work aimed to investigate the visual perception of depth influenced by different illuminations of 3D generated scenes on the computer screen and to answer whether directional lighting and its shadows, compared to diffuse lighting, have a positive effect on recognizing greater relief and depth in a 3D generated image. The results of the experiment conducted in this work did not provide a complete answer, but they also did not contradict the idea that the use of directional lighting contributes to better representing depth in an image. I conclude that utilizing directional light may have a positive effect on depth recognition compared to diffuse light, but further research is required.

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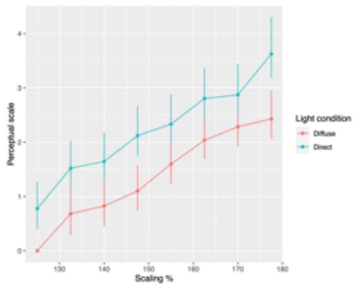
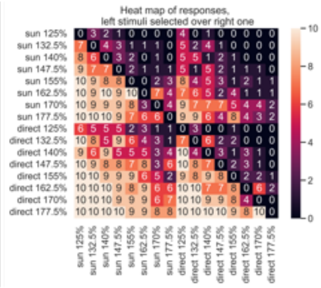
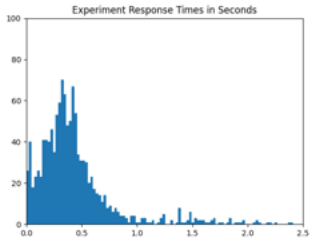
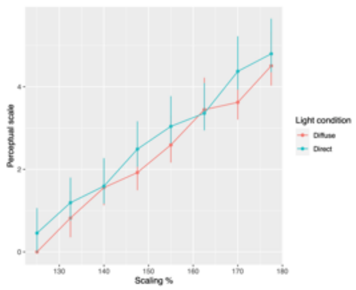
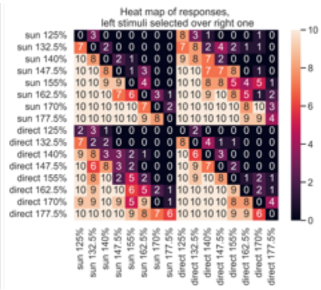
Annex

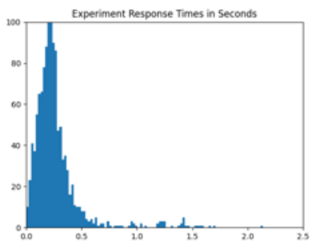

Perceptual scale
Scaling %
Light condition
Diffuse
Direct

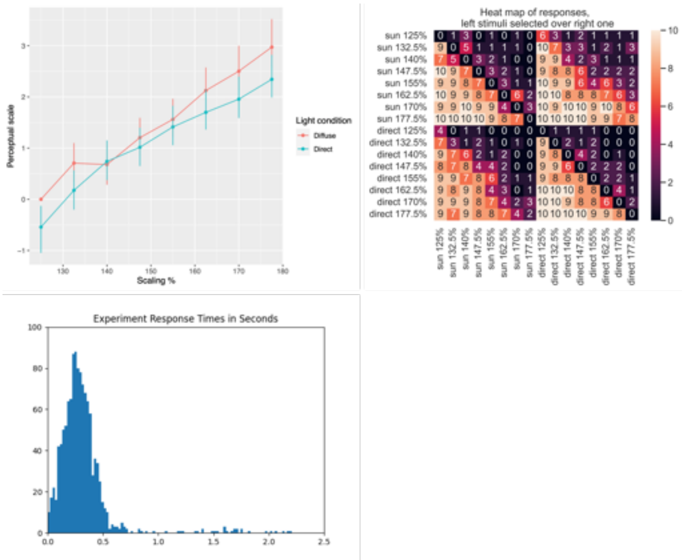

Heat map of responses,
left stimuli selected over right one

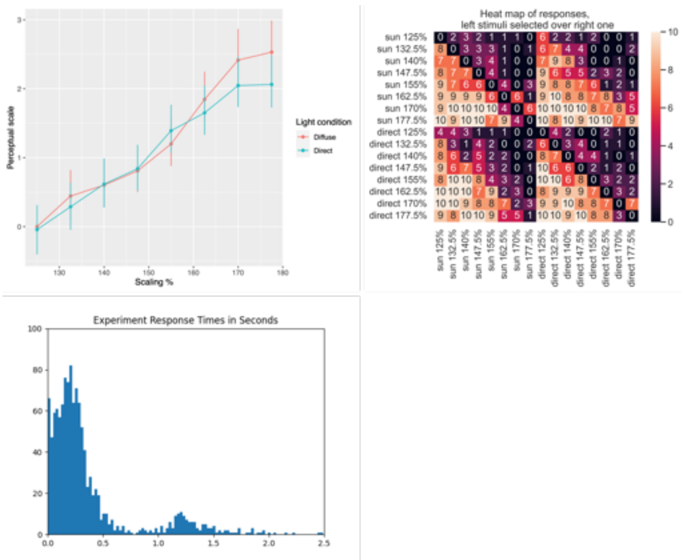

Experiment Response Times in Seconds

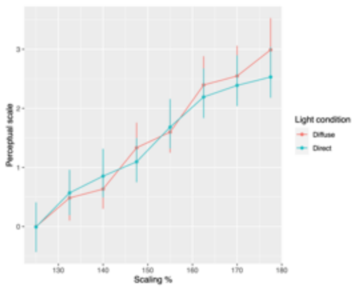

Perceptual scale
Scaling %
Light condition
Diffuse
Direct

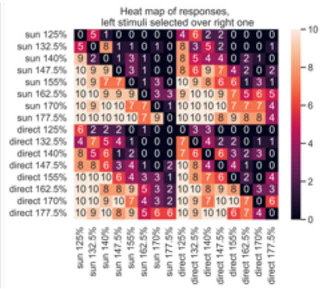

Heat map of responses,
left stimuli selected over right one

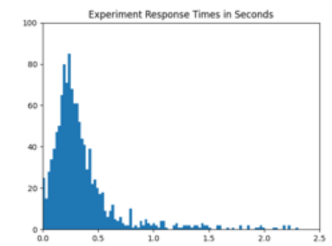

Experiment Response Times in Seconds


Perceptual scale
Scaling %
Light condition
Diffuse
Direct
Heat map of responses,
left stimuli selected over right one
Experiment Response Times in Seconds


Perceptual scale
Scaling %
Light condition
Diffuse
Direct
Heat map of responses,
left stimuli selected over right one
Experiment Response Times in Seconds


Perceptual scale
Scaling %
Light condition
Diffuse
Direct


Heat map of responses,
left stimuli selected over right one
sun 125%
sun 132.5%
sun 140%
sun 147.5%
sun 155%
sun 162.5%
sun 170%
sun 177.5%
direct 125%
direct 132.5%
direct 140%
direct 147.5%
direct 155%
direct 162.5%
direct 170%
direct 177.5%


Experiment Response Times in Seconds