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# Drivers' Evaluation of Performance of LED Traffic Signal Modules

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16. Abstract

This study evaluated the performance of the LED modules from four manufacturers (Leotek, Gelcore, Dialight and Precision Solar) who provided the required number of LEDs for testing and evaluation at the Traffic Operations Lab. The criteria for evaluation were drivers' perception of brightness, dottiness, and color compared to incandescent lenses. For circular red indication, brightness, dottiness, and color of Dialight LED module was similar to incandescent lens, but the other three were brighter, more dottier, and darker than incandescent lens. For circular yellow indication, brightness of Precision Solar LED was the same while the others were brighter than incandescent lens; they all were dottier and darker (orange-yellow) than incandescent lens. For circular green indication all the LED modules were brighter, dottier, darker (bluish) than incandescent lens. For yellow arrow indication, Leotek and Dialight are the same while Gelcore and Precision Solar were brighter than incandescent lens; all the LED modules were dottier and darker than incandescent lens. For green arrow indication, Leotek was the same as incandescent while Dialight, Gelcore and Precision Solar were brighter than incandescent lens; all the LED modules were dottier and darker than incandescent lens. The findings, though limited, indicated that there could be a significant difference in the perception of the LED modules by the older drivers. It is recommended to further study the effect of aging on the perception of the LED modules.

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# Table of Contents

# 1. INTRODUCTION

Nearly everyone is familiar with Light Emitting Diodes (LEDs) from their use as indicator lights and numeric displays on consumer electronic devices. Light Emitting Diodes, which were developed in the late 1960s are solid-state semi-conductor devices that convert electrical energy directly into light. Figure 1[Ref. 1] shows a schematic of a typical T 1-3/4 LED (T-1 ¾ is a type of LED lamp package. Type T-1 3/4= 0.2188 inch lamp diameter or a 5.56mm lamp diameter.).

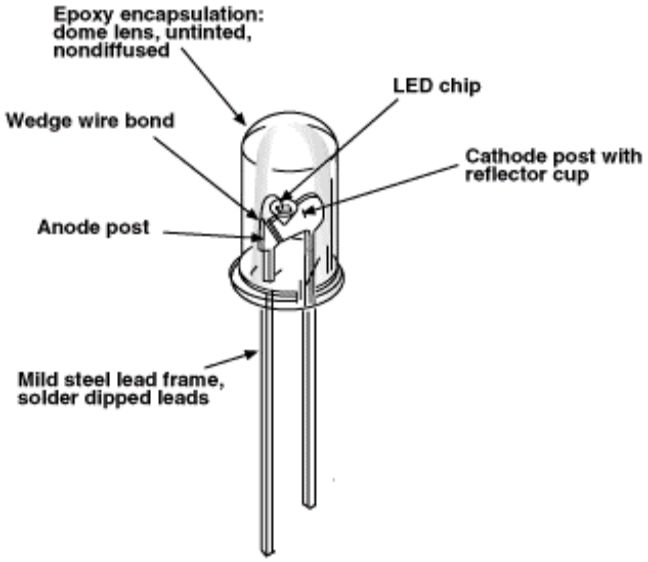
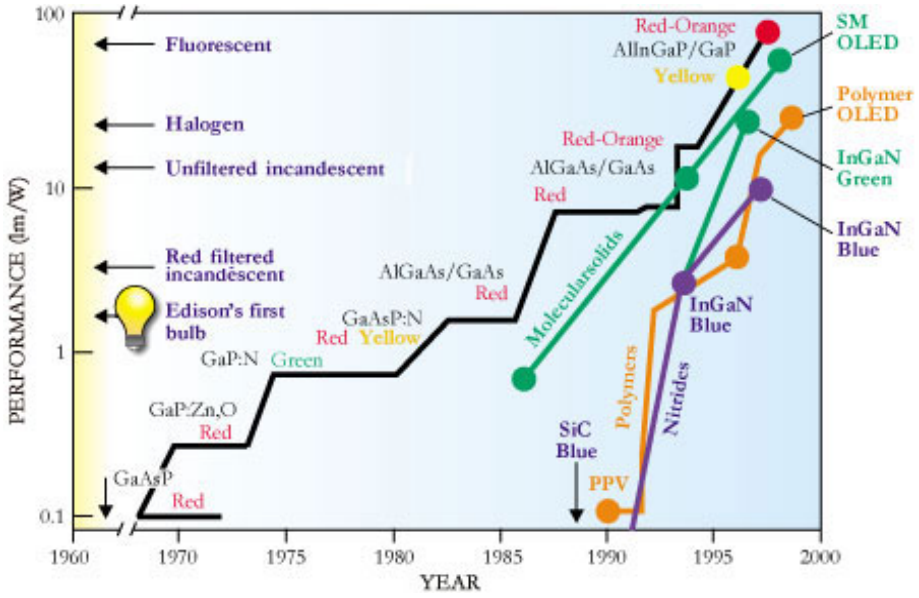



Figure 1. Schematic of a typical T 1-3/4 LED [Ref. 1].

The light-generating chip itself is very small typically 0.25 millimeters square, with rest of the volume being occupied by the plastic encapsulant and the lead frame. Light is generated inside the chip when current flows across the junctions of different materials. The wavelength of the light generated and therefore the color of the light emitted depends on the composition of the materials in the chip.

Light emitting chips in LEDs are essentially layers of different semiconductor material grown on top of one another. They are manufactured using a process called epitaxy. Advances in epitaxial crystal growth processes have made it possible to

manufacture LED materials with high enough purity to produce colors that were not possible previously. Figure 2[Ref. 2] summarizes the performance of different LED technologies as they have evolved over time. The dark line starting from mid 1960s summarizes the steady increase in the LED performance and this can be compared with the performance of several conventional lighting devices, indicated by arrows, near the vertical axis. In the mid-1990s high-performance, nitride-based LEDs, were developed and this is indicated by the line labeled Nitrites which sprouts a branch. The lines labeled




Molecular solids and Polymers show the improving performance of Organic LEDs.

Figure 2. Growth in performance of LEDs over time [Ref. 2]

Presently LEDs are available that can produce light spanning the visible spectrum. AlInGaP (Aluminum Indium Gallium Phosphide) material systems produce red, orange, and yellow light while AlInGaN (Aluminum Indium Gallium Nitride) systems generate green, blue, and near-UV light.

### *1.1. LEDs Vs Incandescent light sources*

Almost 100% of the energy radiated by LEDs lies within the visible spectrum. But for an incandescent source 2% of the emitted energy is in the visible region with the rest 98% being wasted as heat. Owing to the high light output efficiency an LED source can

generate light of same intensity as an incandescent source while consuming significantly less electrical power.

Light emitted by the LEDs falls in very narrow spectral bandwidths, thereby producing nearly monochromatic light and does not need to be filtered to produce the required colors. On the contrary, incandescent sources are broadband emitters of white light that must be optically filtered to achieve the desired color.

The light output of LED modules degrades over time. Degradation of LED light output is a direct function of the junction temperature. However "for any given length of time, the light output degradation of for an LED device is significantly less than that of an incandescent lamp"[Ref. 3]. LEDs are durable and provide longer lamp life than incandescent sources.

### *1.2. LEDs in Traffic Signals*

As can be seen in Figure 2, advances in light emitting diode (LED) technologies have made it possible to produce LEDs that emit colors throughout the visible spectrum and have better performance than conventional technologies. This has made it possible to use LEDs in a variety of lighting applications. Manufacturers have developed traffic signal optical modules using LEDs. According to Strategies Unlimited, a market research organization that conducts an annual market update of LED lighting products , about 10% of all red traffic signals in the United States used LEDs in 2000. "In early signals, more than 600 individual LEDs might be mounted together in a disk formation to produce the circular indication, but these signals did not meet the requirements for distribution of luminous intensity. The addition of lenses in front of the LEDs and increases in LED light output brought their number from 600 to around 200. More recently, very high output LEDs with broader intensity distributions have been developed, and in many ways, the design of LED traffic signals has begun to mirror conventional incandescent signals, with a clustered LED light source set back into a chamber and optical elements diverting the light from this source in the proper distribution."[Ref. 4] Figure 3 [Ref. 4] shows a schematic of the various LED traffic signal modules.

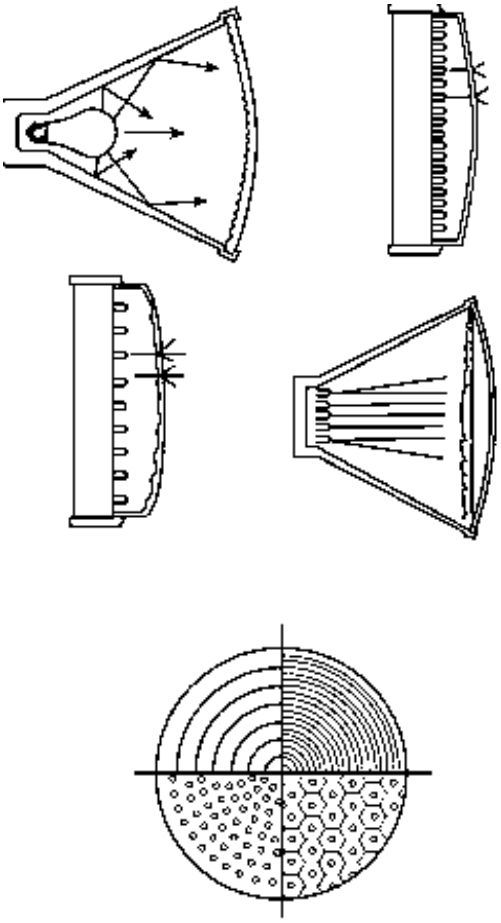


Figure 3. Top left: Incandescent traffic signals have been in use for many decades. Top right: Early LED signals used hundreds of tightly packed LEDs. Center left: With improved optics, fewer LEDs could be used. Center right: High output LEDs result in signals that appear similar to incandescent signals. Bottom: Head-on view of traffic signals, starting top left and going counter-clockwise [Ref. 4].

There are approximately 260,000 intersections with traffic signals in the US. Each intersection has an average of 40 signal indications using either 69, 135, or 150 watts incandescent lamps. Though, the incandescent lamps are very inexpensive, their use in the traffic signals is a considerable economic burden for the governmental agencies because of their high power consumption and annual preventative lamp replacement.

On the contrary, LED based traffic signals offer tremendous savings potential because they consume much less power than the incandescent lenses for producing the

same output and do not require the annual preventive replacement due to their long life. According to an estimate [Ref. 5] Light-emitting diodes (LEDs) could save nearly 2.5 billion kilowatt hours annually, if they replaced incandescent lenses in traffic signals. Thus the use of LEDs in traffic signals results not only in energy cost savings for the governmental agencies, but also helps the environment by using less power for operating the signals. In the following section a literature review of the benefit-cost analyses that were published is presented.

## 2. LITERATURE REVIEW ON BENEFIT - COST ANALYSES

In this section a summary of four benefit-cost analyses of the use of LED modules in traffic signals that have been documented in the literature is presented. Summaries of the four studies followed by our comments are presented in four subsections to follow. However, it should be noted that the conclusions reached in these studies are valid only for the projects under consideration and are not necessarily applicable for any other project. This is primarily because of the difference in:

- The benefits and costs being considered: In each subsection the factors that have been considered in the particular studies are mentioned and it can be seen that the factors that have been considered are different for different studies.
- Cost of the LED modules: The costs of the LED modules have been decreasing over the years and the costs that have been used in these studies would be too high today.

### *2.1. Oregon's Experience*

The Oregon study [Ref. 6] traced the history of introduction of LED traffic signals in Oregon by Oregon Department of Transportation (ODOT) after testing red LED modules and finding them to be reliable. In 1995, ODOT started an LED traffic signal implementation program in conjunction with 8 cities in Oregon (only Red 12" balls, Red 8" balls, Red 12" arrows and Pedestrian "hand" symbols were replaced). The report presents an economic analysis comparing LED and incandescent traffic signals. In the economic analysis, the factors considered were

- Lamp Cost
- Energy cost

It was estimated that for the ODOT project, the annual energy savings (considering only red LEDs) would be 88% and after factoring in the lamp costs would result in annual savings of 26%. The estimated payback period for the project was 3.6 years. However it should be noted that the LEDs that were used in the Oregon study were based on Aluminum Gallium Arsenide (AlGaAs) technology while the present LEDs use Aluminum Indium Gallium Phosphide (AlInGaP) technology. This economic analysis

does not consider the initial cost of replacing incandescent lenses with LEDs and maintenance savings due to the use of LED modules. Also, the data used for estimating the energy costs is based on technical data sheets and not on actual metered energy usage.

For the Oregon project, through the Federal Highway Administration (FHWA) Priority Technology Program, the participating agencies were reimbursed 30% of the cost of the lenses and in addition, electric utility companies provided energy rebates to the participating agencies. However, in the Benefit-Cost analysis performed, the actual cost of the lenses was used and these rebates/reimbursements were not considered.

### *2.2. Missouri's Experience*

The prime objective of the Missouri study [Ref. 7] was to develop an evaluation methodology that would provide data comparing LED signal heads to incandescent signal heads. Towards this objective, all the red and green incandescent indications (a total of 41) at the intersection of US Route 50-63 and Missouri Boulevard in Jefferson City, Missouri were replaced with light emitting diode (LED) signal indications.

The evaluation procedure consisted of collecting data that included installation and material costs for the LED signals as compared to similar incandescent bulb installations, energy usage and cost comparisons of each type of installation, and maintenance and repair costs of the LED installation compared to the previous incandescent installations. From this data signal life cycle costs were computed and life cycle cost analysis was performed. The Life Cycle Cost Analysis (LCCA) gave an Incandescent Bulb/LED ratio of 0.97 based on 1997 costs of LED signal heads. However the ratio was 1.36 when estimated costs of the LED signals in 1999 were used in the analysis. It is also reported that the ratio would be much higher for other intersections because this intersection is located close to the Central District Headquarters, there by having a smaller maintenance cost.

This study clearly highlights the economic benefits of the use of LED signals in lieu of incandescent signals by using actual field data for a particular intersection. For computing the energy savings, actual metered usage of the intersection over several months of operation with LED signals was used. During the course of the study, one of

the left turn LED signals was seriously damaged in a lightning storm and had to be replaced. The resulting repair cost was included in the repair costs for LEDs. However, the cost of the replacing the LED signal was not included as that cost was borne by the vendor under warrantee. The life cycle of the LED lamp was considered to be 7 years and the cash flows were discounted while performing the analysis.

### *2.3. Denver's Experience*

This study [Ref. 8] provides an estimate of the payback period for retrofitting all the 1200 intersections of Denver with LED traffic signals (red 8" and 12" ball, arrow, pedestrian hand only). The factors considered in the analysis were acquisition cost, installation cost, ancillary materials cost (cost of incandescents for yellow, green and white which were group relamped in the retrofit project), energy savings, reduced replacement material savings, labor savings due to reduced maintenance. The average simple payback period for the project was estimated to be 4.28 years.

The net acquisition cost for the complete program was $ 1,333,225 and represents 17,036 units. Denver realized a total rebate of $405,900 for the installation of 14,036 units before the expiration of the Public Service Company of Colorado's (PSCO) Demand Side energy Management (DSM) program. The supplier gave a 1% credit for payment within 31 days, which resulted in an additional decrease of $ 17,556.

This study does not discount the cash flows. But, it should be noted that of the three studies discussed so far, this study accounts for all the benefits and costs and is more realistic and could possibly serve as a model for benefit-cost analyses of future projects.

### *2.4. London Study*

This study [Ref. 9] provides estimates on the expected savings if all traffic signals in London were replaced by LED modules. In this study, the authors considered cost of the LED modules, installation cost of LED modules, electricity and maintenance savings. Based on the then prices of LED modules and electricity costs, the authors estimate that

the payback period for that project would be 8 years for Red, 28 years for Yellow and 18 years for Green LED modules.

It is interesting to note that while the Oregon study indicated a payback period of 3.6 years for their project that involves red signals mostly, the London study indicates a payback period of 8 years for red signals. This is because the incandescent lenses being used in London consume 50 watts while the lenses that are used in Oregon have a consumption of 158 watts and the LED modules in London and Oregon use 13 and 20 watts, respectively. So the payback period for red lenses for London should be approximately three times the payback period for Oregon. But the reported payback period is significantly lower than 10.8(3*3.6 years) because in the London study, the maintenance savings due to the use of LED modules are also considered while computing the payback period. However, it should be noted that the authors assume that the entire annual maintenance costs, which are being currently incurred with incandescent lenses will be saved once the switch to LED modules takes place. It is imperative there will be some maintenance, not necessarily involving relamping, even when the traffic signals are converted to LED modules. It should also be noted that the authors do not consider any replacement cost for LED modules over the payback period of the project, which is quite high at 8 years for red, 28 years for Yellow and 18 years for green.

## 3. OBJECTIVES

The Illinois Department of Transportation (IDOT) is considering replacing the incandescent traffic signal lamps on the state highway system with LED modules by requiring LED modules in the future traffic signal construction projects and retrofitting the existing signals. The objective of this study is to evaluate the performance of the LED modules from four manufacturers. The manufacturers are Leotek, Gelcore, Dialight and Precision Solar. These manufacturers provided the required number of LEDs for testing and evaluation at the Traffic Operations Lab. The purposes of the evaluation are:

- Identify those manufacturers whose LED modules are close to the incandescent lens in their performance.
- Identify subset(s) of manufacturers whose LED modules are statistically the same in their performance.

The criteria used for performance evaluation includes:

1. Brightness: Brightness could have been measured photometrically, but the spectral content and spatial detail may differ between different technologies and that may influence the perception of drivers. So, drivers were asked to compare the brightness of LEDs to incandescent indications.
2. Dottiness: As the LED modules consist of strings of LEDs, they tend to appear like a cluster of dots which is not the case with incandescent lens. Therefore, it is imperative to know how drivers perceive the LED modules compared to incandescent lenses.
3. Color: Since the spectral distributions of different lenses differ, it is required to ensure that any lenses that are used in the traffic signal heads resemble the incandescent lenses in color. So, drivers were asked to compare the color of LED modules to the corresponding colors in incandescent lenses.

# 4. DATA COLLECTION, REDUCTION & METHODOLOGY

## *4.1. Data Collection*

A questionnaire was developed and data collection was conducted at the Traffic Operations Laboratory at University of Illinois. Four manufacturers' lenses were mounted on signal heads. On a given signal head all the lenses were from the same manufacturer. Three signal heads of each manufacturer were used. The model numbers of the lenses used in the survey and their power ratings are shown in Appendix C. Two of the signal heads had only Red, Yellow and Green lenses while the third one included a Yellow left arrow and a Green left arrow. Four frames were assembled and each frame had 3 signal heads. The signal heads of the different manufacturers were arranged in such a way that the signal heads of each manufacturer occupied left, middle and right positions on different frames. A typical frame is shown in Figure 4.

Figure 4. Frame D used in the Survey.

Observers were asked to sit at four different viewing stations and at each station view one of the frames. The distance between the viewing station and frame was about 70 feet. This represents approximately the distance between a stopped vehicle and the signal head at an intersection with 2 through lanes per direction and a left turn pocket. The viewing stations and the frames were clearly marked to avoid any confusion. Observers moved from one station to another station after completing the survey for that frame.

The survey questionnaire requested the drivers to rate the performance of the LED signal lenses relative to incandescent signal lenses in terms of brightness, solidness (as opposed to being a series of dots) and color on a scale of 1 to 5, and 0 referring to No Opinion. In order to avoid ambiguity about what the ratings 1 through 5 indicated, descriptions of each rating were also provided. For example, in the case of brightness, 1 indicated much dimmer and 5 indicated much brighter compared to incandescent lenses and 3 indicated the same as incandescent lenses. The observers had valid driving licenses and were asked to identify their age group and indicate if they needed to wear glasses or had any difficulty in distinguishing different shades of a color. A copy of the Survey Questionnaire is given in Appendix A. Thirty eight drivers participated in the survey. The demographics of the drivers are shown in Table 3.1.

| Group | Age Group | Frequency |
|---|---|---|
| A | < 25 | 0 |
| B | 25 – 40 | 14 |
| C | 40 – 50 | 12 |
| D | 50 – 60 | 11 |
| E | > 60 | 1 |

Table 3.1. Demographics of the survey participants.

The LED signal heads were operated using a NEMA Controller. The cycle length was about 93 seconds and there were four phases. Yellow times were made longer than normal so that the observers had enough time to view them. Some observers reviewed the lenses more than once, before filling in their responses.

### *4.2. Data Reduction*

In an Excel Workbook, three spreadsheets were made corresponding to the three questions in the survey questionnaire. The data from the 38 surveys was coded in spreadsheets. However, after transferring the survey responses to the Excel file, it was observed that not all drivers responded to all the questions in the survey. Therefore, for each question in the survey (pertaining to the three aspects i.e., brightness, dottiness and color) the subset of drivers who gave three ratings for the lenses of all the LED manufacturers were identified. The average rating for each manufacturer's LED modules was calculated. These average ratings of the drivers were used to perform statistical tests and conclude about the performance of the LED modules.

To check for the normality of the data, histograms of the average ratings of the drivers were plotted and visually inspected for normality. As the data is categorical, we could only check to see that there exists a symmetric curve with a peak at the center. To ensure that drivers were consistent in the responses they gave to the three lenses of the same color from a given manufacturer, the range of each driver's responses to each of the manufacturer's LED modules was calculated. It was assumed that a range of one was reasonable and did not constitute an inconsistency in the rating. Therefore, all drivers who had ranges greater than or equal to two for any of their ratings were identified. For each such driver, the sum of the ranges for each of the questions in the survey was computed. The drivers who had a sum of ranges greater than 12 were identified and are listed in Table 3.2.

Those drivers who had a sum of ranges greater than twenty four were not included in the analysis because a sum of twenty four implies that on the average their range was two for all the ratings they gave. Therefore drivers 28 and 34 were not included in the analysis for color. From Table 3.2 we can also observe that all the drivers who had higher ranges, except for driver 10 are aged above 50. This might indicate that the older people are more inconsistent than the younger people in their ratings of the LED modules.

| Driver # | Age Group | Color Problems | Glasses | Aspect | Sum of Ranges |
|---|---|---|---|---|---|
| 9 | 50 – 60 | No | Yes | Brightness | 16 |
| | | | | Dottiness | 13 |
| 10 | 40 – 50 | No | Yes | Dottiness | 18 |
| 26 | 50 – 60 | No | Yes | Brightness | 15 |
| 27 | > 60 | No | Yes | Brightness | 12 |
| | | | | Dottiness | 15 |
| 28 | 50 – 60 | No | No | Color | 25 |
| 34 | 50 – 60 | No | No | Color | 29 |
| 38 | 50 – 60 | No | No | Brightness | 12 |
| | | | | Color | 13 |

Table 3.2. Drivers with inconsistent responses.

### *4.3. Methodology*

The methodology used in this study was asking drivers' opinions on the performance of LED modules compared to incandescent lens. To achieve the objectives of this study, t – tests (one tailed) were conducted to compare the performance of each manufacturer's LED module with incandescent lens and paired t-tests were conducted to compare each manufacturer's LED modules with every other manufacturer's LED module.

Also, in order to verify, if the age of the drivers affects the rating of the LED modules, the responses were classified into two age groups viz., below 50 years and above 50 years. Considering these two data sets as independent samples, independent samples t-test was performed. Equality of variances of the two groups was first tested and if they were statistically equal, regular t – test with pooled variance was used otherwise Welch's t – test was performed.

Furthermore, to check for the effect of wearing glasses, the responses were classified into two groups viz., drivers with glasses and without glasses. Considering these two data sets as independent samples, independent samples t – test was performed.

Equality of variances of the two groups was first tested and if they were statistically equal, regular t – test with pooled variance was used otherwise Welch's t – test was performed. An $\alpha$ value of 0.10 was used in all the statistical tests.

# 5. STUDY FINDINGS

Five types of LED traffic signals (Circular Red, Circular Yellow, Circular Green, Yellow left arrow and Green left arrow) were evaluated. The results for them are presented in five separate sections to follow. Each of these sections is further divided into three subsections corresponding to the three questions in the survey questionnaire (brightness, dottiness, and color). Each subsection contains a discussion on the following items:

- Performance of each manufacturer's lens with respect to incandescent lens
- Relative performance of the manufacturer's lenses
- Effect of age on the responses
- Effect of wearing glasses on the responses

## *5.1. Circular Red*

### 5.1.1.Brightness

Thirty three drivers gave three ratings for brightness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.1. T – tests were performed to find out if the average ratings were statistically different from 3.00. A rating of 3.00 indicates that the LED modules have the same brightness as the incandescent lenses and a higher rating indicates that LED modules are brighter. The results of the t – tests, shown in Table 5.1, indicate that Dialight is statistically same as incandescent lens in brightness and all the others are brighter than incandescent lens.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 33 | 3.75 | 0.63 | 6.82 | 2.733E-08 | Reject | Brighter than Inc |
| GELCORE | 33 | 4.15 | 0.57 | 11.69 | 1.241E-16 | Reject | Brighter than Inc |
| DIALIGHT | 33 | 2.92 | 0.79 | -0.59 | 2.795E-01 | Don't Reject | Statistically same |
| PRESOLAR | 33 | 4.01 | 0.59 | 9.90 | 2.787E-16 | Reject | Brighter than Inc |

Table 5.1.Results of t-tests for brightness of Circular Red

To identify the LED modules which are statistically not different from each other in their brightness, paired t-tests of the six (${}^4C_2$) possible combinations were performed. The results are shown in Table B.1 in Appendix B. The results indicate that the decreasing order of brightness is Gelcore, Precision Solar, Leotek and Dialight. However, it should be noted that Gelcore would not be brighter than Precision Solar if the confidence level were raised to 95%.

Of the 33 drivers who gave three ratings for all the manufacturer's LED modules, 21 had glasses and 10 did not. Two other drivers did not indicate if they used glasses or not. It was found that the variances of the two groups were statistically the same for all the LED modules. Statistically (results shown in Table B.2 in Appendix B) no difference was found between the ratings given by the two groups of drivers for any of the manufacturer's lenses.

When the ratings of the older drivers (over 50 years) were compared (results shown in Table B.3 in Appendix B) with the ratings of the younger drivers (under 50 years), it was found that for all the LED modules the average ratings of the two groups were statistically the same. Also for Leotek the variances for the two groups were found to be statistically different and consequently Welch's t – test was used for Leotek.

### 5.1.2. Dottiness

Thirty four drivers gave three ratings for dottiness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.2. T – tests were performed to find out if the average ratings were statistically different from 3.00. A rating of 3 indicates that the LED module has the same dottiness as the incandescent lens and a higher rating indicates that LED module is dottier than incandescent lens. The results shown in Table 5.2 indicate that Dialight is less dottier than an incandescent lens while all the others are more dottier than incandescent lens. However, it should be noted that for Dialight comparison, the confidence level is 96% while the confidence level for the other comparisons is almost 100%. This means that, if we increase our confidence level to 97%, we cannot say that Dialight is less dottier than incandescent lens.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inferenc e | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 34 | 3.94 | 0.55 | 10.03 | 1.067E-16 | Reject | More Dottier |
| GELCORE | 34 | 4.46 | 0.52 | 16.23 | 1.067E-16 | Reject | More Dottier |
| DIALIGHT | 34 | 2.80 | 0.62 | -1.84 | 3.731E-02 | Reject | Less Dottier |
| PRESOLAR | 34 | 3.61 | 0.52 | 6.88 | 1.906E-08 | Reject | More Dottier |

Table 5.2.Results of t-tests for dottiness of Circular Red

The results of the six paired t-tests are shown in Table B.4 in Appendix B. The results indicate that the descending order of dottiness is Gelcore, Leotek, Precision Solar and Dialight.

Statistically no difference was found (results shown in Table B.5 in Appendix B) between the ratings of drivers with glasses and without glasses for all the four brands.

The ratings of the two age groups for Gelcore were statistically different at 95% confidence level, with the older age group giving a higher rating than the younger age group indicating that older age group found it more dottier than the younger. The Gelcore ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that both the groups found it to be statistically dottier than incandescent. For the other three brands the ratings of the two groups were statistically the same (results shown in Table B.6 in Appendix B).

### 5.1.3. Color

Thirty three drivers gave three ratings for color of all the manufacturer's LED modules and the sample statistics are presented in Table 5.3. T – tests were performed to find out if the average ratings were statistically different from 3.00. A rating of 3 indicates that the LED module has the same color as the incandescent lens and a higher rating indicates

that LED module is darker than incandescent. The results are shown in Table 5.3. The p – values strongly indicate that Dialight is statistically the same as incandescent lens while all the others are darker than incandescent lens.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 33 | 3.35 | 0.52 | 3.91 | 2.267E-04 | Reject | Darker than Inc |
| GELCORE | 33 | 3.37 | 0.45 | 4.73 | 2.205E-05 | Reject | Darker than Inc |
| DIALIGHT | 33 | 2.98 | 0.53 | -0.22 | 4.141E-01 | Don't Reject | Stat same |
| PRESOLAR | 33 | 3.33 | 0.41 | 4.68 | 2.496E-05 | Reject | Darker than Inc |

Table 5.3.Results of t-tests for color of Circular Red

The results of the six paired t-tests are shown in Table B.7 in Appendix B. The results indicate that the Leotek, Gelcore and Precision Solar are statistically same in color and all of them are darker than Dialight. However, it should be noted that Gelcore and Precision Solar would not be statistically the same if the confidence level were lowered to 85%.

Statistically no difference was found between the ratings of drivers with glasses and without glasses (results shown in Table B.8 in Appendix B) for Leotek, Gelcore and Precision Solar. But for Dialight the two groups' ratings were different . Also it should be noted that on the average drivers with glasses said Dialight is paler than incandescent while the drivers without glasses said that it is darker than incandescent. The ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that they were statistically the same as incandescent, but the associated confidence levels are very close to the confidence level of 90%.

The ratings of the two age groups were compared (results shown in Table B.9 in Appendix B) and it was found that for Dialight and Precision Solar they are statistically same. However, for Leotek and Gelcore they were different. In both the cases, the older group gave a higher rating than the younger group indicating that older group found them

darker than the younger. The Leotek and Gelcore ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that all the groups found it to be statistically darker than incandescent. It should also be noted that for Leotek the two groups were found to have statistically different variances. Consequently for Leotek Welch's t – test was used.

## *5.2. Circular Yellow*

### 5.2.1. Brightness

Twenty three drivers gave three ratings for brightness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.4. T – tests were performed to find out if the average ratings were statistically different from 3.00. The results shown in Table 5.4 indicate that Precision Solar is statistically same as incandescent lens in brightness while all the others are brighter than incandescent lens. However, it should be noted that Precision Solar would not be same as incandescent lens if the confidence level were lowered to 87%.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 23 | 3.81 | 0.65 | 5.99 | 2.505E-06 | Reject | Brighter than Inc |
| GELCORE | 23 | 3.43 | 0.62 | 3.35 | 1.460E-03 | Reject | Brighter than Inc |
| DIALIGHT | 23 | 3.26 | 0.47 | 2.66 | 7.207E-03 | Reject | Brighter than Inc |
| PRESOLAR | 23 | 3.16 | 0.64 | 1.19 | 1.234E-01 | Don't Reject | Stat. Same |

Table 5.4.Results of t-tests for brightness of Circular Yellow.

The results of the paired t-tests are shown in Table B.10 in Appendix B. The results indicate that Leotek is brighter than Gelcore, which is brighter than Dialight which is statistically same as Precision Solar. But, it should be noted that Dialight and Precision Solar would not be statistically same if the confidence level were 89%.

The ratings of the drivers with glasses were compared with the ratings of the drivers without glasses (results shown in Table B.11 in Appendix B) and the results indicate that for all the four brands the two ratings were statistically the same. It should be noted that for Gelcore the ratings would be different if the confidence level were lowered to 85%.

The ratings of the two age groups were compared (results shown in Table B.12 in Appendix B) and the results indicate that they are statistically the same for all the four brands. It should be noted that these results hold even if the confidence level of the test were lowered to as low as 30%.

### 5.2.2. Dottiness

Twenty six drivers gave three ratings for dottiness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.5. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.5) strongly indicate that all the LED modules are dottier than incandescent lens. Of the four brands, statistically Dialight is the least dottiest.

The results of the six paired t-tests are shown in Table B.13 in Appendix B. The results indicate that Gelcore is dottier than Precision Solar which is dottier than Dialight which is statistically the same as Leotek.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 26 | 3.43 | 0.56 | 3.94 | 2.918E-04 | Reject | More Dottier |
| GELCORE | 26 | 4.06 | 0.47 | 11.50 | 8.887E-12 | Reject | More Dottier |
| DIALIGHT | 26 | 3.36 | 0.49 | 3.73 | 4.898E-04 | Reject | More Dottier |
| PRESOLAR | 26 | 3.71 | 0.49 | 7.29 | 6.163E-08 | Reject | More Dottier |

Table 5.5.Results of t-tests for dottiness of Circular Yellow.

The ratings of drivers with and without glasses were compared (results shown in Table B.14 in Appendix B) and the results indicate that statistically there is no difference between the ratings of the two groups for any of the four brands.

The ratings of the two age groups were compared (results shown in Table B.15 in Appendix B) and the results indicate that for Leotek, Gelcore and Dialight the two ratings are same. But for Precision Solar they are different statistically. Both age groups indicated that Precision Solar is (statistically) dottier than incandescent lens. Of the two groups, the older group found Precision Solar to be more dottier than the younger group.

### 5.2.3. Color

Twenty nine drivers gave three ratings for color of all the manufacturer's LED modules and the sample statistics are presented in Table 5.6. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.6) strongly indicate that all the LED modules are darker than incandescent lens.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 29 | 3.30 | 0.59 | 2.71 | 5.680E-03 | Reject | Darker than Inc |
| GELCORE | 29 | 3.34 | 0.51 | 3.61 | 5.943E-04 | Reject | Darker than Inc |
| DIALIGHT | 29 | 3.43 | 0.54 | 4.24 | 1.104E-04 | Reject | Darker than Inc |
| PRESOLAR | 29 | 3.41 | 0.62 | 3.59 | 6.257E-04 | Reject | Darker than Inc |

Table 5.6.Results of t-tests for color of Circular Yellow.

The results of the six paired t-tests are shown in Table B.16 in Appendix B. The results indicate that, Dialight is statistically same as Precision Solar but is darker than others and Precision Solar is statistically same as Gelcore but darker than Leotek and Gelcore and Leotek are statistically same. However it should be noted that the confidence

levels associated with some of these tests are close to 90% and therefore these indications should be accepted with caution.

The comparison (results shown in Table B.17 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands and this conclusion holds even if the confidence level were lowered to 50%.

When the ratings of the two age groups were compared statistically (results shown in Table B.18 in Appendix B) the results indicate that for Gelcore and Dialight the two ratings are same while for Leotek and Precision Solar they are different. The Leotek and Precision Solar ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that all the groups found it to be statistically darker than incandescent.

## *5.3. Circular Green*

### 5.3.1. Brightness

Thirty one drivers gave three ratings for brightness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.7. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.7) strongly indicate that all the LED modules are brighter than incandescent lens.

| Manufacturer | N | Mean | Std. Deviation | T | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 31 | 3.53 | 0.56 | 5.27 | 5.379E-06 | Reject | Brighter than Inc |
| GELCORE | 31 | 4.01 | 0.58 | 9.70 | 4.679E-11 | Reject | Brighter than Inc |
| DIALIGHT | 31 | 3.38 | 0.54 | 3.91 | 2.434E-04 | Reject | Brighter than Inc |
| PRESOLAR | 31 | 4.29 | 0.61 | 11.72 | 5.039E-13 | Reject | Brighter than Inc |

Table 5.7.Results of t-tests for brightness of Circular Green.

The results of the paired t-tests are shown in Table B.19 in Appendix B. The results strongly indicate that the decreasing order of brightness is Precision Solar, Gelcore, Leotek and Dialight.

The comparison (results shown in Table B.20 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands. Except for Gelcore this conclusion holds even if the confidence level were lowered to 50%.

When the ratings of the two age groups were compared statistically (results shown in Table B.21 in Appendix B) the results indicate that the two ratings are statistically same for all the four brands. However, it should be noted that for Dialight the ratings would be different if the confidence level were lowered to 86%. Also for Leotek the variances were found to be statistically different and therefore Welch's t – test was used. Although statistically not significant, we can observe that, younger drivers found all the LED modules to be brighter than older drivers.

### 5.3.2. Dottiness

Thirty one drivers gave three ratings for dottiness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.8. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.8) indicate that all the LED modules are dottier than incandescent lens.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 31 | 4.07 | 0.41 | 14.49 | 2.276E-15 | Reject | More Dottier |
| GELCORE | 31 | 4.12 | 0.60 | 10.39 | 9.348E-12 | Reject | More Dottier |
| DIALIGHT | 31 | 3.95 | 0.87 | 6.03 | 6.480E-07 | Reject | More Dottier |
| PRESOLAR | 31 | 3.17 | 0.45 | 2.10 | 2.211E-02 | Reject | More Dottier |

Table 5.8.Results of t-tests for dottiness of Circular Green.

The results of the six paired t-tests are shown in Table B.22 in Appendix B. The results indicate that Gelcore, Dialight and Leotek are statistically same and are dottier than Precision Solar. It should be noted that the confidence level of the tests comparing Precision Solar with other LED modules is very close to 100% which strongly indicates that Precision Solar is the least dottier of the four brands.

The comparison (results shown in Table B.23 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands.

The ratings of the two age groups were compared (results shown in Table B.24 in Appendix B) and the results indicate that the two ratings are statistically same for all the four brands. However, it should be noted that for Dialight, the variances of the two groups were found to be statistically different and therefore Welch's t – test was used.

### 5.3.3. Color

Twenty nine drivers gave three ratings for color of all the manufacturer's LED modules and the sample statistics are presented in Table 5.9. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.9) strongly indicate that all LED modules are darker than incandescent lens. Of the four brands, statistically Precision Solar was found to be least darker than incandescent lens.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 29 | 3.55 | 0.65 | 4.57 | 4.501E-05 | Reject | Darker than Inc |
| GELCORE | 29 | 3.44 | 0.43 | 5.56 | 2.983E-06 | Reject | Darker than Inc |
| DIALIGHT | 29 | 3.52 | 0.52 | 5.39 | 4.819E-06 | Reject | Darker than Inc |
| PRESOLAR | 29 | 3.37 | 0.55 | 3.59 | 6.201E-04 | Reject | Darker than Inc |

Table 5.9.Results of t-tests for color of Circular Green.

The results of the six paired t-tests are shown in Table B.25 in Appendix B. The results indicate that, Leotek is statistically same as Gelcore and Dialight but darker than Precision Solar and Dialight is darker than Precision Solar and Gelcore which are statistically same. However it should be noted that the confidence levels associated with all the tests, except for Leotek and Dialight are very close to 90% and therefore these indications should be accepted with caution.

The comparison (results shown in Table B.26 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands and these conclusions hold even if the confidence level of the test were lowered to 30%.

When the ratings of the two age groups were statistically compared (results shown in Table B.27 in Appendix B) the results indicate that except for Precision Solar the two ratings are statistically same for all the brands. The Precision Solar ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that both the groups found it to be statistically darker than incandescent. Although statistically not significant, for the other three brands arithmetically, the older group found the LED modules to be darker than the younger group.

## *5.4. Yellow Left Arrow*

### 5.4.1. Brightness

Twenty eight drivers gave ratings for brightness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.10. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.10) indicate that Leotek and Dialight are statistically same as incandescent and Gelcore and Precision Solar are brighter than incandescent lens. However it should be noted that the Gelcore would also be same as incandescent if the confidence level were raised to 96%.

The results of the paired t-tests are shown in Table B.28 in Appendix B. The results indicate that Gelcore, Leotek and Dialight are statistically the same and all are

dimmer than Precision Solar. It should be noted that the confidence level for the comparison between Leotek and Gelcore is very close to the 90%.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 28 | 3.04 | 1.00 | 0.19 | 4.257E-01 | Don't Reject | Stat same as Inc |
| GELCORE | 28 | 3.29 | 0.85 | 1.77 | 4.407E-02 | Reject | Brighter than Inc |
| DIALIGHT | 28 | 3.11 | 1.31 | 0.43 | 3.349E-01 | Don't Reject | Stat same as Inc |
| PRESOLAR | 28 | 3.61 | 0.83 | 3.86 | 3.179E-04 | Reject | Brighter than Inc |

Table 5.10. Results of t-tests for brightness of Yellow Left Arrow.

The ratings of the drivers with glasses were compared with the ratings of the drivers without glasses (results shown in Table B.29 in Appendix B) and the results indicate that for Dialight the two ratings are statistically different while for the others they are statistically the same. It should also be noted that drivers with glasses gave a rating below 3.00 indicating that it is dimmer than incandescent while the drivers without glasses gave a rating greater than 3.00 indicating that it is brighter than incandescent. The ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that the group without glasses found it be statistically brighter than incandescent while the rating of the group with glasses is statistically same as the incandescent lens.

When the ratings of the two age groups were statistically compared (results shown in Table B.30 in Appendix B) the results indicate that the two ratings are statistically same for all the brands. However for Precision Solar the ratings would be different if the confidence level were lowered to 88%.

### 5.4.2. Dottiness

Thirty two drivers gave ratings for dottiness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.11. T-tests were performed to find out if the

average ratings were statistically different from 3.00. The results (shown in Table 5.11) indicate that all the LED modules are dottier than incandescent lens. It should be noted that these conclusions hold even if the confidence level were raised to 99.9%, which strongly indicates that all of them are dottier than incandescent.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 32 | 3.72 | 0.73 | 5.58 | 2.098E-06 | Reject | More Dottier |
| GELCORE | 32 | 3.66 | 0.87 | 4.29 | 8.113E-05 | Reject | More Dottier |
| DIALIGHT | 32 | 3.84 | 0.68 | 7.05 | 1.236E-08 | Reject | More Dottier |
| PRESOLAR | 32 | 3.56 | 0.80 | 3.97 | 1.962E-04 | Reject | More Dottier |

Table 5.11.Results of t-tests for dottiness of Yellow Left Arrow.

The results of the six paired t-tests are shown in Table B.31 in Appendix B. The results indicate that Dialight is dottier than Precision Solar and all the other pairs are statistically same. These conclusions should be accepted with caution because, if the confidence level of the tests were lowered to 85% the conclusions would be significantly different.

The comparison (results shown in Table B.32 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands.

When the ratings of the two age groups were statistically compared (results shown in Table B.33 in Appendix B) the results indicate that the two ratings are statistically same for all the brands except Leotek. Although statistically not significant, for the other three manufacturers also, the older group found the LED modules to be darker than the younger group.

### 5.4.3. Color

Twenty five drivers gave ratings for color of all the manufacturer's LED modules and the sample statistics are presented in Table 5.12. T-tests were performed to find out if the

average ratings were statistically different from 3.00. The results (shown in Table 5.12) indicate that all the four brands are darker than incandescent lens. These conclusions should be accepted with caution because, if the confidence level of the tests were raised to 95% the conclusions would be significantly different.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 25 | 3.24 | 0.83 | 1.44 | 8.075E-02 | Reject | Darker than Inc |
| GELCORE | 25 | 3.24 | 0.78 | 1.54 | 6.824E-02 | Reject | Darker than Inc |
| DIALIGHT | 25 | 3.28 | 0.89 | 1.57 | 6.454E-02 | Reject | Darker than Inc |
| PRESOLAR | 25 | 3.28 | 0.61 | 2.28 | 1.585E-02 | Reject | Darker than Inc |

Table 5.12.Results of t-tests for color of Yellow Left Arrow.

The results of the six paired t-tests are shown in Table B.34 in Appendix B. The results indicate that all the pairs are statistically same and these conclusions hold even if the confidence level of the tests were lowered to 60%.

The comparison (results shown in Table B.35 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands and these conclusions hold even if the confidence level of the tests were lowered to 60%.

When the ratings of the two age groups were statistically compared (results shown in Table B.36 in Appendix B) the results indicate that the two ratings are statistically same for all the brands.

## *5.5. Green Left Arrow*

### 5.5.1. Brightness

Twenty seven drivers gave ratings for brightness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.13. T-tests were performed to find out if

the average ratings were statistically different from 3.00. The results (shown in Table 5.13) indicate that Leotek is statistically same as incandescent and Dialight, Gelcore and Precision Solar are brighter than incandescent lens. It should be noted that Leotek would be brighter than incandescent if the confidence level were lowered to 85%, while all the other brands would remain brighter even if the confidence level were raised to 99.9%.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 27 | 3.19 | 0.88 | 1.10 | 1.418E-01 | Don't Reject | Stat same as Inc |
| GELCORE | 27 | 4.15 | 0.72 | 8.31 | 4.324E-09 | Reject | Brighter than Inc |
| DIALIGHT | 27 | 3.89 | 0.80 | 5.77 | 2.239E-06 | Reject | Brighter than Inc |
| PRESOLAR | 27 | 3.63 | 0.69 | 4.76 | 3.188E-05 | Reject | Brighter than Inc |

Table 5.13.Results of t-tests for brightness of Green Left Arrow.

The results of the paired t-tests are shown in Table B.37 in Appendix B. The results indicate that the decreasing order of brightness is Gelcore, Dialight, Precision Solar and Leotek. However it should be noted that Dialight would be same as Gelcore and Precision Solar if the confidence level were raised to 94%. Therefore these indications should be accepted cautiously.

The ratings of the drivers with glasses were compared with the ratings of the drivers without glasses (results shown in Table B.38 in Appendix B) and the results indicate that for Dialight the two ratings are statistically different while for the others they are statistically same. Drivers with glasses gave a lesser rating than the drivers without glasses. The ratings of the two Dialight groups were individually compared with 3.00 (incandescent rating) and it was found that both the groups found it to be statistically brighter than incandescent. It should also be noted that for the other three brands, the two ratings remain equal even if the confidence level were lowered to 40% which strongly indicates that the ratings of the two groups are equal for these three brands.

When the ratings of the two age groups were statistically compared (results shown in Table B.39 in Appendix B) the results indicate that except for Gelcore, the two ratings are statistically same for all the brands. The Gelcore ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that both the groups found it to be statistically brighter than incandescent.

### 5.5.2. Dottiness

Twenty seven drivers gave ratings for dottiness of all the manufacturer's LED modules and the sample statistics are presented in Table 5.14. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.14) indicate that all the LED modules are more dottier than incandescent lens. Of all the brands Precision Solar is statistically least dottier than incandescent. The confidence level for all the tests is very close to 100% which strongly indicates that they are all dottier than incandescent.

The results of the six paired t-tests are shown in Table B.40 in Appendix B. The results indicate that all the pairs are statistically same and these conclusions hold even if the confidence level were lowered to 70%.

The comparison (results shown in Table B.41 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands. However for Gelcore the two ratings would be different if the confidence level were lowered to 85%.

When the ratings of the two age groups were statistically compared (results shown in Table B.42 in Appendix B) the results indicate that the two ratings are statistically same for all the brands.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inferenc e | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 27 | 3.59 | 0.69 | 4.44 | 7.415E-05 | Reject | More Dottier |
| GELCORE | 27 | 3.63 | 0.69 | 4.76 | 3.188E-05 | Reject | More Dottier |
| DIALIGHT | 27 | 3.67 | 0.73 | 4.72 | 3.512E-05 | Reject | More Dottier |
| PRESOLAR | 27 | 3.59 | 0.84 | 3.65 | 5.804E-04 | Reject | More Dottier |

Table 5.14.Results of t-tests for dottiness of Green Left Arrow.

### 5.5.3. Color

Thirty one drivers gave ratings for color of all the manufacturer's LED modules and the sample statistics are presented in Table 5.15. T-tests were performed to find out if the average ratings were statistically different from 3.00. The results (shown in Table 5.15) indicate that all the LED modules are darker than incandescent lens. Of all the brands Gelcore is statistically least darker than incandescent. It should be noted that these conclusions hold even if the confidence level were raised to 99.9%, which strongly indicates that all of them are darker than incandescent.

| Manufacturer | N | Mean | Std. Deviation | t | Sig. (1-tailed) | Inference | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 31 | 3.55 | 0.62 | 4.89 | 1.572E-05 | Reject | Darker than Inc |
| GELCORE | 31 | 3.42 | 0.62 | 3.76 | 3.644E-04 | Reject | Darker than Inc |
| DIALIGHT | 31 | 3.52 | 0.57 | 5.04 | 1.032E-05 | Reject | Darker than Inc |
| PRESOLAR | 31 | 3.35 | 0.49 | 4.06 | 1.610E-04 | Reject | Darker than Inc |

Table 5.15.Results of t-tests for color of Green Left Arrow.

The results of the six paired t-tests are shown in Table B.43 in Appendix B. The results indicate that all the pairs are statistically same except that Leotek and Dialight are darker than Precision Solar.

The comparison (results shown in Table B.44 in Appendix B) of the ratings of the drivers with glasses and without glasses indicates that the two ratings are statistically same for all the four brands and these conclusions would hold even if the confidence level were lowered to 60%.

When the ratings of the two age groups were statistically compared (results shown in Table B.45 in Appendix B) the results indicate that except for Precision Solar, the two ratings are statistically same for all the brands. The Precision Solar ratings of the two groups were individually compared with 3.00 (incandescent rating) and it was found that both the groups found it to be statistically darker than incandescent. Although statistically not significant, for the other three manufacturers also, the older group found the LED modules to be darker than the younger group.

# 6. CONCLUSIONS AND RECOMMENDATIONS

The conclusions for each individual lens type are presented in the following five subsections.

## *6.1. Circular Red*

It was found that the brightness of Dialight is statistically the same as incandescent lens, but the other three are brighter than incandescent lens. The decreasing order of brightness is Gelcore, Precision Solar, Leotek and Dialight. Results indicate that Dialight is less dottier than an incandescent lens with all others are more dottier than incandescent lens. The decreasing order of dottiness is Gelcore, Leotek, Precision Solar and Dialight. The older group found Gelcore to be more dottier than the younger group. The results indicate that Dialight is statistically same as incandescent lens while all others are darker than incandescent lens. Also Leotek, Gelcore and Precision Solar are statistically the same in color and all are darker (purplish) than Dialight. For Leotek and Gelcore, the older group found them to be statistically darker than the younger group. The results indicate that the performance of the Dialight circular red lens is closest to that of the incandescent lens.

## *6.2. Circular Yellow*

Precision Solar is statistically the same as incandescent lens in brightness while the others are brighter than incandescent lens. The decreasing order of brightness is Leotek, Gelcore, Dialight and Precision Solar, with Dialight being statistically the same as Precision Solar. All the lenses were found to be dottier than incandescent lens and the decreasing order of dottiness is Gelcore, Precision Solar, Leotek and Dialight, with Dialight being statistically same as Leotek. The older group found Precision Solar to be more dottier than the younger group. All the LED modules were found to be darker (orange-yellow) in color than incandescent lens.

### *6.3. Circular Green*

It was found that that all the LED modules were brighter than incandescent lens and the decreasing order of brightness was Precision Solar, Gelcore, Leotek and Dialight. All the LED modules were found to be dottier than incandescent lens and Gelcore, Dialight and Leotek were found to be statistically same and dottier than Precision Solar. All the LED modules were found to be darker (bluish) than incandescent lens. For all the four brands the older group found the LED modules to be darker than the younger group, but the difference was statistically significant only for Precision Solar.

### *6.4. Yellow Left Arrow*

It was found that Leotek and Dialight are statistically the same while Gelcore and Precision Solar are brighter than incandescent lens. Gelcore, Leotek and Dialight are statistically the same and all three are dimmer than Precision Solar. For Dialight, the group without glasses found it brighter than incandescent while the group with glasses found it the same as incandescent lens. All the LED modules are dottier than incandescent lens. Dialight is dottier than Precision Solar while all other pairs are statistically same. All four brands are darker than incandescent lens and all the LED pairs are statistically the same.

### *6.5. Green Left Arrow*

Leotek was found to be statistically the same as incandescent while Dialight, Gelcore and Precision Solar were brighter than incandescent lens. The decreasing order of brightness is Gelcore, Dialight, Precision Solar and Leotek. All the LED modules were dottier than incandescent and all the pairs were statistically the same. All the LED modules were darker than incandescent lens and all the pairs were statistically the same except for Leotek and Dialight which are darker than Precision Solar.

### *6.6. Effect of Age*

This study was not designed to examine the effect of age on the ratings of the LED modules, nevertheless the observers were classified into two age groups viz., below 50 and above 50 years to evaluate the effect of age. Although the study involved a small sample and not so distinct grouping of the drivers, the findings indicate that there could be a significant difference in the perception of the LED modules by the older population when compared with the younger population. Given the fact that the percentage of older drivers in America is increasing, it is strongly recommended that a study dedicated to the effect of age on the evaluation of the LED modules be performed.

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# Appendix A

There are 4 Viewing Stations and 4 LED frames. Please view one frame at a time. Your responses will be kept confidential and your opinions about the LED lights are important to us.
THANK YOU FOR YOUR COOPERATION

- Circle the Station number you are at? 1 2 3 4
- Circle the frame number you are viewing? A B C D
- Are you required to wear glasses or contact lens when driving? a. No b. Yes (please wear them now)

HOW BRIGHT ARE THE LED LIGHTS COMPARED TO NEW INCANDESCENT TRAFFIC LIGHTS?

| | Much brighter | Brighter | About the same | Dimmer | Much dimmer | No opinion |
|---|---|---|---|---|---|---|
| • RED light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • RED light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • RED light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN ARROW | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW ARROW | 5 | 4 | 3 | 2 | 1 | 0 |

COMPARED TO NEW INCANDESCENT TRAFFIC LIGHTS, DO THE LED LIGHTS APPEAR SOLID VERSUS A SERIES OF DOTS (DOTTY)?

| | Much more dotty | More dotty | About the same | Less dotty | Much less dotty | No opinion |
|---|---|---|---|---|---|---|
| • RED light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • RED light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • RED light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN ARROW | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW ARROW | 5 | 4 | 3 | 2 | 1 | 0 |

HOW SIMILAR OR DIFFERENT ARE THE COLORS OF LED LIGHTS COMPARED TO NEW INCANDESCENT TRAFFIC LIGHTS?

| | Very dark (purplish) | Somewhat dark | About the same | Somewhat pale | Very pale (orangey) | No opinion |
|---|---|---|---|---|---|---|
| • RED light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • RED light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • RED light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |

| | Very dark (orangey yellow) | Somewhat dark | About the same | Somewhat pale | Very pale (whitish) | No opinion |
|---|---|---|---|---|---|---|
| • YELLOW light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • YELLOW ARROW | 5 | 4 | 3 | 2 | 1 | 0 |

| | Very dark (bluish) | Somewhat dark | About the same | Somewhat pale | Very pale (yellowish) | No opinion |
|---|---|---|---|---|---|---|
| • GREEN light on the LEFT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the MIDDLE signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN light on the RIGHT signal head | 5 | 4 | 3 | 2 | 1 | 0 |
| • GREEN ARROW | 5 | 4 | 3 | 2 | 1 | 0 |

- What age group do you belong to: a) <25 b) 25-40 c) 40-50 d) 50-60 e) >60

- Do you have difficulty in distinguishing shades of colors a) No b) Yes (If yes, what colors?_____)

- Do you have any comments, concerns, and suggestion about any of the LED lights?

_____
_____
_____
_____

THANK YOU FOR YOUR PARTICIPATION

## Appendix B

One of the objectives was to identify those LED modules that are statistically not different in terms of brightness, dottiness and color. For this purpose, paired t – tests were performed to compare the performance of the six possible pairs of the LEDs lenses. The observers' ratings were segregated according to the age group and tests were performed to check if there was any difference in the ratings given by the two age groups. Also the ratings of the observers with and without glasses were compared. For each lens (Circular Red, Circular Yellow, Circular Green, Yellow Left Arrow, Green Left Arrow) and each aspect (Brightness, Dottiness, Color) the results of the above mentioned three statistical tests are shown in the Tables in this Appendix. Note that in the tables Precision Solar is referred to as PreSolar.

***CIRCULAR RED***

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | -0.4040 | 0.4696 | 0.0817 | -4.9424 | 32 | 1.19E-05 | Reject | Gelcore brighter than Leotek |
| Pair 2 | LEOTEK – DIALIGHT | 0.8283 | 0.8085 | 0.1407 | 5.8854 | 32 | 7.47E-07 | Reject | Leotek brighter than Dialight |
| Pair 3 | LEOTEK - PRESOLAR | -0.2626 | 0.6278 | 0.1093 | -2.4031 | 32 | 1.11E-02 | Reject | PreSolar brighter than Leotek |
| Pair 4 | GELCORE - DIALIGHT | 1.2323 | 0.6692 | 0.1165 | 10.5787 | 32 | 1.24E-16 | Reject | Gelcore brighter than Dialight |
| Pair 5 | GELCORE - PRESOLAR | 0.1414 | 0.5002 | 0.0871 | 1.6240 | 32 | 5.71E-02 | Reject | Gelcore brighter than PreSolar |
| Pair 6 | DIALIGHT - PRESOLAR | -1.0909 | 0.7695 | 0.1340 | -8.1437 | 32 | 4.41E-11 | Reject | PreSolar brighter than Dialight |

Table B.1. Results of Paired t- tests for Brightness of Circular Red.

**CIRCULAR RED**

| Manufacturer | GLASSES | N | Mean | Mean Difference | T | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 21 | 3.7148 | -0.2192 | -0.9032 | 0.3739 | Stat. same |
| | No | 10 | 3.9340 | | | | |
| GELCORE | Yes | 21 | 4.1910 | -0.0090 | -0.0427 | 0.9662 | Stat. same |
| | No | 10 | 4.2000 | | | | |
| DIALIGHT | Yes | 21 | 3.0005 | 0.1005 | 0.3318 | 0.7424 | Stat. same |
| | No | 10 | 2.9000 | | | | |
| PRESOLAR | Yes | 21 | 4.0005 | -0.0335 | -0.1418 | 0.8882 | Stat. same |
| | No | 10 | 4.0340 | | | | |

Table B.2. Results of t – tests checking for the effect of Glasses on Brightness of Circular Red.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | T | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 23 | 3.6674 | -0.2656 | -0.9603 | 0.3547 | Stat. same |
| | 2 | 10 | 3.9330 | | | | |
| GELCORE | 1 | 23 | 4.0583 | -0.3087 | -1.4676 | 0.1523 | Stat. same |
| | 2 | 10 | 4.3670 | | | | |
| DIALIGHT | 1 | 23 | 2.9713 | 0.1703 | 0.5657 | 0.5756 | Stat same |
| | 2 | 10 | 2.8010 | | | | |
| PRESOLAR | 1 | 23 | 3.9574 | -0.1756 | -0.7864 | 0.4376 | Stat same |
| | 2 | 10 | 4.1330 | | | | |

Table B.3. Results of t – tests checking for the effect of Age on Brightness of Circular Red.

**CIRCULAR RED**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK - GELCORE | -0.5212 | 0.5069 | 0.0869 | -5.9954 | 33 | 4.705E-07 | Reject | Gelcore dottier than Leotek |
| Pair 2 | LEOTEK - DIALIGHT | 1.1359 | 0.6918 | 0.1186 | 9.5735 | 33 | 2.934E-15 | Reject | Leotek dottier than Dialight |
| Pair 3 | LEOTEK - PRESOLAR | 0.3312 | 0.5244 | 0.0899 | 3.6822 | 33 | 4.105E-04 | Reject | Leotek dottier than PreSolar |
| Pair 4 | GELCORE - DIALIGHT | 1.6571 | 0.8150 | 0.1398 | 11.8555 | 33 | 1.067E-16 | Reject | Gelcore dottier than Dialight |
| Pair 5 | GELCORE - PRESOLAR | 0.8524 | 0.6368 | 0.1092 | 7.8049 | 33 | 2.458E-10 | Reject | Gelcore dottier than PreSolar |
| Pair 6 | DIALIGHT – PRESOLAR | -0.8047 | 0.4795 | 0.0822 | -9.7852 | 33 | 5.823E-16 | Reject | PreSolar dottier than Dialight |

Table B.4. Results of Paired t- tests for dottiness of Circular Red.

**CIRCULAR RED**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 21 | 3.9986 | 0.0904 | 0.4356 | 0.6662 | Stat same |
| | No | 11 | 3.9082 | | | | |
| GELCORE | Yes | 21 | 4.5714 | 0.1769 | 0.9480 | 0.3507 | Stat same |
| | No | 11 | 4.3945 | | | | |
| DIALIGHT | Yes | 21 | 2.8414 | -0.0377 | -0.1717 | 0.8648 | Stat same |
| | No | 11 | 2.8791 | | | | |
| PRESOLAR | Yes | 21 | 3.6038 | -0.1253 | -0.6972 | 0.4910 | Stat same |
| | No | 11 | 3.7291 | | | | |

Table B.5. Results of t – tests checking for the effect of Glasses on Dottiness of Circular Red.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 24 | 3.9571 | 0.0581 | 0.2785 | 0.7824 | Stat same |
| | 2 | 10 | 3.8990 | | | | |
| GELCORE | 1 | 24 | 4.3475 | -0.3865 | -2.0485 | 0.0488 | Different |
| | 2 | 10 | 4.7340 | | | | |
| DIALIGHT | 1 | 24 | 2.8058 | 0.0058 | 0.0246 | 0.9805 | Stat same |
| | 2 | 10 | 2.8000 | | | | |
| PRESOLAR | 1 | 24 | 3.5708 | -0.1292 | -0.6592 | 0.5145 | Stat same |
| | 2 | 10 | 3.7000 | | | | |

Table B.6. Results of t – tests checking for the effect of Age on Dottiness of Circular Red.

**CIRCULAR RED**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | -0.0203 | 0.2479 | 0.0432 | -0.4705 | 32 | 3.206E-01 | Don't Reject | Gelcore stat. same as Leotek |
| Pair 2 | LEOTEK – DIALIGHT | 0.3739 | 0.6763 | 0.1177 | 3.1762 | 32 | 1.648E-03 | Reject | Leotek darker than Dialight |
| Pair 3 | LEOTEK – PRESOLAR | 0.0206 | 0.3328 | 0.0579 | 0.3557 | 32 | 3.622E-01 | Don't Reject | PreSolar stat. same as Leotek |
| Pair 4 | GELCORE – DIALIGHT | 0.3942 | 0.6208 | 0.1081 | 3.6480 | 32 | 4.654E-04 | Reject | Gelcore darker than Dialight |
| Pair 5 | GELCORE – PRESOLAR | 0.0409 | 0.2167 | 0.0377 | 1.0845 | 32 | 1.431E-01 | Don't Reject | Gelcore stat. same as PreSolar |
| Pair 6 | DIALIGHT – PRESOLAR | -0.3533 | 0.5954 | 0.1036 | -3.4093 | 32 | 8.891E-04 | Reject | PreSolar darker than Dialight |

Table B.7. Results of Paired t- tests for Color of Circular Red.

**CIRCULAR RED**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 20 | 3.3505 | -0.0731 | -0.3632 | 0.7191 | Stat same |
| | No | 11 | 3.4236 | | | | |
| GELCORE | Yes | 20 | 3.3830 | -0.0425 | -0.2427 | 0.8100 | Stat same |
| | No | 11 | 3.4255 | | | | |
| DIALIGHT | Yes | 20 | 2.8500 | -0.3618 | -1.8157 | 0.0798 | Different |
| | No | 11 | 3.2118 | | | | |
| PRESOLAR | Yes | 20 | 3.2995 | -0.1550 | -1.0014 | 0.3249 | Stat same |
| | No | 11 | 3.4545 | | | | |

Table B.8. Results of t – tests checking for the effect of Glasses on Color of Circular Red.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 25 | 3.2268 | -0.5232 | -2.0572 | 0.0715 | Different |
| | 2 | 8 | 3.7500 | | | | |
| GELCORE | 1 | 25 | 3.2936 | -0.3314 | -1.8631 | 0.0720 | Different |
| | 2 | 8 | 3.6250 | | | | |
| DIALIGHT | 1 | 25 | 3.0000 | 0.0838 | 0.3814 | 0.7055 | Stat same |
| | 2 | 8 | 2.9163 | | | | |
| PRESOLAR | 1 | 25 | 3.2932 | -0.1643 | -0.9898 | 0.3299 | Stat same |
| | 2 | 8 | 3.4575 | | | | |

Table B.9. Results of t – tests checking for the effect of Age on Color of Circular Red.

***CIRCULAR YELLOW***

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK - GELCORE | 0.3768 | 0.5972 | 0.1245 | 3.0262 | 22 | 0.0031 | Reject | Leotek brighter than Gelcore |
| Pair 2 | LEOTEK - DIALIGHT | 0.5507 | 0.6245 | 0.1302 | 4.2293 | 22 | 0.0002 | Reject | Leotek brighter than Dialight |
| Pair 3 | LEOTEK - PRESOLAR | 0.6522 | 0.5901 | 0.1231 | 5.3000 | 22 | 0.0000 | Reject | Leotek brighter than PreSolar |
| Pair 4 | GELCORE - DIALIGHT | 0.1739 | 0.3463 | 0.0722 | 2.4088 | 22 | 0.0124 | Reject | Gelcore brighter than Dialight |
| Pair 5 | GELCORE - PRESOLAR | 0.2754 | 0.3713 | 0.0774 | 3.5562 | 22 | 0.0009 | Reject | Gelcore brighter than PreSolar |
| Pair 6 | DIALIGHT - PRESOLAR | 0.1014 | 0.3684 | 0.0768 | 1.3207 | 22 | 0.1001 | Don't Reject | Dialight and Presolar are Stat. same |

Table B.10. Results of Paired t- tests for Brightness of Circular Yellow.

**CIRCULAR YELLOW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | T | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 13 | 3.8723 | 0.0398 | 0.1304 | 0.8976 | Stat same |
| | No | 8 | 3.8325 | | | | |
| GELCORE | Yes | 13 | 3.3600 | -0.3888 | -1.5089 | 0.1478 | Stat same |
| | No | 8 | 3.7488 | | | | |
| DIALIGHT | Yes | 13 | 3.2315 | -0.1435 | -0.6627 | 0.5155 | Stat same |
| | No | 8 | 3.3750 | | | | |
| PRESOLAR | Yes | 13 | 3.1285 | -0.2053 | -0.7006 | 0.4377 | Stat same |
| | No | 8 | 3.3338 | | | | |

Table B.11. Results of t – tests checking for the effect of Glasses on Brightness of Circular Yellow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 15 | 3.7773 | -0.0977 | -0.3364 | 0.7399 | Stat same |
| | 2 | 8 | 3.8750 | | | | |
| GELCORE | 1 | 15 | 3.4000 | -0.1000 | -0.3598 | 0.7226 | Stat same |
| | 2 | 8 | 3.5000 | | | | |
| DIALIGHT | 1 | 15 | 3.2453 | -0.0459 | -0.2178 | 0.8297 | Stat same |
| | 2 | 8 | 3.2913 | | | | |
| PRESOLAR | 1 | 15 | 3.2007 | 0.1182 | 0.4129 | 0.7311 | Stat same |
| | 2 | 8 | 3.0825 | | | | |

Table B.12. Results of t – tests checking for the effect of Age on Brightness of Circular Yellow.

**CIRCULAR YELLOW**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | -0.6338 | 0.6490 | 0.1273 | -4.9799 | 25 | 1.963E-05 | Reject | Gelcore dottier than Leotek |
| Pair 2 | LEOTEK – DIALIGHT | 0.0723 | 0.4266 | 0.0837 | 0.8642 | 25 | 1.978E-01 | Don't Reject | Leotek and Dialight are stat. same |
| Pair 3 | LEOTEK – PRESOLAR | -0.275 | 0.6125 | 0.1201 | -2.2893 | 25 | 1.539E-02 | Reject | PreSolar dottier than Leotek |
| Pair 4 | GELCORE – DIALIGHT | 0.7062 | 0.5978 | 0.1172 | 6.0235 | 25 | 1.360E-06 | Reject | Gelcore dottier than Dialight |
| Pair 5 | GELCORE – PRESOLAR | 0.3588 | 0.5320 | 0.1043 | 3.4397 | 25 | 1.027E-03 | Reject | Gelcore dottier than PreSolar |
| Pair 6 | DIALIGHT – PRESOLAR | -0.3473 | 0.6074 | 0.1191 | -2.9155 | 25 | 3.695E-03 | Reject | PreSolar dottier than Dialight |

Table B.13. Results of Paired t- tests for Dottiness of Circular Yellow.

**CIRCULAR YELLOW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 16 | 3.4175 | -0.1038 | -0.4228 | 0.6766 | Stat same |
| | No | 8 | 3.5213 | | | | |
| GELCORE | Yes | 16 | 4.1038 | -0.0225 | -0.1111 | 0.9126 | Stat same |
| | No | 8 | 4.1263 | | | | |
| DIALIGHT | Yes | 16 | 3.3531 | -0.0206 | -0.0990 | 0.9220 | Stat same |
| | No | 8 | 3.3738 | | | | |
| PRESOLAR | Yes | 16 | 3.7500 | -0.0425 | -0.2657 | 0.7930 | Stat same |
| | No | 8 | 3.7925 | | | | |

Table B.14. Results of t – tests checking for the effect of Glasses on Dottiness of Circular Yellow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 17 | 3.4224 | -0.0232 | -0.0989 | 0.9220 | Stat same |
| | 2 | 9 | 3.4456 | | | | |
| GELCORE | 1 | 17 | 4.0000 | -0.1856 | -0.9522 | 0.3505 | Stat same |
| | 2 | 9 | 4.1856 | | | | |
| DIALIGHT | 1 | 17 | 3.3518 | -0.0182 | -0.0886 | 0.9301 | Stat same |
| | 2 | 9 | 3.3700 | | | | |
| PRESOLAR | 1 | 17 | 3.5688 | -0.3945 | -2.0611 | 0.0307 | Different |
| | 2 | 9 | 3.9633 | | | | |

Table B.15. Results of t – tests checking for the effect of Age on Dottiness of Circular Yellow.

**CIRCULAR YELLOW**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | -0.0459 | 0.3859 | 0.0717 | -0.6399 | 28 | 2.637E-01 | Don't Reject | Gelcore stat. same as Leotek |
| Pair 2 | LEOTEK – DIALIGHT | -0.1269 | 0.3929 | 0.0730 | -1.7393 | 28 | 4.648E-02 | Reject | Dialight darker than Leotek |
| Pair 3 | LEOTEK – PRESOLAR | -0.1148 | 0.4016 | 0.0746 | -1.5398 | 28 | 6.742E-02 | Reject | PreSolar darker than Leotek |
| Pair 4 | GELCORE – DIALIGHT | -0.0810 | 0.3295 | 0.0612 | -1.3242 | 28 | 9.807E-02 | Reject | Dialight darker than Gelcore |
| Pair 5 | GELCORE – PRESOLAR | -0.0690 | 0.3711 | 0.0689 | -1.0008 | 28 | 1.627E-01 | Don't Reject | Gelcore stat. same as PreSolar |
| Pair 6 | DIALIGHT – PRESOLAR | 0.0121 | 0.3623 | 0.0673 | 0.1794 | 28 | 4.295E-01 | Don't Reject | PreSolar stat. same as Dialight |

Table B.16. Results of Paired t- tests for Color of Circular Yellow.

**CIRCULAR YELLOW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 18 | 3.2967 | 0.0307 | 0.1271 | 0.8999 | Stat same |
| | No | 10 | 3.2660 | | | | |
| GELCORE | Yes | 18 | 3.3328 | -0.0012 | -0.0058 | 0.9954 | Stat same |
| | No | 10 | 3.3340 | | | | |
| DIALIGHT | Yes | 18 | 3.4633 | 0.1293 | 0.5902 | 0.5602 | Stat same |
| | No | 10 | 3.3340 | | | | |
| PRESOLAR | Yes | 18 | 3.3889 | -0.0111 | -0.0445 | 0.9649 | Stat same |
| | No | 10 | 3.4000 | | | | |

Table B.17. Results of t – tests checking for the effect of Glasses on Color of Circular Yellow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 21 | 3.1743 | -0.4520 | -1.9163 | 0.0660 | Different |
| | 2 | 8 | 3.6263 | | | | |
| GELCORE | 1 | 21 | 3.2700 | -0.2713 | -1.2831 | 0.2104 | Stat same |
| | 2 | 8 | 3.5413 | | | | |
| DIALIGHT | 1 | 21 | 3.3343 | -0.3320 | -1.5102 | 0.1426 | Stat same |
| | 2 | 8 | 3.6663 | | | | |
| PRESOLAR | 1 | 21 | 3.2700 | -0.5213 | -2.1466 | 0.0603 | Different |
| | 2 | 8 | 3.7913 | | | | |

Table B.18. Results of t – tests checking for the effect of Age on Color of Circular Yellow.

***CIRCULAR GREEN***

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK - GELCORE | -0.4839 | 0.7396 | 0.1328 | -3.6428 | 30 | 0.0005 | Reject | Gelcore brighter than Leotek |
| Pair 2 | LEOTEK - DIALIGHT | 0.1505 | 0.5633 | 0.1012 | 1.4879 | 30 | 0.0736 | Reject | Leotek brighter than Dialight |
| Pair 3 | LEOTEK - PRESOLAR | -0.7634 | 0.7897 | 0.1418 | -5.3825 | 30 | 0.0000 | Reject | PreSolar brighter than Leotek |
| Pair 4 | GELCORE - DIALIGHT | 0.6344 | 0.5117 | 0.0919 | 6.9023 | 30 | 0.0000 | Reject | Gelcore brighter than Dialight |
| Pair 5 | GELCORE - PRESOLAR | -0.2796 | 0.6212 | 0.1116 | -2.5057 | 30 | 0.0089 | Reject | PreSolar brighter than Gelcore |
| Pair 6 | DIALIGHT - PRESOLAR | -0.9140 | 0.7199 | 0.1293 | -7.0686 | 30 | 0.0000 | Reject | PreSolar brighter than Dialight |

Table B.19. Results of Paired t- tests for Brightness of Circular Green.

**CIRCULAR GREEN**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 19 | 3.5268 | -0.1072 | -0.4846 | 0.6319 | Stat same |
| | No | 10 | 3.6340 | | | | |
| GELCORE | Yes | 19 | 3.9468 | -0.2862 | -1.3024 | 0.2038 | Stat same |
| | No | 10 | 4.2330 | | | | |
| DIALIGHT | Yes | 19 | 3.3858 | -0.1142 | -0.5569 | 0.5822 | Stat same |
| | No | 10 | 3.5000 | | | | |
| PRESOLAR | Yes | 19 | 4.3505 | 0.1175 | 0.4709 | 0.6415 | Stat same |
| | No | 10 | 4.2330 | | | | |

Table B.20. Results of t – tests checking for the effect of Glasses on Brightness of Circular Green.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 21 | 3.5395 | 0.0375 | 0.1386 | 0.8922 | Stat same |
| | 2 | 10 | 3.5020 | | | | |
| GELCORE | 1 | 21 | 4.0795 | 0.2145 | 0.9595 | 0.3453 | Stat same |
| | 2 | 10 | 3.8650 | | | | |
| DIALIGHT | 1 | 21 | 3.4762 | 0.3092 | 1.5374 | 0.1350 | Stat same |
| | 2 | 10 | 3.1670 | | | | |
| PRESOLAR | 1 | 21 | 4.3648 | 0.2318 | 0.9827 | 0.3339 | Stat same |
| | 2 | 10 | 4.1330 | | | | |

Table B.21. Results of t – tests checking for the effect of Age on Brightness of Circular Green.

**CIRCULAR GREEN**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK - GELCORE | -0.0484 | 0.6944 | 0.1247 | -0.3880 | 30 | 0.3504 | Don't Reject | Leotek and Gelcore are Stat. same |
| Pair 2 | LEOTEK - DIALIGHT | 0.1239 | 0.9028 | 0.1621 | 0.7639 | 30 | 0.2254 | Don't Reject | Leotek and Dialight are Stat. same |
| Pair 3 | LEOTEK - PRESOLAR | 0.8981 | 0.6150 | 0.1105 | 8.1302 | 30 | 0.0000 | Reject | Leotek dottier than PreSolar |
| Pair 4 | GELCORE - DIALIGHT | 0.1723 | 0.9493 | 0.1705 | 1.0103 | 30 | 0.1602 | Don't Reject | Gelcore and Dialight are Stat same |
| Pair 5 | GELCORE - PRESOLAR | 0.9465 | 0.6380 | 0.1146 | 8.2595 | 30 | 0.0000 | Reject | Gelcore dottier than PreSolar |
| Pair 6 | DIALIGHT – PRESOLAR | 0.7742 | 0.9030 | 0.1622 | 4.7736 | 30 | 0.0000 | Reject | Dialight dottier than PreSolar |

Table B.22. Results of Paired t- tests for Dottiness of Circular Green.

**CIRCULAR GREEN**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 19 | 4.0353 | -0.1137 | -0.6782 | 0.5034 | Stat same |
| | No | 10 | 4.1490 | | | | |
| GELCORE | Yes | 19 | 4.0526 | -0.2134 | -0.8781 | 0.3876 | Stat same |
| | No | 10 | 4.2660 | | | | |
| DIALIGHT | Yes | 19 | 4.1568 | 0.4568 | 1.3671 | 0.1829 | Stat same |
| | No | 10 | 3.7000 | | | | |
| PRESOLAR | Yes | 19 | 3.1753 | -0.0577 | -0.3293 | 0.7445 | Stat same |
| | No | 10 | 3.2330 | | | | |

Table B.23. Results of t – tests checking for the effect of Glasses on Dottiness of Circular Green.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 22 | 4.0377 | -0.1101 | -0.6703 | 0.5079 | Stat same |
| | 2 | 9 | 4.1478 | | | | |
| GELCORE | 1 | 22 | 4.0450 | -0.2517 | -1.0637 | 0.2962 | Stat same |
| | 2 | 9 | 4.2967 | | | | |
| DIALIGHT | 1 | 22 | 4.0450 | 0.3417 | 0.6872 | 0.5097 | Stat same |
| | 2 | 9 | 3.7033 | | | | |
| PRESOLAR | 1 | 22 | 3.1814 | 0.0336 | 0.1835 | 0.8557 | Stat same |
| | 2 | 9 | 3.1478 | | | | |

Table B.24. Results of t – tests checking for the effect of Age on Dottiness of Circular Green.

**CIRCULAR GREEN**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | 0.1100 | 0.5385 | 0.1000 | 1.1000 | 28 | 0.1404 | Don't Reject | Leotek and Gelcore are Stat. same |
| Pair 2 | LEOTEK – DIALIGHT | 0.0348 | 0.5444 | 0.1011 | 0.3445 | 28 | 0.3665 | Don't Reject | Leotek and Dialight are Stat. same |
| Pair 3 | LEOTEK – PRESOLAR | 0.1845 | 0.5667 | 0.1052 | 1.7530 | 28 | 0.0453 | Reject | Leotek darker than PreSolar |
| Pair 4 | GELCORE – DIALIGHT | -0.0752 | 0.2877 | 0.0534 | -1.4071 | 28 | 0.0852 | Reject | Dialight darker than Gelcore |
| Pair 5 | GELCORE – PRESOLAR | 0.0745 | 0.3435 | 0.0638 | 1.1677 | 28 | 0.1264 | Don't Reject | Gelcore and PreSolar are Stat same |
| Pair 6 | DIALIGHT – PRESOLAR | 0.1497 | 0.4765 | 0.0885 | 1.6913 | 28 | 0.0509 | Reject | Dialight darker than PreSolar |

Table B.25. Results of Paired t- tests for Color of Circular Green.

**CIRCULAR GREEN**

| Manufacturer | GLASSES | N | Mean | Mean Difference | T | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 17 | 3.5888 | 0.0434 | 0.1683 | 0.8676 | Stat same |
| | No | 11 | 3.5455 | | | | |
| GELCORE | Yes | 17 | 3.4600 | 0.0055 | 0.0324 | 0.9744 | Stat same |
| | No | 11 | 3.4545 | | | | |
| DIALIGHT | Yes | 17 | 3.5094 | -0.0670 | -0.3293 | 0.7446 | Stat same |
| | No | 11 | 3.5764 | | | | |
| PRESOLAR | Yes | 17 | 3.3724 | -0.0213 | -0.0970 | 0.9235 | Stat same |
| | No | 11 | 3.3936 | | | | |

Table B.26. Results of t – tests checking for the effect of Glasses on Color of Circular Green.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | T | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 20 | 3.4670 | -0.2741 | -1.0515 | 0.3023 | Stat same |
| | 2 | 9 | 3.7411 | | | | |
| GELCORE | 1 | 20 | 3.3830 | -0.1903 | -1.1128 | 0.2756 | Stat same |
| | 2 | 9 | 3.5733 | | | | |
| DIALIGHT | 1 | 20 | 3.4665 | -0.1635 | -0.7823 | 0.4408 | Stat same |
| | 2 | 9 | 3.6300 | | | | |
| PRESOLAR | 1 | 20 | 3.2500 | -0.3789 | -1.7777 | 0.0867 | Different |
| | 2 | 9 | 3.6289 | | | | |

Table B.27. Results of t – tests checking for the effect of Age on Color of Circular Green.

***YELLOW LEFT ARROW***

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK - GELCORE | -0.2500 | 1.0408 | 0.1967 | -1.2710 | 27 | 0.1073 | Don't Reject | Gelcore and Leotek are stat same |
| Pair 2 | LEOTEK - DIALIGHT | -0.0714 | 1.0862 | 0.2053 | -0.3480 | 27 | 0.3653 | Don't Reject | Leotek and Dialight are Stat. same |
| Pair 3 | LEOTEK - PRESOLAR | -0.5714 | 0.9201 | 0.1739 | -3.2863 | 27 | 0.0014 | Reject | PreSolar brighter than Leotek |
| Pair 4 | GELCORE - DIALIGHT | 0.1786 | 1.1564 | 0.2185 | 0.8171 | 27 | 0.2105 | Don't Reject | Gelcore and Dialight are stat. same |
| Pair 5 | GELCORE - PRESOLAR | -0.3214 | 0.8630 | 0.1631 | -1.9709 | 27 | 0.0295 | Reject | PreSolar brighter than Gelcore |
| Pair 6 | DIALIGHT - PRESOLAR | -0.5000 | 1.1386 | 0.2152 | -2.3238 | 27 | 0.0140 | Reject | PreSolar brighter than Dialight |

Table B.28. Results of Paired t- tests for Brightness of Yellow Left Arrow.

**YELLOW LEFT ARROW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 19 | 3.0526 | 0.0526 | 0.1203 | 0.9052 | Stat same |
| | No | 8 | 3.0000 | | | | |
| GELCORE | Yes | 19 | 3.2632 | -0.1118 | -0.3000 | 0.7666 | Stat same |
| | No | 8 | 3.3750 | | | | |
| DIALIGHT | Yes | 19 | 2.7895 | -1.0855 | -2.0354 | 0.0525 | Different |
| | No | 8 | 3.8750 | | | | |
| PRESOLAR | Yes | 19 | 3.6842 | 0.1842 | 0.5136 | 0.6120 | Stat same |
| | No | 8 | 3.5000 | | | | |

Table B.29. Results of t – tests checking for the effect of Glasses on Brightness of Yellow Left Arrow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 20 | 3.0000 | -0.1250 | -0.2939 | 0.7712 | Stat same |
| | 2 | 8 | 3.1250 | | | | |
| GELCORE | 1 | 20 | 3.2000 | -0.3000 | -0.8345 | 0.4116 | Stat same |
| | 2 | 8 | 3.5000 | | | | |
| DIALIGHT | 1 | 20 | 3.0500 | -0.2000 | -0.2983 | 0.7719 | Stat same |
| | 2 | 8 | 3.2500 | | | | |
| PRESOLAR | 1 | 20 | 3.4500 | -0.5500 | -1.6283 | 0.1155 | Stat same |
| | 2 | 8 | 4.0000 | | | | |

Table B.30. Results of t – tests checking for the effect of Age on Brightness of Yellow Left Arrow.

**YELLOW LEFT ARROW**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK - GELCORE | 0.0625 | 0.9483 | 0.1676 | 0.3728 | 31 | 0.3559 | Don't Reject | Leotek and Gelcore are Stat. same |
| Pair 2 | LEOTEK - DIALIGHT | -0.1250 | 0.6599 | 0.1167 | -1.0715 | 31 | 0.1461 | Don't Reject | Leotek and Dialight are Stat. same |
| Pair 3 | LEOTEK - PRESOLAR | 0.1563 | 0.8076 | 0.1428 | 1.0945 | 31 | 0.1411 | Don't Reject | Leotek and PreSolar are stat. same |
| Pair 4 | GELCORE – DIALIGHT | -0.1875 | 0.9980 | 0.1764 | -1.0628 | 31 | 0.1480 | Don't Reject | Gelcore and Dialight are Stat same |
| Pair 5 | GELCORE– PRESOLAR | 0.0938 | 1.2011 | 0.2123 | 0.4416 | 31 | 0.3309 | Don't Reject | Gelcore and PreSolar are stat. same |
| Pair 6 | DIALIGHT – PRESOLAR | 0.2813 | 0.8126 | 0.1436 | 1.9580 | 31 | 0.0296 | Reject | Dialight dottier than PreSolar |

Table B.31. Results of Paired t- tests for Dottiness of Yellow Left Arrow.

**YELLOW LEFT ARROW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | T | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 22 | 3.7273 | 0.0273 | 0.0965 | 0.9237 | Stat same |
| | No | 10 | 3.7000 | | | | |
| GELCORE | Yes | 22 | 3.5455 | -0.3545 | -1.0769 | 0.2901 | Stat same |
| | No | 10 | 3.9000 | | | | |
| DIALIGHT | Yes | 22 | 3.9091 | 0.2091 | 0.8049 | 0.4272 | Stat same |
| | No | 10 | 3.7000 | | | | |
| PRESOLAR | Yes | 22 | 3.6364 | 0.2364 | 0.7689 | 0.4480 | Stat same |
| | No | 10 | 3.4000 | | | | |

Table B.32. Results of t – tests checking for the effect of Glasses on Dottiness of Yellow Left Arrow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | T | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 23 | 3.5652 | -0.5459 | -1.9943 | 0.0553 | Different |
| | 2 | 9 | 4.1111 | | | | |
| GELCORE | 1 | 23 | 3.5652 | -0.3237 | -0.9497 | 0.3499 | Stat same |
| | 2 | 9 | 3.8889 | | | | |
| DIALIGHT | 1 | 23 | 3.6957 | -0.5266 | -1.7481 | 0.1084 | Stat same |
| | 2 | 9 | 4.2222 | | | | |
| PRESOLAR | 1 | 23 | 3.4783 | -0.2995 | -0.9499 | 0.3498 | Stat same |
| | 2 | 9 | 3.7778 | | | | |

Table B.33. Results of t – tests checking for the effect of Age on Dottiness of Yellow Left Arrow.

**YELLOW LEFT ARROW**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | 0.0000 | 0.8165 | 0.1633 | 0.0000 | 24 | 0.5000 | Don't Reject | Leotek and Gelcore are Stat. same |
| Pair 2 | LEOTEK – DIALIGHT | -0.0400 | 0.8888 | 0.1778 | -0.2250 | 24 | 0.4119 | Don't Reject | Leotek and Dialight are Stat. same |
| Pair 3 | LEOTEK – PRESOLAR | -0.0400 | 0.7895 | 0.1579 | -0.2533 | 24 | 0.4011 | Don't Reject | Leotek and PreSolar are Stat. Same |
| Pair 4 | GELCORE – DIALIGHT | -0.0400 | 0.8888 | 0.1778 | -0.2250 | 24 | 0.4119 | Don't Reject | Gelcore and Dialight are Stat same |
| Pair 5 | GELCORE – PRESOLAR | -0.0400 | 0.7348 | 0.1470 | -0.2722 | 24 | 0.3939 | Don't Reject | Gelcore and PreSolar are Stat. same |
| Pair 6 | DIALIGHT – PRESOLAR | 0.0000 | 0.8165 | 0.1633 | 0.0000 | 24 | 0.5000 | Don't Reject | Dialight and PreSolar are stat. same |

Table B.34. Results of Paired t- tests for Color of Yellow Left Arrow.

**YELLOW LEFT ARROW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 16 | 3.3125 | 0.1696 | 0.4250 | 0.6752 | Stat same |
| | No | 7 | 3.1429 | | | | |
| GELCORE | Yes | 16 | 3.1250 | -0.3036 | -0.8366 | 0.4122 | Stat same |
| | No | 7 | 3.4286 | | | | |
| DIALIGHT | Yes | 16 | 3.3750 | 0.2321 | 0.5442 | 0.5920 | Stat same |
| | No | 7 | 3.1429 | | | | |
| PRESOLAR | Yes | 16 | 3.3750 | 0.2321 | 0.8002 | 0.4326 | Stat same |
| | No | 7 | 3.1429 | | | | |

Table B.35. Results of t – tests checking for the effect of Glasses on Color of Yellow Left Arrow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 18 | 3.2222 | -0.0635 | -0.1681 | 0.8680 | Stat same |
| | 2 | 7 | 3.2857 | | | | |
| GELCORE | 1 | 18 | 3.1111 | -0.4603 | -1.3493 | 0.1904 | Stat same |
| | 2 | 7 | 3.5714 | | | | |
| DIALIGHT | 1 | 18 | 3.1667 | -0.4048 | -1.0211 | 0.3178 | Stat same |
| | 2 | 7 | 3.5714 | | | | |
| PRESOLAR | 1 | 18 | 3.2222 | -0.2063 | -0.7479 | 0.4621 | Stat same |
| | 2 | 7 | 3.4286 | | | | |

Table B.36. Results of t – tests checking for the effect of Age on Color of Yellow Left Arrow.

***GREEN LEFT ARROW***

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | -0.9630 | 0.8979 | 0.1728 | -5.5725 | 26 | 0.0000 | Reject | Gelcore brighter than Leotek |
| Pair 2 | LEOTEK – DIALIGHT | -0.7037 | 0.9121 | 0.1755 | -4.0090 | 26 | 0.0002 | Reject | Dialight brighter than Leotek |
| Pair 3 | LEOTEK – PRESOLAR | -0.4444 | 0.8916 | 0.1716 | -2.5903 | 26 | 0.0078 | Reject | PreSolar brighter than Leotek |
| Pair 4 | GELCORE – DIALIGHT | 0.2593 | 0.8590 | 0.1653 | 1.5683 | 26 | 0.0645 | Reject | Gelcore brighter than Dialight |
| Pair 5 | GELCORE – PRESOLAR | 0.5185 | 0.8024 | 0.1544 | 3.3577 | 26 | 0.0012 | Reject | Gelcore brighter than PreSolar |
| Pair 6 | DIALIGHT – PRESOLAR | 0.2593 | 0.8590 | 0.1653 | 1.5683 | 26 | 0.0645 | Reject | Dialight brighter than PreSolar |

Table B.37. Results of Paired t- tests for Brightness of Green Left Arrow.

**GREEN LEFT ARROW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 17 | 3.2353 | 0.1242 | 0.3304 | 0.7439 | Stat same |
| | No | 9 | 3.1111 | | | | |
| GELCORE | Yes | 17 | 4.1765 | 0.0654 | 0.2125 | 0.8335 | Stat same |
| | No | 9 | 4.1111 | | | | |
| DIALIGHT | Yes | 17 | 3.7059 | -0.6275 | -2.0272 | 0.0539 | Different |
| | No | 9 | 4.3333 | | | | |
| PRESOLAR | Yes | 17 | 3.7059 | 0.1503 | 0.5211 | 0.6070 | Stat same |
| | No | 9 | 3.5556 | | | | |

Table B.38. Results of t – tests checking for the effect of Glasses on Brightness of Green Left Arrow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 18 | 3.1667 | -0.0556 | -0.1519 | 0.8805 | Stat same |
| | 2 | 9 | 3.2222 | | | | |
| GELCORE | 1 | 18 | 3.8889 | -0.7778 | -3.0464 | 0.0054 | Different |
| | 2 | 9 | 4.6667 | | | | |
| DIALIGHT | 1 | 18 | 3.7778 | -0.3333 | -1.0206 | 0.3172 | Stat same |
| | 2 | 9 | 4.1111 | | | | |
| PRESOLAR | 1 | 18 | 3.5000 | -0.3889 | -1.4113 | 0.1705 | Stat same |
| | 2 | 9 | 3.8889 | | | | |

Table B.39. Results of t – tests checking for the effect of Age on Brightness of Green Left Arrow.

**GREEN LEFT ARROW**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK - GELCORE | -0.0370 | 0.8540 | 0.1644 | -0.2253 | 26 | 0.4117 | Don't Reject | Leotek and Gelcore are Stat. same |
| Pair 2 | LEOTEK - DIALIGHT | -0.0741 | 0.7299 | 0.1405 | -0.5273 | 26 | 0.3012 | Don't Reject | Leotek and Dialight are Stat. same |
| Pair 3 | LEOTEK - PRESOLAR | 0.0000 | 1.0000 | 0.1925 | 0.0000 | 26 | 0.5000 | Don't Reject | Leotek and PreSolar are stat. same |
| Pair 4 | GELCORE – DIALIGHT | -0.0370 | 0.8077 | 0.1554 | -0.2383 | 26 | 0.4068 | Don't Reject | Gelcore and Dialight are Stat same |
| Pair 5 | GELCORE– PRESOLAR | 0.0370 | 1.2242 | 0.2356 | 0.1572 | 26 | 0.4381 | Don't Reject | Gelcore and PreSolar are stat. same |
| Pair 6 | DIALIGHT – PRESOLAR | 0.0741 | 0.9168 | 0.1764 | 0.4198 | 26 | 0.3390 | Don't Reject | Dialight and PreSolar are stat. same |

Table B.40. Results of Paired t- tests for Dottiness of Green Left Arrow.

**GREEN LEFT ARROW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 17 | 3.4706 | -0.3072 | -1.0632 | 0.2983 | Stat same |
| | No | 9 | 3.7778 | | | | |
| GELCORE | Yes | 17 | 3.4706 | -0.4183 | -1.4905 | 0.1491 | Stat same |
| | No | 9 | 3.8889 | | | | |
| DIALIGHT | Yes | 17 | 3.7647 | 0.2092 | 0.6820 | 0.5017 | Stat same |
| | No | 9 | 3.5556 | | | | |
| PRESOLAR | Yes | 17 | 3.7059 | 0.2614 | 0.7374 | 0.4680 | Stat same |
| | No | 9 | 3.4444 | | | | |

Table B.41. Results of t – tests checking for the effect of Glasses on Dottiness of Green Left Arrow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 20 | 3.6500 | 0.2214 | 0.7199 | 0.4783 | Stat same |
| | 2 | 7 | 3.4286 | | | | |
| GELCORE | 1 | 20 | 3.6500 | 0.0786 | 0.2554 | 0.8005 | Stat same |
| | 2 | 7 | 3.5714 | | | | |
| DIALIGHT | 1 | 20 | 3.7000 | 0.1286 | 0.3924 | 0.6981 | Stat same |
| | 2 | 7 | 3.5714 | | | | |
| PRESOLAR | 1 | 20 | 3.4500 | -0.5500 | -1.5210 | 0.1408 | Stat same |
| | 2 | 7 | 4.0000 | | | | |

Table B.42. Results of t – tests checking for the effect of Age on Dottiness of Green Left Arrow.

**GREEN LEFT ARROW**

| Pair # | Brands | Paired Differences | | | t | df | Significance (1-tailed) | Inference (Reject / Don't Reject) | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | | | |
| Pair 1 | LEOTEK – GELCORE | 0.1290 | 0.7184 | 0.1290 | 1.0000 | 30 | 0.1627 | Don't Reject | Leotek and Gelcore are Stat. same |
| Pair 2 | LEOTEK – DIALIGHT | 0.0323 | 0.4819 | 0.0866 | 0.3727 | 30 | 0.3560 | Don't Reject | Leotek and Dialight are Stat. same |
| Pair 3 | LEOTEK – PRESOLAR | 0.1935 | 0.4774 | 0.0858 | 2.2571 | 30 | 0.0157 | Reject | Leotek darker than PreSolar |
| Pair 4 | GELCORE – DIALIGHT | -0.0968 | 0.5388 | 0.0968 | -1.0000 | 30 | 0.1627 | Don't Reject | Gelcore and Dialight are Stat same |
| Pair 5 | GELCORE – PRESOLAR | 0.0645 | 0.6290 | 0.1130 | 0.5710 | 30 | 0.2861 | Don't Reject | Gelcore and PreSolar are stat. same |
| Pair 6 | DIALIGHT – PRESOLAR | 0.1613 | 0.3739 | 0.0672 | 2.4019 | 30 | 0.0114 | Reject | Dialight darker than PreSolar |

Table B.43. Results of Paired t- tests for Color of Green Left Arrow.

**GREEN LEFT ARROW**

| Manufacturer | GLASSES | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | Yes | 21 | 3.6190 | 0.1190 | 0.4499 | 0.6564 | Stat same |
| | No | 8 | 3.5000 | | | | |
| GELCORE | Yes | 21 | 3.4286 | -0.0714 | -0.2676 | 0.7910 | Stat same |
| | No | 8 | 3.5000 | | | | |
| DIALIGHT | Yes | 21 | 3.5714 | 0.0714 | 0.2954 | 0.7699 | Stat same |
| | No | 8 | 3.5000 | | | | |
| PRESOLAR | Yes | 21 | 3.3333 | -0.1667 | -0.8073 | 0.4266 | Stat same |
| | No | 8 | 3.5000 | | | | |

Table B.44. Results of t – tests checking for the effect of Glasses on Color of Green Left Arrow.

| Manufacturer | AGE GROUP | N | Mean | Mean Difference | t | Sig. (2 tailed) | Conclusion |
|---|---|---|---|---|---|---|---|
| LEOTEK | 1 | 21 | 3.4762 | -0.2238 | -0.9316 | 0.3592 | Stat same |
| | 2 | 10 | 3.7000 | | | | |
| GELCORE | 1 | 21 | 3.3333 | -0.2667 | -1.1235 | 0.2704 | Stat same |
| | 2 | 10 | 3.6000 | | | | |
| DIALIGHT | 1 | 21 | 3.4286 | -0.2714 | -1.2514 | 0.2208 | Stat same |
| | 2 | 10 | 3.7000 | | | | |
| PRESOLAR | 1 | 21 | 3.2381 | -0.3619 | -2.0356 | 0.0510 | Different |
| | 2 | 10 | 3.6000 | | | | |

Table B.45. Results of t – tests checking for the effect of Age on Color of Green Left Arrow.

# Appendix C

Model numbers and the power characteristics of the lenses used in the survey. Note that, for the lenses manufactured by Leotek the voltage rating was 80 to 135 V AC, while for the rest it was 120 V AC.

| Lens ↓ / Manufacturer → | | Leotek | Gelcore | Dialight | Precision Solar |
|---|---|---|---|---|---|
| Circular Red | Model | TSL-12R-MG | D12RA4<br>MS: 4 | 433-1210-033 | 1877 RED |
| | Characteristics | 11 W | 9.4 W<br>9.5 VA | 10.5 W<br>10.8 VA | 13 W<br>13.2 VA |
| Circular Yellow | Model | TSL-12Y-MF | D12YA4<br>MS: 4 | 431-3235-001 | 2015<br>YELLOW |
| | Characteristics | 22 W<br>23.2 VA | 17.5 W<br>17.6 VA | 32 W<br>33 VA | 24 W<br>24.2 VA |
| Circular Green | Model | TSL-12G-MG | D12GA4<br>MS: 4 | 432-2275-001 | 2035<br>GREEN |
| | Characteristics | 12 W<br>12.6 VA | 13 W<br>13.1 VA | 10.7 W<br>11.5 VA | 19 W,<br>19.3 VA |
| Yellow Arrow | Model | TSL-12YA-MF | D12YA7<br>MS: 4C | 430-3334-001 | 1652<br>YELLOW |
| | Characteristics | 7.5 W<br>7.7 VA | 10 W<br>10.1 VA | 9 W<br>10 VA | 11 W<br>11.3 VA |
| Green Arrow | Model | TSL-12GA-MF | D12GA7<br>MS: 3 | 430-2374-001 | 1654<br>GREEN |
| | Characteristics | 10 W<br>10.2 VA | 9.5 W<br>9.6 VA | 11 W<br>11.5 VA | 6 W<br>6.4 VA |