Gaze strategies for coping with glare under intense contra light viewing conditions – A pilot study

by

Nicholas Lorentz

A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Science

in

Vision Science

Waterloo, Ontario, Canada, 2011

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Purpose: This is a pilot study to investigate gaze strategies for coping with glare when performing a simple visual task under intense contra light viewing conditions.

Method: Twenty-four normally sighted participants were recruited for this study. They consisted of a young subgroup (n=12), aged 21-29 (mean = 25.3 ± 2.5), and an older subgroup (n=12), aged 51-71 (mean = 57.3 ± 6.1). Visual acuity (VA) and Brightness Acuity testing (BAT) were used to assess central vision. Participants were required to locate and approach (from 15m) a small platform that was contra lit by a powerful light source. Upon arrival at the platform, participants were required to insert a small ball into a similarly sized receptacle. An ASL Mobile Eye (Bedford, MA) eye tracker was used to monitor gaze position throughout until the task was completed. Scene and pupil videos were recorded for each participant and analyzed frame by frame to locate the participant's eye movements.

Results: Two participants (one from each subgroup) adopted aversion gaze strategies wherein they avoided looking at the contra lit task for more than 50% of the task completion time. For the remainder of the experimental trial, these two participants were either looking toward the glare source or blinking. The other twenty-two participants opted to endure the contra light condition by gazing directly into the glare for the majority of the task completion time. An individual t-test between the younger

subgroup’s BA scores vs. the older subgroup’s BA scores was statistically significant ($p<0.05$).

Significantly poorer BAT scores were found in the older subgroup, however, individual participant’s BAT scores did not necessarily predict the ability to cope with a contra lit glare source. Although, statistically significant differences were not found between the two subgroups when examining their VA and length of time to complete the course, a trend was found, as the older subgroup consistently had poorer VA scores and took longer to complete the course.

Further research must be completed with a larger sample size to fully understand the glare aversion strategies one must elicit when dealing with a contra lit glare source within the built environment, and to confirm the three glare strategies proposed by this pilot study.

ACNKNOWLEDGEMENTS

I would like to thank a number of people that have helped me throughout my degree, as without your help, I would have never been able to finish this chapter of my academic career.

I would like to thank Dr. Graham Strong. You have been an excellent mentor and supervisor. Your patience really knows “no bounds” and you always backed me up when I hit a snag or two. Your kind reminders that every problem that came up was “character building” was always a great way to calm the nerves and set me on the right path.

I would like to thank my co-supervisors, Dr. Trefford Simpson and Dr. Ann Plotkin. Your help throughout my degree has been wonderful.

I would also like to thank Dr. Jeff Hovis for all of his help with my new “found” knowledge of lighting and illumination.

I would like to thank my fellow graduate students, as you are not only co-workers, but have become wonderful friends. This time that I have spent here would not have been nearly as enjoyable had I not met you, and I will value the friendships that I have made.

DEDICATION

This thesis is dedicated to my beautiful, loving wife Holly and my two wonderful children Gabrielle and Natalie. You have always been supportive of me, no matter what problems arose. You have never lost faith in me, and have always brought advice, encouragement and understanding. You three bring so much joy into my life, that I would have never been able to complete this degree without all of your help. I am truly a lucky man to be blessed with such a wonderful family.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

‘	Foot
>	Greater Than
Hz	Hertz
“	Inches
<	Less than
M	Meters
S	Seconds

LIST OF ABBREVIATIONS

AFOV	Attended Field of View
ANOVA	Analysis of Variance
ASL	Applied Sciences Laboratories
BA	Brightness Acuity
BAT	Brightness Acuity Test
IR	Infra-Red
LED	Light Emitting Device
UD	Universal Design
VA	Visual Acuity

1 INTRODUCTION

Throughout our lives, we all have basic needs that must be met to ensure our survival. These include food, sleep and shelter.[1] Beyond these three basic needs we have additional requirements in order to enjoy our lives, to function effectively, and to engender a sense of worth and accomplishment. It should be possible for everyone to satisfy these needs with our modern conveniences and technology. However, these needs are not met if people are unable to fully negotiate their living and work environments, such as mobility-impaired individuals faced with inaccessible physical facilities.[2-5] The concept of Universal Design (UD) was developed to lessen these disparities for people with diminished capabilities. The underlying principle of UD is that all products and environments should be usable to the greatest extent possible by everyone, regardless of their age and physical abilities.[2, 5, 6] This concept is especially relevant for people as they experience some of the common functional changes associated with ageing, such as general health changes, a diminution of vision[7-9] and reduced agility and mobility.[10-13] When seniors become unable to function within their own housing, they may be required to move into retirement homes or assisted living environments. These relocations often result in a heightened reliance on others and a significant loss of independence.[5, 11, 14-16] Anything that can be done to adjust their habitual living environments and to alleviate any conditions that interfere with their ability to perform basic activities of daily living will ensure a much fuller, happier, and more independent life for these individuals.[3, 16, 17]

Research has shown that normal ageing is associated with decreased visual performance. In addition, there is an increased prevalence of eye-related diseases[18-21] that cause functional vision loss.[18, 22-24] There is limited research about how elderly people cope visually in their built environments (i.e. a kitchen or bathroom) and the consequent visual requisites for more inclusive universal design guidelines.[25-28] Vision functions such as visual acuity, colour discrimination, contrast sensitivity, and visual fields show characteristic decreases as people age. Older individuals also exhibit heightened vulnerability to adverse viewing conditions such disability glare, (the presence of competing light sources within the field of view),[23, 29-32] divided attention,[31] or discomfort glare (when the overall illumination is too bright).[33-35] Previous research has been completed assessing visual performance factors under optimal conditions within a laboratory setting, but those artificial environments are significantly different than real life situations when people are required to maneuver and function in built environments.[25-28, 36]

A literature search revealed that most clinical testing and assessments of visual performance and visual acuity are conducted in office or laboratory settings, with the participants looking straight ahead (primary position of gaze). However, during everyday life, most of our visual interactions within the built environment involve dynamic seeing activities; an individual's eyes, head, and body are always in motion. Furthermore, when an elderly individual is moving though a built environment their habitual directionality of gaze is not straight ahead toward the horizon as it is with most younger people, but is directed primarily downwards relative to the horizon.[28, 37-40]

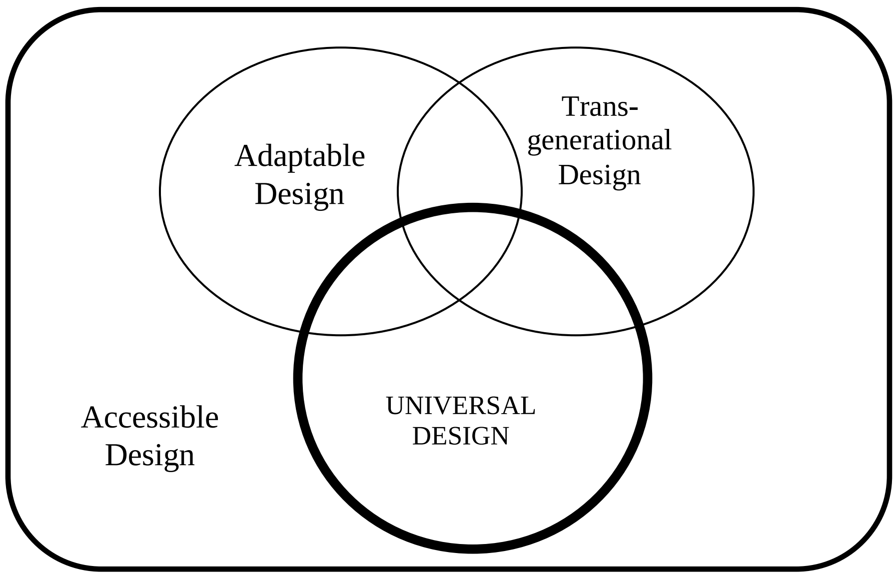
Seeing performance while navigating within a built environment may be further compounded if the individual is concurrently engaged in an activity that requires divided attention (reading, talking, etc.). This situation may be further exacerbated if there are any hostile viewing conditions (such as glare, excessive brightness, and/or dim lighting conditions). Accordingly, the individual may feel so disoriented and overwhelmed that they may not be able to safely, or even wish to, navigate through the environment.

All of these concerns must be considered by architects, planners and developers if they wish to implement universal design functionality in assisted living facilities and retirement homes for people who are elderly.[4]

1.1 UNIVERSAL DESIGN

The idea of universal design, or design for all, has been around for decades, but the shift towards incorporating universal design into design planning and implementation has only been seen over the past twenty or so years. This concept is based on basic fundamentals, and yet to see their fruition, they require much more detailed planning, thought and design including: barrier-free design, accessible design, inclusive design and assistive technology.[4, 5, 41-43] The design itself must be adaptable, trans-generational (useable by any age group) and fully accessible (Figure 1).[4] These ideals are based on the fact that buildings should be able to accommodate individuals with physical impairments, allowing everyone access to and un-restricted movement within every aspect of their environment, and that this utility should extend to the widest possible range of individuals regardless of their age or abilities.[41] UD concepts have not been implemented universally and many newer buildings have obvious barriers for people with special needs because they reflect the same general building guidelines that were instituted in the 1960's.[44]

Figure 1. The relationship between Accessible, Adaptable, Trans-generational and Universal Design. [5]



Mace (1998), who is widely attributed with introducing the term of "universal design", states that "*the term universal is not ideal because nothing can be truly universal; there will always be people who cannot use an item no matter how thoughtfully it is designed*."[4] He notes that there is a hierarchy on design that can range from the most universal – no or very little human interaction is needed, to the least – the most human interaction is needed.[4] It is likely impossible to create a design that will accommodate every possible ability deficit. Accordingly, the objective of universal design is to create environments that preclude full utilization by the fewest possible number of individuals or groups. A generic doorframe that is installed in many houses will allow the majority of individuals to go through, but if an individual uses a mobility aid (i.e. walker, wheelchair, scooter) they may not be able to fit through the doorway.[44, 45] An accessible doorframe will allow most device assisted people to go through unimpeded, but may be impassible for persons with larger or more substantial mobility aids.

The Center of Universal Design, at the University of North Carolina proposes seven principles of universal design as a framework for the creation of new housing developments for housing people who are elderly.[46] These principles apply to all design disciplines and all people and are especially useful for instruction, design and evaluation.[43] The principles outlined below were adapted from The Center for Universal Design, NC State University.[46] (Copyright © 1997 NC State University, The Center for Universal Design)

Principle One: Equitable Use: This design is useful and marketable to people with diverse abilities.
Example of this principle: Entering or leaving a building, where there is little or no slope at the entrance, and the door would open automatically, thereby ensuring that everyone would be able to use the door equally.

Principle Two: Flexibility in Use: This design specifically looks at a wide range of preferences and abilities of the individual.

Example of this principle: New slot machines at a casino. The screen is situated where a person can see it either sitting or standing, the individual can use either the pull-down bar or simply push a button to start playing. The display, incorporated with the sound, ensures that those with limited vision can see and hear if they indeed did win.

Principle Three: Simple and Intuitive Use: Use of the design is easy to understand, regardless of the individual's attention level, experience, knowledge or language skills.
Example of this principle: Talking raised elevator buttons. This allows individuals to be able to effectively use an elevator, regardless of visual or auditory impairments.

Principle Four: Perceptible Information: The design gives the necessary information effectively to the individual, regardless of ambient conditions, or the individual's sensory capabilities.
Example of this principle: A large print talking calculator with raised numbers. The information is given as numbers for those who can see, the numbers on the calculator should be large enough for those who have limited vision, and it will have raised numbers and speak out the number that is pressed for those who cannot see.

Principle Five: Tolerance for Error: This design minimizes hazards and any actions or consequences of accidental or unintended actions.
Example of this principle: Signage at a mall: Properly directing an individual to where they need to go is vital in keeping them safe. The use of signs, arrows and maps will allow the individual to get to the location that they need to go without the worry of them

wandering aimlessly. These signs should have raised letters, and speak where the individual is within a mall. Once a button is pressed, the sign will become audible, allowing a low-visioned individual the ability to find out where they are.

Principle Six: Low Physical Effort: This design can be used with minimum fatigue and can be used efficiently and comfortably.
Example of this principle: Using a lever-style door knob: The door knob should be easy to grab and allow for a minimum amount of force to open. The door knob can be opened with limited grasp ability also.

Principle Seven: Size and Space for Approach and Use: Appropriate size and space is given for approach, reach, use and manipulation, regardless of the individual's body size, posture or mobility.
Example of this principle: Kitchen area:[6] The aisle between stove, fridge and cabinetry should be wide enough for a person in a wheelchair, walker, or assisted mobility vehicle (i.e. scooter) to move freely. There should be an open space beneath a work surface so that a wheelchair could fit under it. A lower placed oven, microwave and shelving so that individuals with poor mobility can reach these items easier.[46]

Numerous studies have shown that these principles of universal design can be introduced into modern facilities or buildings without creating a great burden for the architect, the builder or the individual who wishes to use the facility.[2, 6, 11] Danford (2003)[2] selected a strategically diversified group of 32 subjects (eight with mobility impairments, eight with hearing impairments, eight with vision impairments and eight control participants with no impairments) to complete 14 activities in a case-study building that had been constructed in accordance with the principles of universal design.[2,6,11] The participants were asked to perform common activities of daily living, such as finding a phone, using a drinking fountain and using an elevator. All four groups perceived the case-study building to be much more usable than most other buildings they had experienced and it came very close to meeting the ideals of universal design, that all participants could use the building and that each could use it equally well.[2,6,11]

Null (1998)[6] examined UD concepts within a kitchen setting, since much of the assistance required by elderly individuals is with cooking or household chores.[6] This is especially important for individuals whose vision naturally decreases with ageing, and thence who may require more assistance with these activities (either from another individual or through the use of a visual aid), to minimize any potential risks when completing these activities (i.e. burns, spoiled food, cuts, etc.).[6, 7, 31, 47, 48] A test kitchen at the San Diego Center for the Blind was modified to incorporate all seven concepts of universal design so that both elderly and low visioned individuals could use it effectively. There were no negative consequences or drawbacks for the non-low vision participants and everyone was able to use the kitchen fairly and equitably.[6]

Crews and Zavotka (2006)[11] took this notion one step further and introduced frailty into the realm of aging and universal design. They found that universal design is a novel, yet rather difficult concept for builders to employ, since many activities of daily living, such as bathing or dressing one's self, take place in areas that usually are not spacious.[11] They observed that many of the building requirements that are in place are outdated and from the mid-1960's when the dimensions were established to meet the requirements of a fit, military man.[44] The authors stressed that homes for elderly people must incorporate more universal design principles into their buildings and living environments if frail elderly individuals are to lead independent lives that are less dependent on assisted living.[11]

Universal design is a concept that is being contemplated all over the world. Trost (2005)[49] found that many Europeans preferred the wording "design-for-all" rather than "universal design" because they felt that it had more practical connotations associated with it. The design-for-all concept was shown to the general public with two motives: a social motive and a marketing motive.[49] The social motive is to make people aware of this concept because the general public is still generally uneducated in the concept in spite of the efforts of numerous advocacy groups. . The marketing motive is to encourage the development, manufacturing, and marketing of competitively priced products that encompass the principles of the design-for-all concept.[49] There are many initiatives and projects started throughout Europe, ranging from design for all public transit in Stockholm, to a Nordic design competition put on by the Nordic Council on Disability policy where designers and architects looked at and tried to solve problems people have when they travel using the universal design concept.[49] There also is a German hotel, Haus Rheinsberg, which is the first hotel designed to be completely accessible to all users, following the design-for-all concept. Trost states that UD does not represent a new demand, but products need to respond to the needs and expectations of people, along with encompassing their strengths.[49]

Universal design, by definition, benefits everyone, either as newly enabled individuals, individuals who interact with UD beneficiaries, or as people who care about other people who would be disadvantaged without UD. Improved UD requires a great deal of more research. Among the outstanding research issues are a number of vision concerns that must be investigated to contribute to UD designs that can truly be universal.[2, 4, 11, 50]

1.2 VISUAL GAZE AND ACUITY

As with many human abilities, vision deteriorates over an individual's lifetime. This decline has been documented by numerous research studies.[7-9, 25, 31, 51-56] Vision is the primary sense that humans use to obtain information about their surrounding environments. When vision is lost or diminished, people have a serious disadvantage when obtaining important information for daily living.[9] People with vision loss may also experience significant difficulty navigating and moving about safely within their living environments. This is one of the main reasons that universal design is indeed needed in the creation of new retirement settings or homes for the aged.

Visual information about the surrounding environment is vital for an individual to move safely within it.[57] With ageing and diminished visual function, individuals are more inclined to tilt their heads downwards and to look where they are walking, rather than maintaining a straight ahead posture while fixating on a distant landmark.[28, 57-60]

Marigold et al (2008)[57] had ten healthy young adults (mean age = 26) and ten healthy older adults (mean age = 74) navigate across a walkway with irregular surfaces (bumpy, slippery etc.) while wearing specially designed spectacles that blocked out their lower fields of view.[57] They found that the maximum head pitch increased at a downward angle and speed and gait were reduced. They concluded that the lower visual field is used when walking on multi-surfaced terrains.[57] Previous studies had shown that looking at a visual target has a cascade effect that influences an individual's body posture.[58] Initially looking at a target affects the person's eye orientation, which then affects the head posture, which leads to how the rest of the body is postured.[58] While walking, many elderly individuals use their central vision to obtain and track important visual information within their field of view.[60, 61] This affects how the individual interacts with the environment, especially whenever the environment is new or unfamiliar.

This information is important when trying to incorporate a UD concept or design in an area where many daily activities occur. Kuyk et al (1998)[25] looked at mobility with respect to visual function, with special attention to contrast sensitivity, high and low contrast glare sensitivity, colour diffusion and spatial contrast.[25] They found that mobility was adversely affected by reducing the light level from photopic (overhead fluorescent lights) to mesopic (neutral gray sun shades). They found that the participants walked more slowly along the set course and made more errors when lighting levels were reduced.[25]. Haegerstrom-Portnoy et al (1999)[23] looked at sample of 900 elderly individuals (mean age 75.5), and found that older individuals are able to maintain their high contrast acuity into their elder ages (80+). They found that elderly individuals have significant spatial visual impairments under conditions of reduced contrast or luminance and glare.[23] They found that a reduction in light levels or contrast, or increased glare significantly diminishes visual acuity performance. When combined with loss of colour vision, these factors will influence how effectively individuals can operate within their environment and in their daily lives.[23]

Universal design is a novel concept that has the capability to efficiently and effectively change the world and make it easier for many people. A great deal of research has investigated environments that provide improved accessibility for people with vision and mobility impairments. However, additional research is required to investigate the potentially unique problems of elderly individuals and their housing environments. One important vision issue is to understand where these individuals are looking while performing various activities, including where they are looking while walking within these living environments.

Canada’s elderly population continues to grow as the baby boomers become elderly. More and more resources will be needed to accommodate these people as they age and are placed in retirement and assisted living facilities.[9, 55, 63] As people age and their vision deteriorates, it becomes much more difficult to perform and enjoy many activities of daily living, such as making a cup of tea, reading a newspaper or watching television.[64-66] Universal design poses an obvious solution to help these elderly individuals to retain independence and to live their lives to the fullest potential. This research will contribute to the body of knowledge that is required by UD professionals to create living environments that realize this potential (more inclusive working and living environments).

1.3 LIGHT AND LIGHT SOURCES

For normally-sighted persons to navigate safely in any environment, the environment must be evenly illuminated (luminance) and the visibility must be sufficient for the individual to visually recognize various objects within it.[67, 68] Numerous problems and issues can arise when there is inadequate lighting within an environment, including a range of vision-related symptoms such as eye strain, headaches, and nausea[69-71] that may worsen as the day progresses. These problems are well known to contemporary architects and designers and lighting concerns are in the forefront of most current building design strategies.

1.3.1 PHOTOMETRY

Illuminance describes the quantity of light that actually reaches a surface, which is differentiated from the amount of light that is generated by an external light source or luminaire.[72] It is important to note that illuminance is not directly visible, since we only see whatever light is reflected off of the surfaces and is incident onto our eyes.[67, 68, 72] Illuminance is commonly measured in lux or in foot candles (1 foot candle= 10.8 lux).[68]

The following definitions are taken from Pritchard (1990):[68]

Luminous Intensity (unit, candela): “The quantity which describes the power of a source of illuminated surface to emit light in a given direction.”

Luminous Flux (unit, lumen): “The light emitted by a source, or received by a surface.”

Illuminance (unit, lux): “The luminous flux density at a point on a surface, or incident per unit area.”

Luminance (unit, candela per square meter): “The intensity of the light emitted in a given direction per projected area of a luminous or reflecting surface.”

Throughout a normal day, an average individual must cope with incredible variations in light levels within our living environments. The illuminance of the sun can range from 60,000 lux to 130,000 lux compared with the overnight sky at 10^{-4} lux, and yet human eyes accommodate and adapt to the ensuing light levels on a daily basis.[67, 73-76]

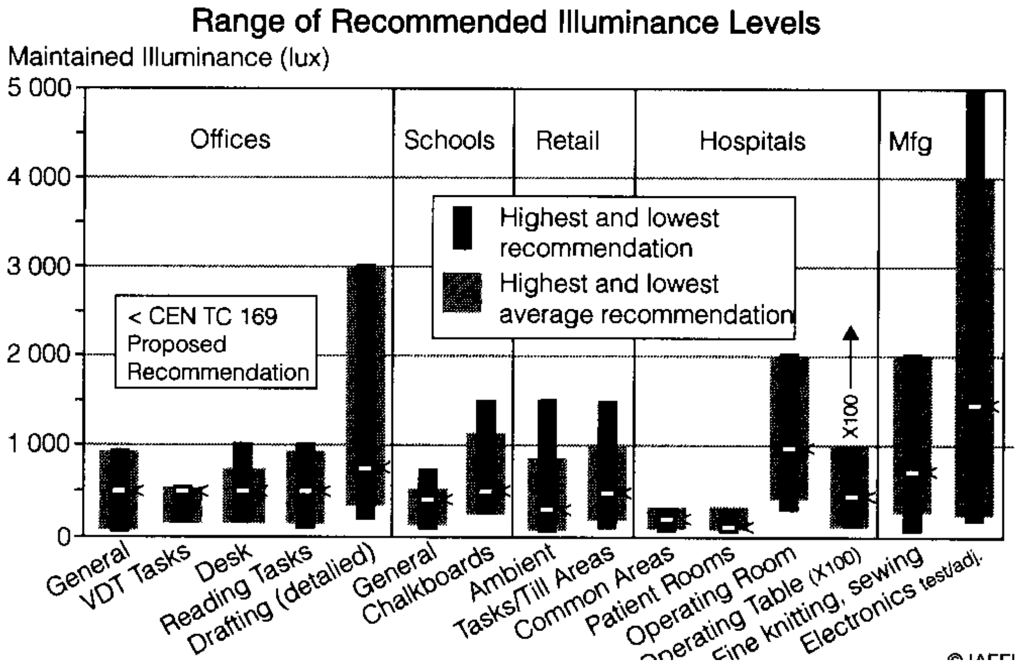
Illuminance levels are extremely important for people who are performing visual tasks and the suitability of these levels has an obvious impact on their ability to complete those tasks.[74, 77, 78] Modern indoor environments often feature a wide range of illumination levels, all of which are selected in accordance with the tasks that are being undertaken in each area within that environment. Restaurants invariably have less light than office buildings or operating rooms. Fine dining establishments seek to create an ambiance of seclusion and privacy by having less light, whereas hospital operating rooms require high lighting levels to ensure that the surgeon has optimum visibility.[67] Table 1 shows the recommended levels of illuminance for each selected activity area.[67]

Table 1. Ranges of recommended illuminance for different areas or activities.[67]

Range of recommended illuminance (lux)	Type of area or activity
20 - 30 - 50	Outdoor circulation and work areas
50 - 100 - 150	Simple orientation for short periods
100 - 150 - 200	Rooms not used for continuous visual tasks
200 - 300 - 750	Tasks with simple visual requirements (Warehouses, less demanding office work, most homes)
500 - 750 - 1000	Tasks with demanding visual requirements (Most office work, grocery and shopping stores, mechanical workshops)
750 - 1000 - 1500	Tasks with difficult visual requirements (Detailed mechanical workshops, Detailed drawing work)
1000 - 1500 - 2000	Tasks with special visual requirements (Operating theaters, very small size for an extended period of time)
Above 2000	Performance of very exact visual tasks (Extremely low contrast and prolonged period of time)

Mills and Borg (1999)[79] took this idea one step further examined the various ranges of illuminance throughout residential and non-residential buildings in 19 different countries (Americas, Eastern and Western Europe and Asia). See Figure 2.[79]

Figure 2. Ranges of recommended illuminance levels (19 countries)[79]



Reprinted with permission from Mills, E. and N. Borg, Trends in Recommended Illuminance Levels: An International Comparison, Journal of the Illuminating Engineering Society, 1999, 28(1): p. 155-163, by the Illuminating Engineering Society of North America.

Mills and Borg (1999)[79] report very large differences in how each industry within each country determine the recommendations for different illuminance ranges.[79] These differences can lead to a vast array of complications when one looks at an individual's own visual acuity and comfort.[79] Within one sector of industry (office, school, retail etc.), the recommended levels can vary considerably, thereby leading to an individual's discomfort due to eye strain or glare, when the issue may not exist within another country.[79]

There is a great deal of variability and disagreement concerning the optimum illuminance levels for different living and working settings.[79] Depending on the location of the light sources and the existence of other external light sources (windows, sky lights etc.) there will be some level of glare for an individual to cope with, either by blocking it out, disregarding it or by using some compensatory aversion strategy.[31, 72, 77, 80-82] This is one of the major focuses of the experiment that was conducted for this thesis.

1.4 GLARE

The International Committee on Illumination defines glare as: "that condition of vision in which there is discomfort or a reduction in the ability to see significant objects, or both, due to an unsuitable distribution or range of luminance or to extreme contrasts in space or time."[69] Glare is present in one form or another when people undertake many seeing tasks.[74, 76, 77, 83]

Leaving a building into the sunshine, driving at night and viewing on-coming headlights, and even looking out a window from an office all describe glare conditions. Glare can be caused by lamps, windows and painted surfaces appearing too bright in comparison with their general surroundings.[33, 71, 75, 80, 81, 84, 85] Glare can be further described and classified as disability or discomfort glare.

1.4.1 DISCOMFORT GLARE

Discomfort glare is the glare that causes visual discomfort without necessarily lessening the ability to see detail.[68] An unshielded lamp (or a bare light bulb) is a common example of discomfort glare. The amount of discomfort depends on the angle of view and the type of location. If the direction of gaze is fixed on a particular seeing task, then glare caused by lighting conditions is more noticeable. A person walking around in a large but well-lit warehouse or store is able to tolerate much brighter luminance levels because their eyes are constantly moving from item to item or from shelf to shelf,[68] Conversely, an individual in an office or classroom setting has a limited or fixed direction of gaze and becomes much more sensitive to the increased light from external light sources such as sunlight coming through a window.[68] Rosenberg (1984)[86] describes the example of an individual looking towards a building while facing into the sun (located above the building's roof).[86] When attempting to derive visual information from this observation, their person's eyes go through a series of conflicting events; the pupils will ordinarily dilate to allow more light in when looking into a dark alcove or the building entrance/hallway, but they also would ordinarily constrict to diminish the bright light from the sunlight overhead. These contradictory demands on pupil action have been cited as the reason why discomfort glare is problematic, and can lead to headaches, eye fatigue and other eye discomfort over a prolonged period of time.[86]

1.4.2 DISABLILITY GLARE

Disability glare is the glare that lessens the ability to see detail. It does not necessarily cause visual discomfort.[68] This form of glare relies mainly on the amount of light that comes into contact with the eye, and the eye's ability to adapt to that increase in light. Driving at night is one of the biggest areas of research into disability glare, as it is the light from oncoming headlights entering a person's line of sight and the individual's ability or inability to adapt to these changes that is believed to cause many nighttime driving accidents.[29, 76, 83, 87-89] Disability glare is less dependent on exposure duration than discomfort glare. Often the offending external light source/factor only enters the person's field of view for a very short period of time,[69, 76, 83] and is not as prominent in the task setting as discomfort glare sources are thought to be (they are more likely to pose a constant increase in brightness or glare throughout the day, rather than over a relatively brief time period).

1.4.3 BRIGHTNESS ACUITY TESTING

The Brightness Acuity tester (BAT) provides objective measurements of functional visual acuity performance under three common brightness levels. The instrument is shown in Figure 3.

Figure 3. A brightness acuity tester

The following are the brightness level settings:[90]

Low: Equivalent to the participant being in bright overhead fluorescent lighting such as in a department store, plant assembly line or classroom.

Medium: Equivalent to the participant being in indirect sunlight and standing on a white concrete sidewalk or sandy beach on a cloudy day.

High: Equivalent to the participant being in direct overhead sunlight and standing on a white concrete sidewalk or sandy beach.

Trying to replicate an outdoor setting to test whether or not the brightness acuity tester is indeed useful to clinicians is rather difficult, as outdoor lighting varies a great deal (direct sunlight, cloudy cover, rain etc.). Holladay et al (1987)[90] replicated a sunny day in an enclosed room and tested the BAT on normal visioned and cataract patients.[90]

They found that the normal individuals found no difference in the outdoor/brightness acuity settings, whereas the cataract patients demonstrated acuity reductions that ranged from one to ten acuity rows.[90] They concluded that the BAT is a simple and reliable way to predict a patient's outdoor visual acuity.[90]

2 OBJECTIVES AND IMPORTANCE

Many factors must be taken into account in order to understand how an individual can operate within an indoor environment. External glare sources, such as from sunlight or outdoor lighting, can have a significant impact on an individual's ability to operate within this environment over any extended period of time. This thesis describes a pilot study to investigate gaze strategies for coping with glare when performing a simple visual task while walking a pre-set course, under intense contra light viewing conditions. These countermeasures for coping with glare in real life activities are mediated by several dynamic factors such as the habitual directionality of gaze (customary line of sight), and the relative contributions of eye, head, and trunk movements when visualizing objects of interest within the environment.

The purpose of this study is to investigate compensatory strategies of gaze adjustments adopted by two different age groups to help cope with an obvious glare source in an otherwise relatively unstructured physical environment. This study will also investigate whether brightness acuity, an individual's functional visual acuity in bright light conditions, (BA) and age are significant factors for predicting glare-aversive gaze behaviours.

3 METHODS

3.1 ILLUMINANCE

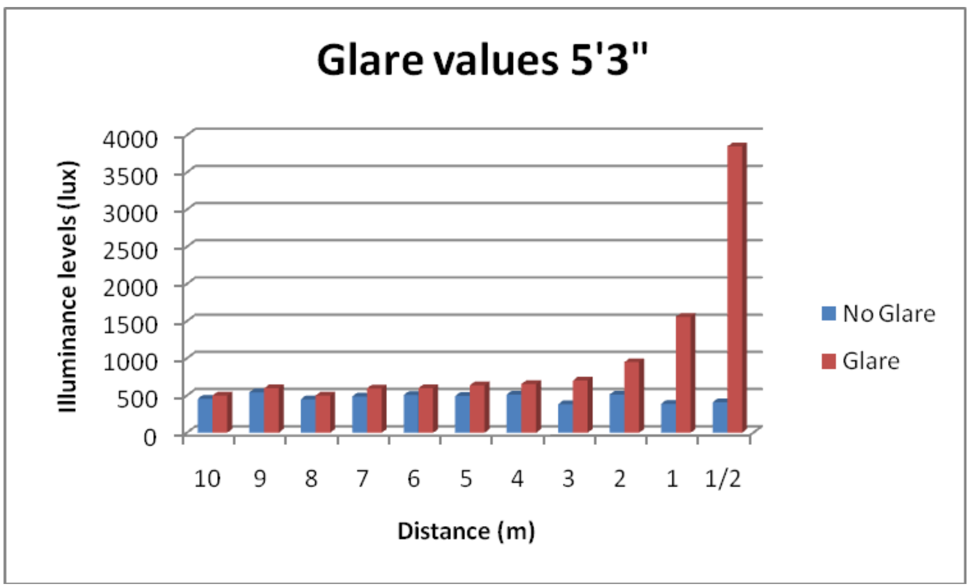
In this experiment, the Designers Edge 130 Watt Fluorescent Twin-head Worklight Model # L-2005 (Bellevue, WA), (Figure 4) was used as a glare source. In order to test the illuminance with and without the glare source on, the Minolta Illuminance Meter T-1 (Ramsey, NJ), was used. Illuminance levels were taken at two pre-determined heights[91, 92] from 10 meters towards the glare source, at 1 meter increments along the pre-set course. The height of the glare source is 4’6”, with each glare emitting light-casing measuring 12” wide, 8” tall.

Figure 4. Designers Edge 130 Watt Fluorescent Twin head Worklight Model # L-2005

Two heights were chosen as the selected average heights for the sub-groups, 5’3” for the females, and 5”8” for the males.[91, 92] These values represent the average height of the participants for each gender and age groups.

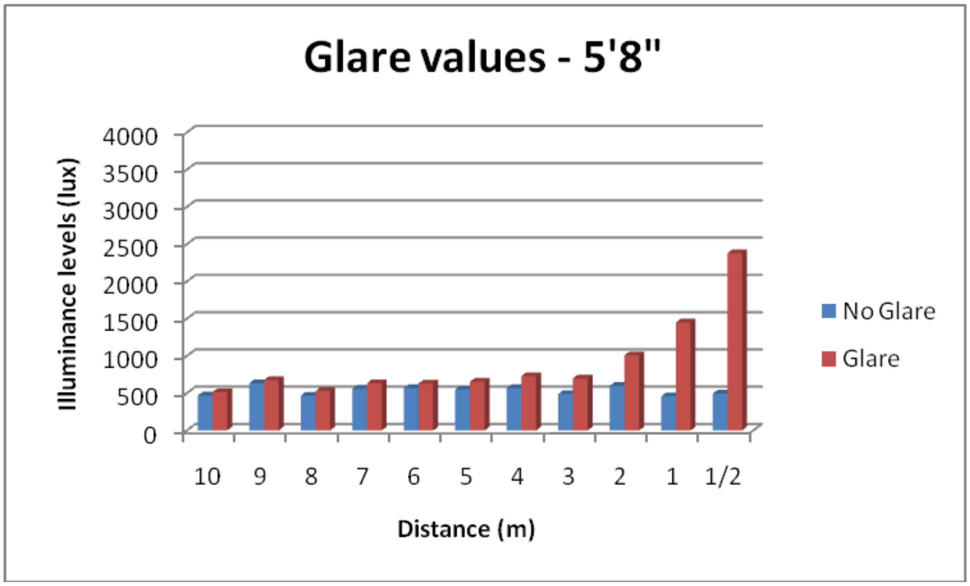
With the glare source turned off, there was a reasonable amount of ambient light present (shown as “No Glare” in Tables 2 and 3). Once the glare source was switched on, the second value shows the illuminance values (“Glare”) recorded in Table 2 and 3.

Table 2. Illuminance measurements in 1 meter increments for 5’3” (lux).



Distance = Distance from the glare source (m)

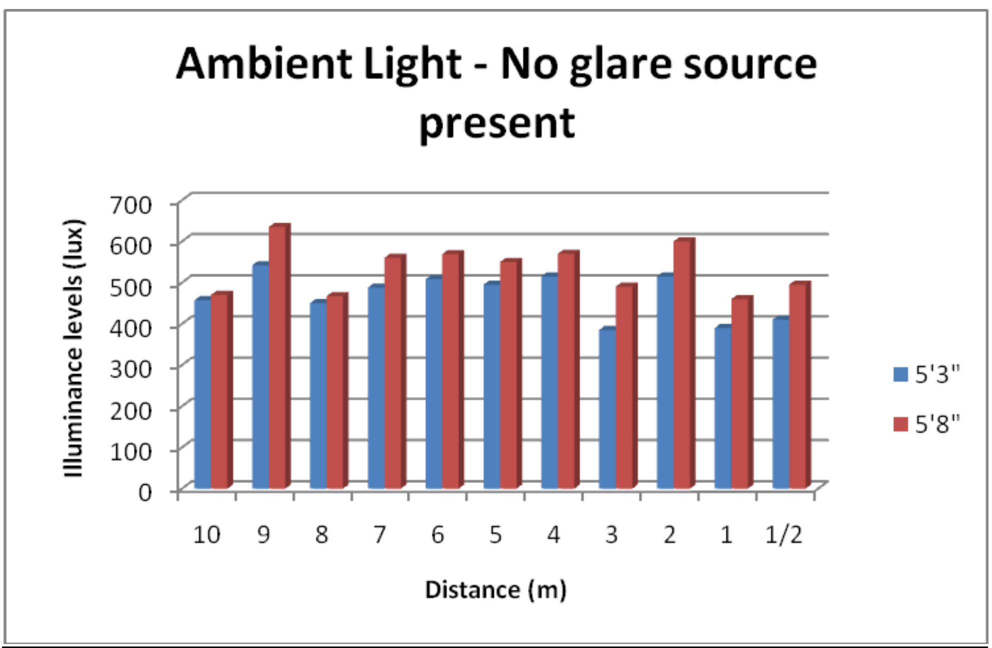
Table 3. Illuminance measurements in 1 meter increments for 5’8” (lux).



Distance = Distance from the glare source (m)

As participants get closer to the light source, the illuminance from the work light increases, which corresponds to an increase in the prevalent glare level.

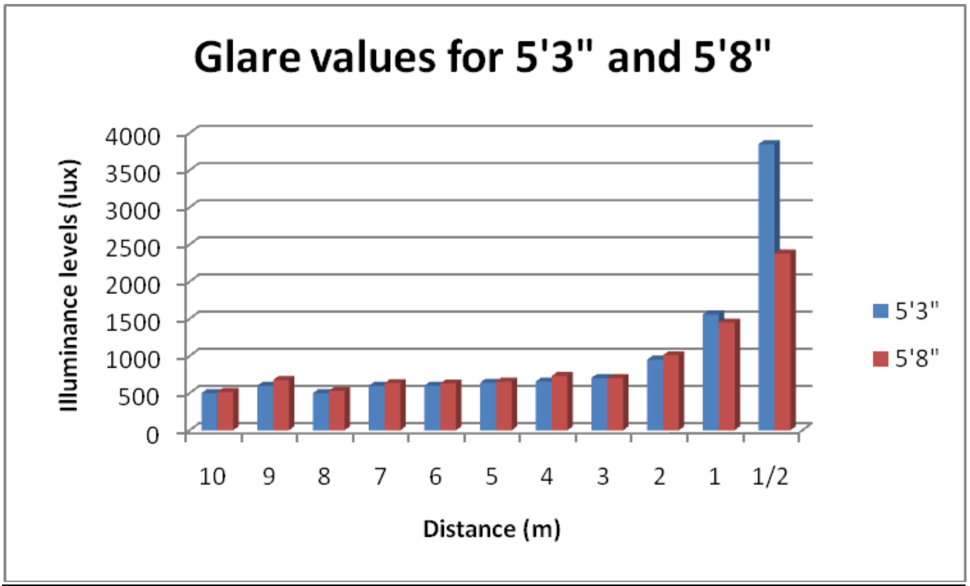
Table 4. Illuminance measurements in 1 meter increments for 5’3” and 5'8" without glare source (ambient lighting) (lux).



Distance = Distance from the glare source (m)

It should be noted, the disparities in ambient light levels from each distance are due to the ceiling light fixtures running perpendicular to the pathway. The lights were not evenly spaced throughout the room, and as such, certain increment measurments had an increase in ambient light (9m and 2m), and causing other increments (10m, 8m, 3m and 1m) to seem less bright.

Table 5. Illuminance measurements in 1 meter increments for 5’3” and 5'8" with glare source (lux).



Distance = Distance from the glare source (m)

3.2 PARTICIPANTS

Twenty-six normally sighted participants were recruited for this study. One participant failed to meet the inclusion criteria, and one was disqualified due to the inability to calibrate the Mobile Eye correctly to ascertain accurate eye tracking. The remaining twenty-four participants consisted of a young subgroup (n=12), aged 21-29 years (mean = 25.3 ± 2.5), and an older subgroup (n=12), aged 51-71 years (mean = 57.58 ± 5.9).

The guidelines of the Declaration of Helsinki were followed and the procedures applied were approved by the Office of Research Ethics, University of Waterloo. All participants gave their consent to participate and signed the informed consent letter before proceeding with the rest of the experiment.

3.2.1 INCLUSION/EXCLUSION CRITERIA

3.2.1.1 INCLUSION CRITERIA

A person was eligible for inclusion in the study if he/she:

1. Fell within either of the age groups and had full legal capacity to volunteer.
2. Read, understood and signed an information consent letter.
3. Was willing and able to follow instructions.
4. Was correctable to a visual acuity of 20/100 or better (in each eye) with their habitual vision correction.
5. Had no severe ocular disease (Age-Related Macular Degeneration). Other visual diseases may have been suitable, based on researcher's discretion.
6. Had had an ocular examination in the last two years.

3.2.1.2 EXCLUSION CRITERIA

A person was excluded from the study if he/she had:

1. Severe vision loss (Visual acuity <20/70 or visual field constriction <120 degrees by confrontation)
2. Dementia or acute confusional state.
3. Subject incapacity or unwillingness to give informed consent -at least, verbally

4. Reduced life expectancy (<12 months) due to advanced or terminal concomitant condition
5. Severe impairment of movement.
6. Any significant brain injury, cognitive impairment, or neurologic disease (including Alzheimer's disease).
7. History of alcohol or substance abuse or dependency within the past 2 years
8. Any significant systemic illness or unstable medical condition which could lead to difficulty complying with the protocol
9. Psychotic features, agitation or behavioral problems within the last 3 months which could lead to difficulty complying with the protocol.

3.2.2 PRE-SCREENING

Each participant had their habitual monocular visual acuity measured and recorded using an Early Treatment Diabetic Retinopathy Study (ETDRS) visual acuity chart at a 6m test distance.[93] They then had their monocular brightness acuity (BA) tested using the Brightness Acuity Tester at the “high” setting while viewing an ETDRS acuity chart at a 6m test distance.[94] These values were recorded.

Table 6. Visual Acuity and Brightness Acuity Scoring (Snellen) – Young Subgroup, from 6m

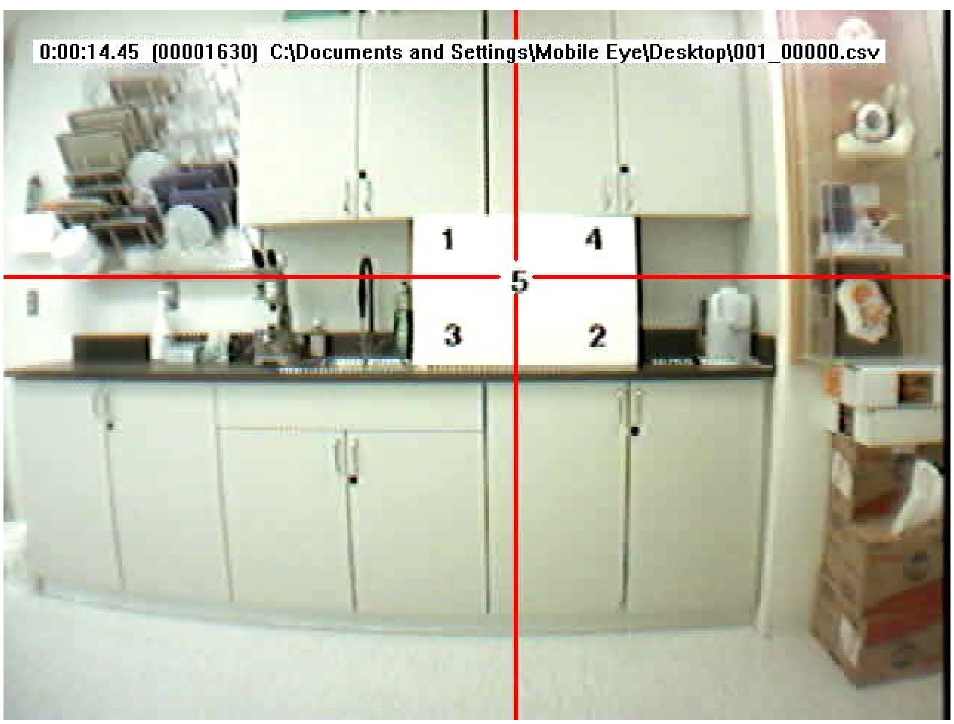
YOUNG	VA		BA	
	OD	OS	OD	OS
1	6/2.4	6/2.4	6/3	6/3
2	6/1.9	6/1.9	6/2.4	6/2.4
3	6/6	6/6	6/6	6/6
4	6/4.5	6/6	6/7.5	6/6
5	6/4.5	6/6	6/4.5	6/6
6	6/6	6/6	6/6	6/6
7	6/3	6/3	6/3	6/3
8	6/4.5	6/4.5	6/4.5	6/4.5
9	6/12	6/7.5	6/9.5	6/6
10	6/4.5	6/4.5	6/6	6/9.5
11	6/6	6/6	6/6	6/7.5
12	6/4.5	6/4.5	6/4.5	6/4.5

Table 7. Visual Acuity and Brightness Acuity Scoring (Snellen) – Older Subgroup, from 6m

OLD	VA		BA	
	OD	OS	OD	OS
1	6/7.5	6/7.5	6/7.5	6/7.5
2	6/4.5	6/9	6/6	6/9
3	6/7.5	6/15	6/9.5	6/15
4	6/4.5	6/4.5	6/6	6/6
5	6/12	6/6	6/12	6/7.5
6	6/6	6/4.5	6/6	6/6
7	6/6	6/4.5	6/4.5	6/4.5
8	6/4.5	6/4.5	6/9.5	6/9.5
9	6/7.5	6/6	6/9.5	6/9.5
10	6/4.5	6/3	6/4.5	6/4.5
11	6/7.5	6/7.5	6/15	6/19
12	6/6	6/6	6/6	6/6

After confirming the VA and BA values, participants were seated and the Mobile Eye eye-tracking system (Figure 8) was mounted on their heads. The system was calibrated to each participant's right eye (monocularly), using a 5-point chart as recommended by the manufacturer. From a 3m observation distance, each participant's gaze was serially directed to the #1 in the top left corner, #2 in the bottom right corner, #3 in the bottom left corner, #4 in the top right corner, and #5 in the center (See Figure 5). This allowed the researcher to monitor for and potentially exclude any participants who demonstrated restricted head movement due to the weight of device (n=0), or who demonstrated too much head tilt (more than 10 degrees) in either forward - back or left – right (n=0).

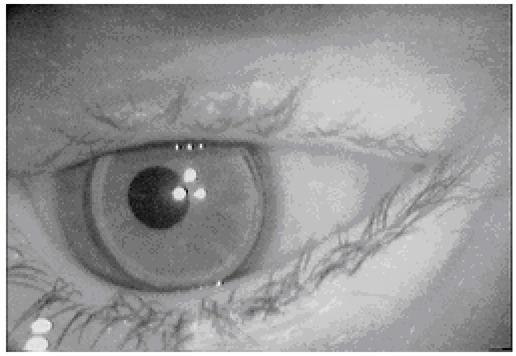
Figure 5. The 5 point calibration chart from 3m away



The ASL Mobile Eye (Bedford, MA) eye tracker monitored gaze position for the duration of the task until the task was completed (Figure 8). A scene camera recorded where the participant's head was directed while walking toward the target task and the pupil camera recorded the direction of gaze (where their eyes were pointing) while the participant completing the trial. The Mobile Eye records data at 60Hz by interspersing images taken from two cameras. Both image streams are recorded on the same digital videotape by alternating frames. As a result, the actual practical sampling of point of gaze data is 30Hz.[95] The gaze direction video was superimposed on the scene direction video and these data were analyzed frame by frame to identify head and eye posture over the trial interval.

The Mobile Eye uses a technique of eye tracking known as dark pupil tracking.[95] This method utilizes the relationship between two eye features, the pupil and a reflection from the cornea, to calculate gaze direction within an environment. A set of three infra-red (IR) lights are projected on the pupil by a set of light emitting devices (LED) in the eye camera. The IR light is not visible to the participant so it will not cause any discomfort for the participant, however the eye camera is able to detect and record it. A portion of these three lights will be reflected by the cornea and will appear to the camera as a triangular pattern of three dots, called the spot cluster (Figure 6).[95] When the eye turns, the center of the pupil will move relative to the head, and as such the Mobile Eye then compares the angle and distance between the pupil and the cornea, and then computes the angle that the eye is pointed.[95]

Figure 6. The spot cluster of infra-red lights reflecting off the cornea



Reprinted from the Mobile Eye Operations Manual, 16, Copyright 2008, with permission from Applied Science Laboratories[95]

A frame-by-frame analysis was used from the time the light source came into view until the participants turned away from the light source, returning to the original starting point. The glare source was split into three distinct zones:

1. Centered on target- Glare confrontation – Participant looked directly into the light source, targeting the ball on receptacle (red box – Figure 7)

2. Neutral or equivocal targeting – Glare Coping – Participant did not look directly into the light source, but did not look away from the source either, on the “fringes” of the glare source (area of red box to yellow box – Figure 7)

3. Peripheral targeting – Glare Aversive – Participant looks away from the glare source (outside of yellow box)

Figure 7. The three zones of distinction for determining if a participant was looking into, slightly away or away from the glare source.

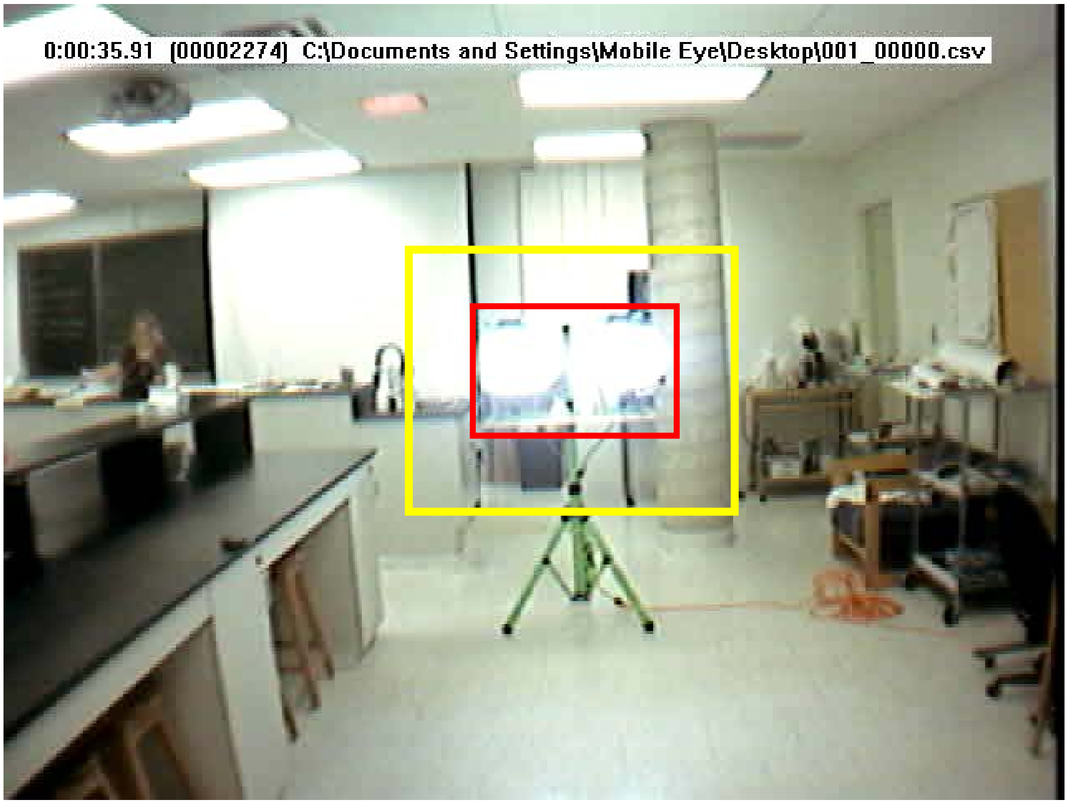
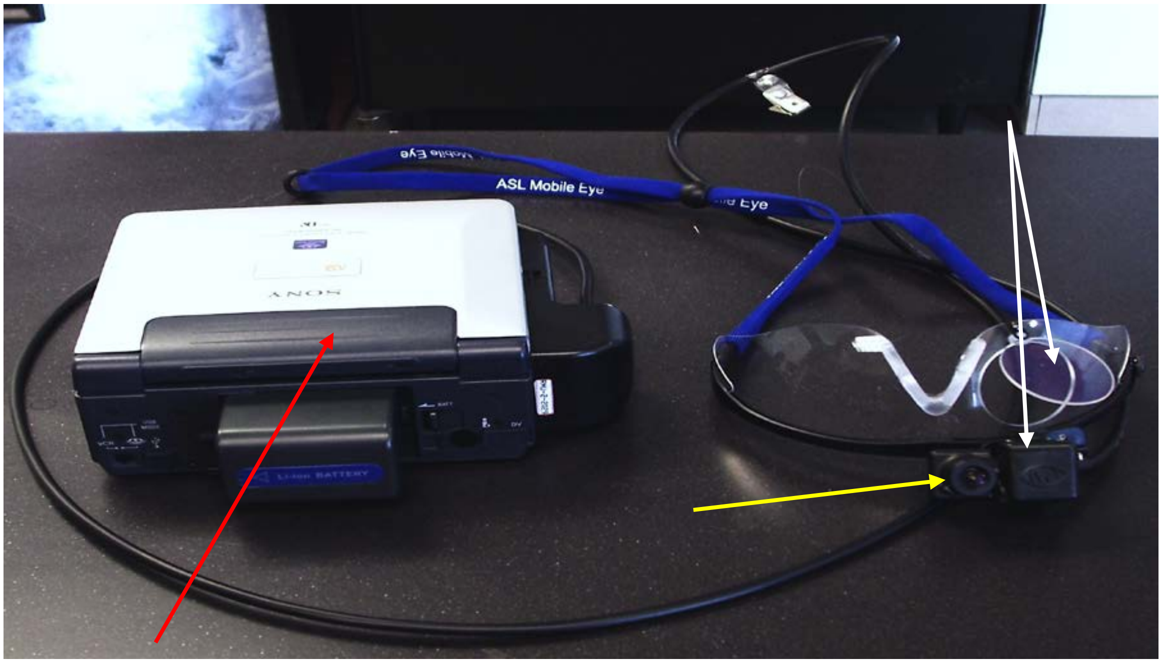


Figure 8. The ASL Mobile Eye eye-tracking unit.



Red arrow = Recording Device, Yellow arrow =Scene Camera, White Arrows = Infra-red (IR) lights reflect off monocle to enable pupil tracking

3.2.3 EXPERIMENTAL OUTLINE

Following system calibration, participants were asked to stand up and walk along a pre-set course. This required them to turn to the left and then to proceed for 5 meters along a straight path at which point they then turned to their left again and walked for 10 meters towards a small platform that was contra lit by a powerful light source (Figure 4). On the platform were two small side by side receptacles, one containing a small white ball and the other containing a similarly sized receptacle. These containers were mounted on a platform 3” directly in front of and 6” slightly beneath the powerful tandem work lights. While walking towards the light source, participants were asked to look for the ball (a white ping pong ball) on the platform and instructed that they were required to remove this ball from one receptacle and relocate it into the receptacle next to it. The receptacles were transparent and posed no contrast issues with either the glare source, or the ball. No further instructions were issued, as to ensure that there was not any bias due to researcher influence, and thereby allowing the participant to look where they wished while walking towards the glare source. The placement of the work lights ensured that they would experience significant levels of glare whenever they looked in the direction of either receptacle.

After completing the ball relocation task, participants were instructed to turn around and walk back to the starting point. They were then instructed to sit back down on the chair and face the calibration chart again, and each participant was re-calibrated one more time. This second calibration was a safeguard in-case the eye tracking system was jostled or moved during the experiment, thereby allowing the researcher to "re-calibrate" the data set without losing the data, or requiring the participant to complete the circuit again. The whole process was then repeated for a second "run" and once the participant reached the starting point for the third time, the mobile eye was taken off and the data was saved to a secure, removable hard drive. The participants were then told the purpose of the experiment, as telling them the purpose of the experiment previous to the "run" could have influenced what and where they were looking with regards to the glare source.

4 RESULTS

4.1 TIME

A number of qualitative factors were examined for this experiment. One data set described the time it took participants to complete each experimental run. These data would reveal whether one age group was slower than the other, which might suggest that they collectively experienced more difficulty completing their "runs." An independent t-test was completed looking at the length of time that each group took to complete the "run" (TIME), the results are shown below in Table 6.

Table 8. Independent T-test summary table – Young Time vs. Older Time

	T-test for Independent Samples				
	Mean - Group 1	Mean- Group 2	t-value	df	p
Youngtime vs. Oldtime	14.04250	16.04667	-2.02632	22	0.055025

Statistical analysis showed no statistical significance for the young subgroup vs. the older subgroups (p>0.05).

Figure 9. Young time vs. Old time Box and Whisker plot

This graph shows that even though the older subgroup did indeed take longer to complete the experimental run, there is not enough of a difference between the groups to become statistically significant, as seen by the overlapping error bars.

4.2 VISUAL ACUITY AND BRIGHTNESS ACUITY

Both VA and BA results were analyzed to determine whether these scores there were any significant age effects as reported in the literature.[7, 25, 36, 96]

4.2.1 VISUAL ACUITY

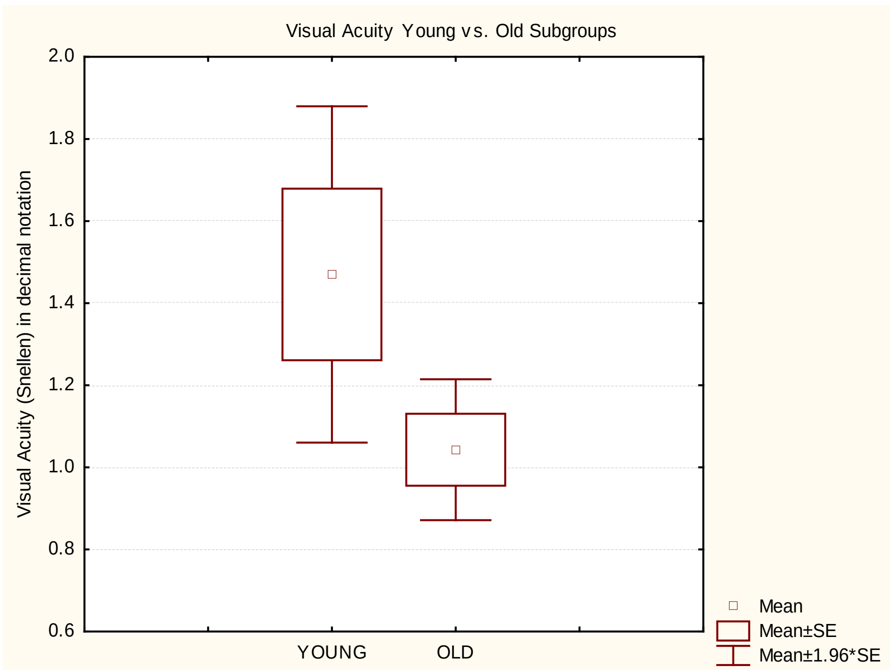
Visual acuity (VA) data was analyzed to determine whether there were any significant differences between the young and old subgroups. An independent t-test was completed looking at the each subgroup's visual acuity scores, the results are shown in Table 9.

Table 9. Independent T-Test summary table – Young VA vs. Older VA

	T-test for Independent Samples				
	Mean - Group 1	Mean- Group 2	t-value	df	p
Young VA vs. Old VA	1.470102	1.043056	1.884509	22	0.072777

Statistical analysis showed no statistical significance for the young subgroup vs. the older subgroups (p>0.05).

Figure 9. Visual Acuity Young Vs. Old subgroups



Although the younger subgroup had better VA scores, both sets of subgroups have overlapping visual acuities and the difference between the groups was not statistically significant.

4.2.2 BRIGHTNESS ACUITY

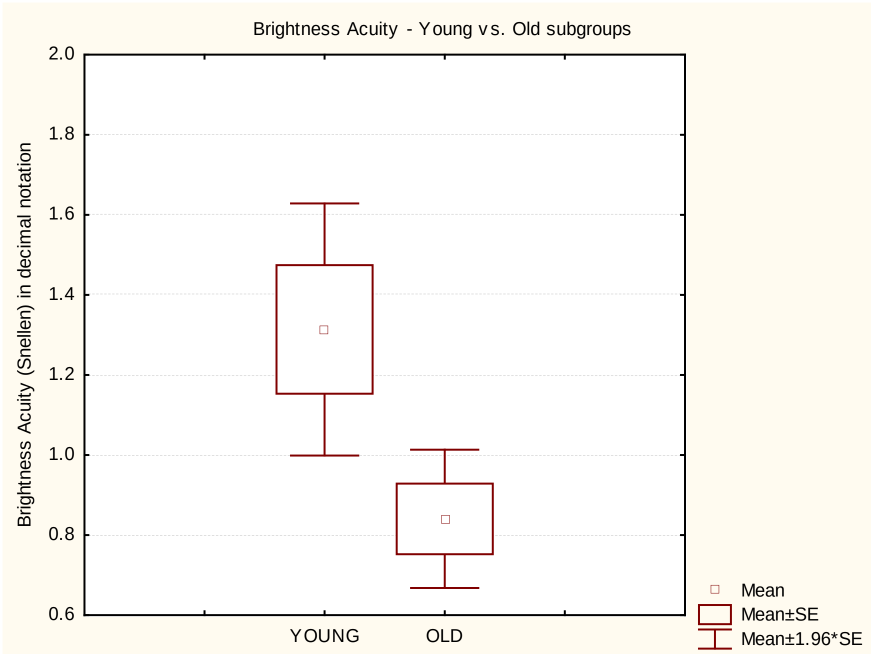
BA scores for young and old subgroups were also analyzed to see whether they predicted problems with the glare source during the experimental run. An independent t-test was completed looking at the each subgroup's brightness acuity scores, the results are shown below:

Table 10. Independent T-Test summary table – Young BA vs. Older VA

	T-test for Independent Samples				
	Mean - Group 1	Mean- Group 2	t-value	df	p
Young BA vs. Old BA	1.313743	0.840570	2.582193	22	0.017002

Statistical analysis showed statistical significance for the BA scores within the two subgroups ($p<0.05$), with the older subgroup having poorer BA scores (See Figure 11). This difference is consistent with the results reported in the literature, wherein people tend to become more susceptible to glare and brightness as they get older.[76, 83, 87, 97]

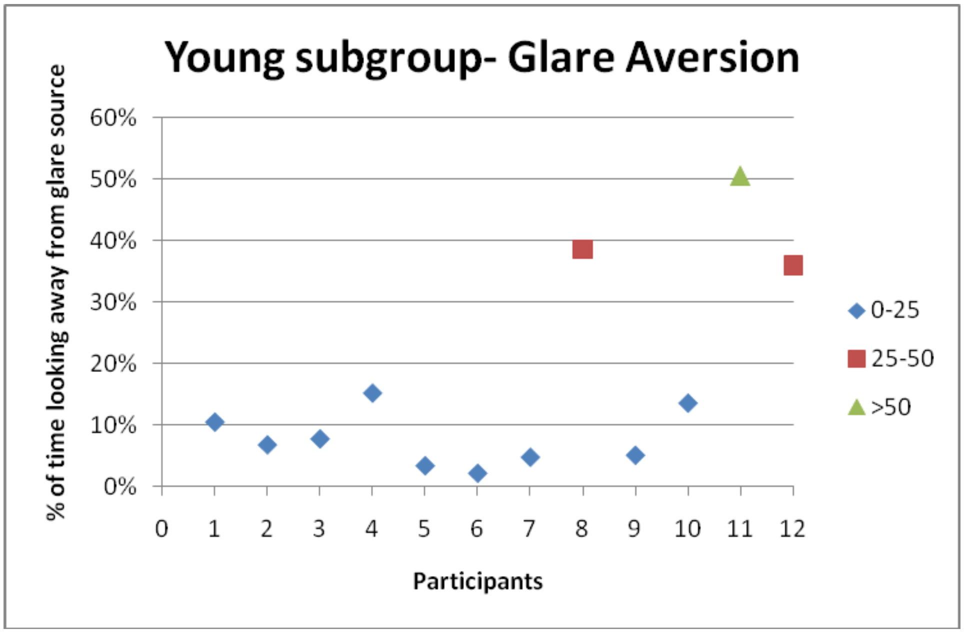
Figure 10. Brightness Acuity – Young vs. Old subgroup



4.3 GLARE AVERSION

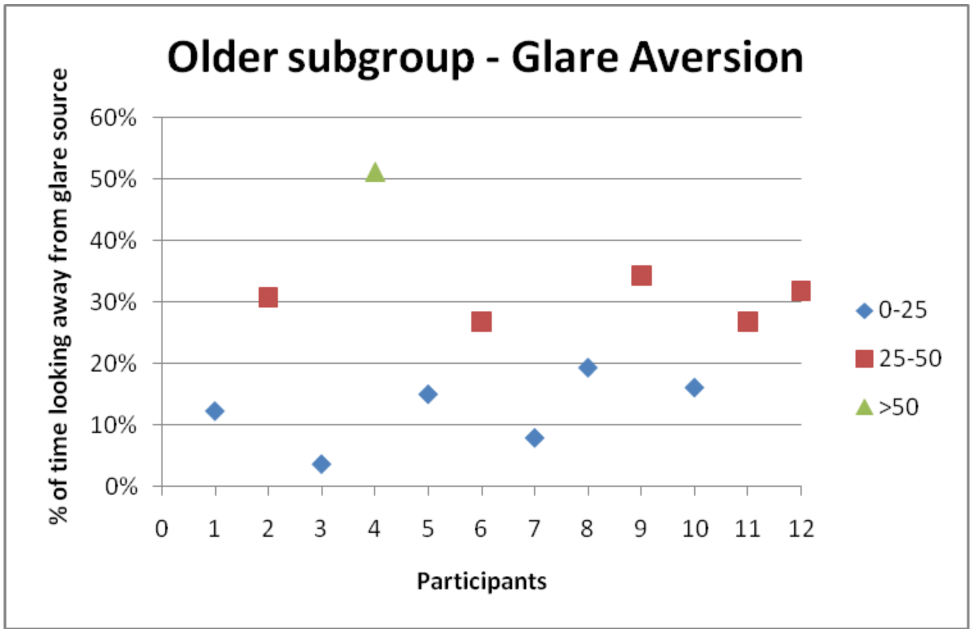
Two participants (one from each subgroup) adopted gaze aversive strategies wherein they avoided looking at the contra lit task for more than 50% of the task completion time. The following tables show the percentage of time each participant looked away. A value of 0 % would show that the glare source had absolutely no effect on the participant's ability to complete the task. Any values in excess of 50% were deemed to indicate that the glare source has a significant impact on the participant who opted to avoid looking near the source for more than half of the experimental run.

Figure 11. The percentage of time spent looking away from the glare source (glare aversive) for the young subgroup in 10% increments.



Within the younger subgroup, participant 11 had the greatest difficulty coping with the glare source, opting to avert his gaze for more than 50% (51%) of the time (green plot). Two of the participants opted to utilize a coping strategy, albeit not to a large degree, by looking away for over one third of the experimental run period. Participant 8 looked away 39% of the time, and participant 12 looked away 36% of the time (red plots). The other participants were largely unaffected by the glare source and managed to complete the experimental run while looking away less than 20% of the time.

Figure 12. The percentage of time spent looking away from the glare source (glare aversive) for the older subgroup in 10% increments.



For the older subgroup, the data are more variable. Participant 4 had the greatest difficulty coping with the glare source, and opted to avert his gaze 51% of the time (green plot). Five of the participants engaged a coping strategy, but still opted to look away more than 25% the experimental run period. Participant 2 looked away 31% of the time, participant 6 looked away 27% of the time, participant 9 looked away 34% of the time, participant 11 looked away 27% of the time, and participant 12 looked away 32% of the time, (red plots). The other participants were relatively unaffected by the glare source and completed the experimental run while looking away less than 20% of the time.

5 DISCUSSION

This pilot experiment reveals three distinct gaze strategies for completing a simple visual task in the presence of a prominent glare source exist; an aversive gaze strategy, a coping gaze strategy, and a confrontational gaze strategy. Two of the participants chose to adopt a glare aversion strategy by looking away from the glare source while walking towards it, 7 participants chose a glare coping strategy by looking towards the glare source, but not directly at it, while walking towards it. The remaining 15 participants opted for a confrontational glare strategy by looking directly unto the glare while completing the task.

Tables 8 and 9 show how the glare aversion strategies differ for each age group. In the young subgroup, 9 out of the 12 individuals had no obvious issues completing the task with the glare source present. One might have expected that participants would tend to avert their gaze as they moved closer to the glare source. Moving from 3m to 2m, the illuminance doubles to almost 1000 lux for both male and female observation heights. The illuminance further increases to almost 1,500 lux as they move from 3m to 1m. At the final task completion distance (approximately 0.50 m), the illuminance levels become almost 4000 lux for a 5’3” observer and almost 2500 lux for a 5’8” observer.

These illuminance levels rival or exceed those in the most demanding work environments (such as surgical suites or high technology inspection areas) which are in the vicinity of 2000 lux[67] and is almost 4-6x brighter than an average classroom or office setting. 9 out of the 12 younger participants, and 6 out of the 12 older participants were able to fixate onto and locate the receptacles from a distance, disregarding the levels of glare throughout the experimental run. Future research will have to be conducted to see if larger levels of glare will affect participants in the same way.

Even though there was statistical significance between the two subgroups BAT scores, it is interesting to note that the BAT results failed to predict which participants would opt for a gaze aversion response to the contra light condition under these test conditions. Participants who scored poorer on the BA did not always adopt a glare aversive strategy. The majority of the older subgroup had worse BA scores than their VA scores, and yet only one fully adopted a glare aversion strategy (looking away for more than 50% of the test run). This is somewhat surprising since BAT testing has been advocated for use by general practitioners to test glare sensitivity.[90] The simplicity of the BAT commends its use by many optometrists, but it is no longer available commercially and a new test may be needed to assess glare sensitivity in people having glare problems within a built environment.

The participants chose different strategies when walking and looking towards the glare source. These strategies fall into three different categories; glare aversion, glare coping and glare confrontation. Each of the three proposed strategies will now be discussed.

5.1.1 GLARE AVERSION

Glare aversion describes a strategy that may be used by some people when confronted with glare interference while completing a visual task, wherein individuals redirect their gaze away from the glare source in a completely different direction. Although effective for minimizing the visual impact of the glare, this may be a dangerous strategy because they then lose sight of important information. For example, there are obvious risks if gaze is directed away from oncoming traffic while driving at night or directed away from obstacles while navigating within hazardous environments. Within built environments, looking away from a glare source (such as a window[74, 81]) may lead to a fall or a collision with other objects within the setting.

Only one participant from each subgroup used this strategy, having looked away from the glare source direction for more than 50% of the time. Both of these participants opted to look around the test environment, but not in the direction of the task and the glare source. They continued to walk towards the source with their gaze averted until arriving at the task site, whereupon they completed the task while looking into the glare source. By looking away from the glare source, these individuals avoided the associated discomfort glare,[86, 98-100] but taking one's eyes off of a visual object can lead to disastrous consequences.

5.1.2 GLARE COPING

Glare aversion describes a strategy that may be used by some people when confronted with glare interference while completing a visual task, wherein individuals opts to look in the general direction of the glare source, but not directly at it. This ensures some relief from discomfort glare source. These individuals are able to cope with modest amounts of glare, but avoid looking directly into the glare source. An individual might choose this strategy if the glare source is not too bright, or they have to follow an object through a glare source. It might also be a relevant strategy when performing a high priority or risky task in the presence of an uncomfortable amount of glare, such as driving into bright headlights or navigating within glare-compromised hazardous environments. This glare coping strategy was utilized by two participants from the young subgroup, and five from the older subgroup. They were mostly able to cope with the glare being emitted from the source, but nonetheless averted their gaze more that 25% of the time over the duration of the experimental run. Another fact that should be discussed about this strategy is that although there were five participants from the older subgroup who looked away about a third of the time, the two participants from the young group looked away for a greater percentage, almost 40%. This is interesting as the younger subgroup had much better VA and BA scores, and yet they could not predict that two participants would look shy away from a glare source for almost 40% of the course run time.

5.1.3 GLARE CONFRONTATION

Glare confrontation describes a strategy that may be used by some people when confronted with glare interference while completing a visual task, wherein they opt to look directly into the glare source, thereby facing the full force of the glare, but remain able to function without any associated loss of mobility or function. This would be the ideal strategy for most glare conditions, but it is the hardest to utilize because most people do not want to look directly into a glare source. Also, if any eye or vision problems exist (such as dry eye, photophobia etc.) the person's ability to cope with glare diminishes accordingly.[101] The majority of the younger subgroup, 9 out of the 12 participants, used this strategy, only looking away for less than 15% of the course completion time. This is an expected finding since this younger subgroup had better BA scores than the older subgroup, which suggest that they should be better able to complete the task in the presence of the glare source. Half of the older participants were able to use this strategy, looking away for less than 20% of the course run. This is intriguing because this subgroup has poorer BA scores, thus one would expect them to want to use a less direct mean of glare strategy, rather than look directly into the light source.

All of the results that have been shown are based upon the first experimental run, as each participant was not told what the researcher was examining during the experiment. After compiling all of the data from the second "run," it was shown that there was a remarkable decrease in the average amount of time it took to complete the run (3 seconds faster for each subgroup), and a large increase in the percentage of time the participant looked away from the glare source (10 % - young, 13 % old). A learning effect can be attributed to the decrease in overall average time for each subgroup, and an increase in percentage of time looking away from the glare source. After each participant completed the first run, they knew what was expected of them for subsequent runs. This allowed them to complete the task faster (showing a decrease in average overall time) and it may have encouraged participants to look around more, knowing that they only had to look into the glare source to finish the task.[102, 103] This learning effect is troublesome, but any direct instruction to look towards the glare source would interfere with the participant's ability to adopt an uninhibited gaze strategy, which is what we hoped to monitor during this experiment.

With all other factors remaining identical throughout each experimental run, it is interesting to note that taller individuals (average 5’8” tall) encountered more ambient glare (without the glare source present) that shorter individuals (average 5’3” tall), ranging from 30 to 100 lux difference (Table 4). The reason for this is that the eyes of taller people are closer to the ceiling luminaries. With the glare source present, these differences become almost irrelevant, up until 2m away, as the 5’3” person than faces a much larger amount of glare, not from the ambient glare, but from the glare source itself. Taller people (5’8” average height) encounter less glare at a 0.50 m distance than their smaller (5’3” average height) counterparts because their eyes are above the experimental glare source. Further research will need to be conducted to see if various heights will have an impact on the amount of visible glare an individual can withstand, or if the glare source is placed at varying heights, will that impact individuals based on their own height.

There are a number of different options for conducting further research into different coping strategies that may be used when confronted by glare within the environment. Based on the results of this preliminary research, a larger number of participants are required, as this was a pilot study and the smaller sample size allowed for preliminary trends to be established, therefore, a larger sample size would allow for more diverse collection of results based on these trends. The results also show that a much older age range for the older subgroup (80+ years) should be used.[23, 104] The results show that there is a trend happening and using a much older subgroup of 80+ years would allow data to be collected that might mimic previous literature that shows that there are dramatic changes that occur in the impact of glare on vision for older individuals over the age of 80.[23, 104]

Another area of interest is to conduct similar studies with participants having different eye conditions and different levels of vision loss. All participants who were enrolled in this study had normal vision in both eyes, with no serious visual impairments. Participants who, have acceptable visual acuity (in accordance with the inclusion criteria) with underlying visual issues (e.g. Albinism, photophobia, severe dry eye and severe light sensitivity), might react much differently to a well-lit environment with a prominent glare source than age matched normal participants. A key objective for Universal Design is to create environments that can be used equally well by people with different ability levels. To realize this goal, we must understand the impact of environmental features, such as glare, on people with different visual abilities. Further research is required to determine the extent to which prominent glare sources interfere with people's inherent ability to perform different seeing activities in different physical environments.

Taking this idea a step further, individuals should complete a glare questionnaire to see how people subjectively report coping with certain common glare conditions before participating in a new study. This questionnaire would allow for perceived or self-reported impairment of discomfort caused by glare, thereby allowing the researcher to assess whether the individual is an acceptable candidate for that experiment, or allow for a self-reported vs. actual glare effect style of experiment.

This questionnaire could be modified to look at various examples of glare that can be modified towards the experimental goal. This would allow a researcher to look at a various glare issues, ranging from driving at night with an on-coming car's headlights, sunlight and looking from a darker area to a sunny well lit area, to indoor lighting and window placement in a built environment setting.

Glare is prevalent everywhere, in both working and outdoor environments, and yet is difficult to assess for both. Future research will need to be completed to assess whether the predictability of BAT scores will improve, given that the participants have a more profound sensitivity towards glare, thereby leading to more universal designs of how indoor and outdoor environments are created for the future.

6 CONCLUSION

In conclusion, significantly poorer BAT scores were found in the older subgroup, however, individual participant's BAT scores did not necessarily predict the ability to cope with a contra lit glare source. Although, statistically significant differences were not found between the two subgroups when examining their VA and length of time to complete the course, a trend was found, as the older subgroup consistently had poorer VA scores and took longer to complete the course. Each subgroup adopted one of three glare strategies; glare aversion, glare coping or glare confrontation, but each strategy was not utilized equally within each subgroup, but a trend did emerge whereas the majority of individuals chose the glare confrontation strategy in both subgroups. Further research must be completed with a larger sample size and a much older subgroup (80 years and older) to fully understand the glare aversion strategies one must elicit when dealing with a contra lit glare source within the built environment, and to confirm the three glare strategies proposed by this pilot study.

REFERENCES

1. Maslow, A.H., *A theory of human motivation.* Psychological Review, 1943. 50: p. 370-396.

2. Danford, G.S., *Universal design - People with vision, hearing, and mobility impairments evaluate a model building.* Generations-Journal of the American Society on Aging, 2003. 27(1): p. 91-94.

3. Demirbilek, O. and H. Demirkan, *Universal product design involving elderly users: a participatory design model.* Applied Ergonomics, 2004. 35(4): p. 361-70.

4. Mace, R.L., *Universal design in housing.* Assist Technol, 1998. 10(1): p. 21-28.

5. Story, M.F., *Maximizing usability: the principles of universal design.* Assist Technol, 1998. 10(1): p. 4-12.

6. Null, R.L., *Model Kitchen Design for the Low Vision Elderly Community.* Journal of Visual Impairment & Blindness, 1988. 82(6): p. 240-245.

7. Bailey, I.L., *Low Vision and Rehabilitation.* Current Opinion in Ophthalmology, 1991. 2(1): p. 85-87.

8. Elliott, A.J., *Low Vision Aids and the Elderly.* British Medical Journal, 1988. 296(6620): p. 501.

9. Elliott, D.B., et al., *Demographic characteristics of the vision-disabled elderly.* Investigative Ophthalmology & Visual Science, 1997. 38(12): p. 2566-2575.

10. Binder, E.F., J.P. Miller, and L.J. Ball, *Development of a test of physical performance for the nursing home setting.* Gerontologist, 2001. 41(5): p. 671-679.

11. Crews, D.E. and S. Zavotka, *Aging, disability, and frailty: implications for universal design.* J Physiol Anthropol, 2006. 25(1): p. 113-118.

12. Fried, L.P., et al., *Frailty in older adults: evidence for a phenotype.* J Gerontol A Biol Sci Med Sci, 2001. 56(3): p. M146-156.

13. Gill, T.M., et al., *A program to prevent functional decline in physically frail, elderly persons who live at home.* N Engl J Med, 2002. 347(14): p. 1068-1074.

14. Kane, R.A., *Transforming care institutions for the frail elderly: Out of one shall be many.* Generations-Journal of the American Society on Aging, 1995. 19(4): p. 62-68.

15. Landi, F., et al., *Physical activity prevented functional decline among frail community-living elderly subjects in an international observational study*. Journal of Clinical Epidemiology, 2007. 60(5): p. 518-524.

16. Storey, E. and R.L. Thomas, *Understanding the ameliorating frailty in the elderly*. Topics in Geriatric Rehabilitation, 2004. 20(1): p. 4-13.

17. Lipsitz, L.A., *Dynamics of stability: The physiologic basis of functional health and frailty*. Journals of Gerontology Series a-Biological Sciences and Medical Sciences, 2002. 57(3): p. B115-B125.

18. Haronian, E., N.C. Wheeler, and D.A. Lee, *Prevalence of Eye Disorders among the Elderly in Los-Angeles*. Archives of Gerontology and Geriatrics, 1993. 17(1): p. 25-36.

19. Klein, R., *Age-Related Eye Disease, Visual Impairment, and Driving in the Elderly*. Human Factors, 1991. 33(5): p. 521-525.

20. Massin, P. and E. Kaloustian, *The elderly diabetic's eyes*. Diabetes & Metabolism, 2007. 33: p. S4-S9.

21. Nowak, J.Z., *Age-related macular degeneration (AMD): pathogenesis and therapy*. Pharmacological Reports, 2006. 58(3): p. 353-363.

22. De Jong, P.T.V.M., et al., *Age-specific prevalence and causes of blindness and visual impairment in an older population - The Rotterdam Study*. Archives of Ophthalmology, 1998. 116(5): p. 653-658.

23. Haegerstrom-Portnoy, G., M.E. Scheck, and J.A. Brabyn, *Seeing into old age: Vision function beyond acuity*. Optometry and Vision Science, 1999. 76(3): p. 141-158.

24. Keller, B.K., et al., *The effect of visual and hearing impairments on functional status*. Journal of the American Geriatrics Society, 1999. 47(11): p. 1319-1325.

25. Kuyk, T., J.L. Elliott, and P.S.W. Fuhr, *Visual correlates of mobility in real world settings in older adults with low vision*. Optometry and Vision Science, 1998. 75(7): p. 538-547.

26. Pointer, J.S., *Habitual vs optimal distance visual acuity*. Ophthalmic and Physiological Optics, 2008. 28(5): p. 457-466.

27. Turano, K., et al., *Visual Stabilization of Posture in the Elderly - Fallers Vs Nonfallers*. Optometry and Vision Science, 1994. 71(12): p. 761-769.

28. Turano, K.A., et al., *Direction of gaze while walking a simple route: Persons with normal vision and persons with retinitis pigmentosa*. Optometry and Vision Science, 2001. 78(9): p. 667-675.

29. Bailey, I.L. and M.A. Bullimore, *A New Test for the Evaluation of Disability Glare.* Optometry and Vision Science, 1991. 68(12): p. 911-917.

30. Bane, M.C., G.E. Fish, and R. Spencer, *Disability glare testing in patients with age-related maculopathy (ARM): With and without cataracts.* Investigative Ophthalmology & Visual Science, 1996. 37(3): p. 521-521.

31. Brabyn, J.A., et al., *Visual impairments in elderly people under everyday viewing conditions.* Journal of Visual Impairment & Blindness, 2000. 94(12): p. 741-755.

32. Rubin, G.S., et al., *A comprehensive assessment of visual impairment in a population of older Americans - The SEE study.* Investigative Ophthalmology & Visual Science, 1997. 38(3): p. 557-568.

33. Bailey, I.L., et al., *Objective and Subjective Assessment of Discomfort Glare.* Investigative Ophthalmology & Visual Science, 1992. 33(4): p. 966-966.

34. Berman, S.M., et al., *An Objective-Measure of Discomfort Glare.* Journal of the Illuminating Engineering Society, 1994. 23(2): p. 40-48.

35. Bullough, J.D., et al., *Predicting discomfort glare from outdoor lighting installations.* Lighting Research & Technology, 2008. 40(3): p. 225-242.

36. Underwood, G., et al., *Eye fixation scanpaths of younger and older drivers in a hazard perception task.* Ophthalmic and Physiological Optics, 2005. 25(4): p. 346-356.

37. Dubrovsky, A.S. and K.E. Cullen, *Gaze-, eye-, and head-movement dynamics during closed- and open-loop gaze pursuit.* Journal of Neurophysiology, 2002. 87(2): p. 859-875.

38. Imai, T., et al., *Interaction of the body, head, and eyes during walking and turning.* Experimental Brain Research, 2001. 136(1): p. 1-18.

39. Land, M.F., *Eye movements and the control of actions in everyday life.* Progress in Retinal and Eye Research, 2006. 25(3): p. 296-324.

40. Patla, A.E. and J.N. Vickers, *Where and when do we look as we approach and step over an obstacle in the travel path?* Neuroreport, 1997. 8(17): p. 3661-3665.

41. Audirac, I., *Accessing transit as universal design.* Journal of Planning Literature, 2008. 23(1): p. 4-16.

42. Bernacchio, C. and M. Mullen, *Universal design for learning.* Psychiatric Rehabilitation Journal, 2007. 31(2): p. 167-169.

43. Kose, S., *From barrier-free to universal design: An international perspective.* Assistive Technology, 1998. 10(1): p. 44-50.

44. Boshchetti, M.A., *An observational study of older people's use of standard US kitchens.* Housing and Society, 2002. 29: p. 1-12.

45. Peterson, W., *Public policy affecting universal design.* Assistive Technology, 1998. 10(1): p. 13-20.

46. Center for Universal Design, *The principles of universal design (Version 2.0)*, 1997, North Carolina State University: Raleigh: North Carolina State University.

47. Allen, D., *Orientation and Mobility for Persons with Low Vision.* Journal of Visual Impairment & Blindness, 1977. 71(1): p. 13-15.

48. Jones, T. and T. Troscianko, *Mobility performance of low-vision adults using an electronic mobility aid.* Clinical and Experimental Optometry, 2006. 89(1): p. 10-17.

49. Trost, G., *State of affairs in universal design in Europe.* Fujitsu Scientific & Technical Journal, 2005. 41(1): p. 19-25.

50. Joines, S., *Enhancing quality of life through Universal Design.* Neurorehabilitation, 2009. 25(3): p. 155-167.

51. Doorduyn, K.E., et al., *Measuring the outcomes of low vision rehabilitation.* Investigative Ophthalmology & Visual Science, 1996. 37(3): p. 1385-1385.

52. Harper, K., et al., *Low vision service models in Alberta: innovation, collaboration, and future opportunities.* Canadian Journal of Ophthalmology-Journal Canadien D Ophtalmologie, 2006. 41(3): p. 373-377.

53. Li, C.Y., et al., *Low vision and methods of rehabilitation: a comparison between the past and present.* Chang Gung Med J, 2002. 25(3): p. 153-161.

54. Robbins, H.G. and B.C. Sun, *Low Vision Care and the Elderly.* Chinese Medical Journal, 1986. 99(8): p. 665-672.

55. Strong, J.G., R.J. Pace, and A.D. Plotkin, *Low Vision Services - a Model for Sequential Intervention and Rehabilitation.* Canadian Journal of Public Health-Revue Canadienne De Sante Publique, 1988. 79(3): p. S50-S53.

56. Watson, G.R., *Low vision in the geriatric population: Rehabilitation and management.* Journal of the American Geriatrics Society, 2001. 49(3): p. 317-330.

57. Marigold, D.S. and A.E. Patla, *Visual information from the lower visual field is important for walking across multi-surface terrain.* Experimental Brain Research, 2008. 188(1): p. 23-31.

58. Hill, S.G. and K.H.E. Kroemer, *Preferred Declination of the Line of Sight.* Human Factors, 1986. 28(2): p. 127-134.

59. Turano, K.A., D. Yu, and L. Hao, *Vision impairment affects the visual strategy persons use to walk toward a goal.* Investigative Ophthalmology & Visual Science, 2004. 45: p. U473-U473.

60. Turano, K.A., et al., *Optic-flow and egocentric-direction strategies in walking: Central vs peripheral visual field.* Vision Research, 2005. 45(25-26): p. 3117-3132.

61. Loviekitchin, J., et al., *What Areas of the Visual-Field Are Important for Mobility in Low Vision Patients.* Clinical Vision Sciences, 1990. 5(3): p. 249-263.

62. Taylor, H.R., et al., *Visual impairment in Australia: Distance visual acuity, near vision, and visual field findings of the Melbourne Visual Impairment Project.* American Journal of Ophthalmology, 1997. 123(3): p. 328-337.

63. Elliott, D.B., et al., *The Waterloo Vision and Mobility Study - Postural Control Strategies in Subjects with Arm.* Ophthalmic and Physiological Optics, 1995. 15(6): p. 553-559.

64. Lamoureux, E.L., et al., *The effectiveness of low-vision rehabilitation on participation in daily living and quality of life.* Investigative Ophthalmology & Visual Science, 2007. 48(4): p. 1476-1482.

65. Peel, C., et al., *Assessing mobility in older adults: The UAB Study of Aging Life-Space Assessment.* Physical Therapy, 2005. 85(10): p. 1008-1019.

66. Wedding, U., et al., *How many and which items of activities of daily living (ADL) and instrumental activities of daily living (IADL) are necessary for screening.* Critical Reviews in Oncology Hematology, 2007. 62(2): p. 164-171.

67. Illumination, I.C.o., *Guide on Interior Lighting*. 2 ed. Vol. 29. 1986, Vienna. 1-113.

68. Pritchard, D.C., *Lighting*. 4th ed, ed. L.S. Technical 1990, Essex: Longman Group Limited.

69. *Discomfort Glare in the Interior Working Environment - Commiss-Int-Eclairage.* Lighting Design & Application, 1984. 14(7): p. 1-44.

70. Haubner, P. and H. Johanni, *Investigations into Discomfort Glare in Interiors .1.* Lichttechnik, 1970. 22(6): p. 304-310.

71. Lulla, A.B. and C.A. Bennett, *Discomfort Glare - Range Effects.* Journal of the Illuminating Engineering Society, 1981. 10(2): p. 74-80.

72. Illumination, I.C.o., *Discomfort Glare in the Interior Working Environment*, 1983, Commission Internationale De L'Eclairage: Paris, France. p. 1-43.

73. Kim, J.T. and W. Kim, *Effect of Background Luminance on Discomfort Glare in Relation to the Glare Source Size.* Indoor and Built Environment, 2010. 19(1): p. 175-183.

74. Kim, J.T., W. Kim, and H.T. Ahn, *A first approach to discomfort glare in the presence of non-uniform luminance.* Building and Environment, 2008. 43(11): p. 1953-1960.

75. Kim, W. and Y. Koga, *Effect of local background luminance on discomfort glare.* Building and Environment, 2004. 39(12): p. 1435-1442.

76. Vos, J.J., *On the cause of disability glare and its dependence on glare angle, age and ocular pigmentation.* Clinical and Experimental Optometry, 2003. 86(6): p. 363-370.

77. Nazzal, A.A., *A new evaluation method for daylight discomfort glare.* International Journal of Industrial Ergonomics, 2005. 35(4): p. 295-306.

78. Wienold, J. and J. Christoffersen, *Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras.* Energy and Buildings, 2006. 38(7): p. 743-757.

79. Mills, E. and N. Borg, *Trends in recommended illuminance levels: An international comparison.* Journal of the Illuminating Engineering Society, 1999. 28(1): p. 155-163.

80. Osterhaus, W.K.E., *Discomfort glare assessment and prevention for daylight applications in office environments.* Solar Energy, 2005. 79(2): p. 140-158.

81. Tregenza, P.R. and N. Tuaycharoen, *View and discomfort glare from windows.* Lighting Research & Technology, 2007. 39(2): p. 185-200.

82. Velds, M., *User acceptance studies to evaluate discomfort glare in daylit rooms.* Solar Energy, 2002. 73(2): p. 95-103.

83. Reading, V.M., *Disability Glare and Age.* Vision Research, 1968. 8(2): p. 207-&.

84. Kim, B.S. and J.S. Lee, *Development of the nomo-graph for evaluation on discomfort glare of windows.* Solar Energy, 2007. 81(6): p. 799-808.

85. Piccolo, A. and F. Simone, *Effect of switchable glazing on discomfort glare from windows.* Building and Environment, 2009. 44(6): p. 1171-1180.

86. Rosenberg, R., *Light, glare and contrast in low vision care* 2nd ed. Clinical Low Vision, ed. E.E. Faye1984, Boston: Little, Brown.

87. Bane, M.C., et al., *Are disability glare test measures predictive of pedestrian travel problems in patients with age-related maculopathy?* Investigative Ophthalmology & Visual Science, 1997. 38(4): p. 3175-3175.

88. Rabin, J.C., K.S. Bower, and D. Chun, *Quantitative assessment of disability glare.* Investigative Ophthalmology & Visual Science, 2002. 43: p. U1179-U1179.

89. Verriest, G. and A. Uvijls, *Disability Glare in Normal and Diseased Eyes.* Clinical Vision Sciences, 1989. 4(3): p. 253-256.

90. Holladay, J.T., et al., *Brightness Acuity Test and Outdoor Visual-Acuity in Cataract Patients.* Journal of Cataract and Refractive Surgery, 1987. 13(1): p. 67-69.

91. Shields, M., Connor Gorber, S., Tremblay, M.S., *Effects of obesity based on self-report versus direct measures.* Health Reports, 2008. 19(2): p. 61-76.

92. Shields, M., Connor Gorber, S., Tremblay, M.S., *Effects of measurement on obesity and morbidity.* Health Reports, 2008. 19(2): p. 77-84.

93. Brajkovich, H.L., *Snellen 20/20 - the Development and Use of the Eye Chart.* Journal of School Health, 1980. 50(8): p. 472-474.

94. Zdral, J. and L.S. Evans, *The Brightness Acuity Tester, Disability Glare, and Cataract Evaluation in the Clinical Setting.* Investigative Ophthalmology & Visual Science, 1995. 36(4): p. S805-S805.

95. Laboratories, A.S., *MobileEye Operations Manual*, 2008, Applied Sciences Laboratories: Bedford, MA.

96. West, C.G., et al., *Is vision function related to physical functional ability in older adults?* Journal of the American Geriatrics Society, 2002. 50(1): p. 136-145.

97. Steen, R., et al., *Effect of Glare on Luminance and Color Contrast Sensitivity as a Function of Age.* Investigative Ophthalmology & Visual Science, 1994. 35(4): p. 1952-1952.

98. Adrian, W., *Modification of Method Permitting to Evaluate Glare in Street Lighting.* Lichttechnik, 1971. 23(8): p. 441-446.

99. Hopkinson, R.G., *Glare from daylighting in buildings.* Applied Ergonomics, 1972. 3(4): p. 206-15.

100. Hopkinson, R.G. and J.B. Collins, *The Prediction and Avoidance of Glare in Interior Lighting.* Ergonomics, 1963. 6(1-4): p. 379-383.

101. Drummond, P.D., *Photophobia and autonomic responses to facial pain in migraine.* Brain, 1997. 120: p. 1857-1864.

102. Argote, L., *Group and Organizational Learning-Curves - Individual, System and Environmental Components.* British Journal of Social Psychology, 1993. 32: p. 31-51.

103. Argote, L., *Organizational learning curves: Persistence, transfer and turnover.* International Journal of Technology Management, 1996. 11(7-8): p. 759-769.

104. Brabyn, J., et al., *The Smith-Kettlewell Institute (SKI) longitudinal study of vision function and its impact among the elderly: An overview.* Optometry and Vision Science, 2001. 78(5): p. 264-269.

APPENDIX A – Copyright Permissions

ILLUMINATING ENGINEERING SOCIETY

I would modify slightly:
Reprinted with permission from Mills, E. and N. Borg, Trends in Recommended Illuminance Levels: An International Comparison, Journal of the Illuminating Engineering Society, 1999, 28(1): p. 155-163, by the Illuminating Engineering Society of North America.

Regards,
Clay

Clayton Gordon
Marketing Manager
Illuminating Engineering Society
of North America
120 Wall Street, 17th floor
T 212-248-5000 x 110
F 212-248-5018
cgordon@ies.org
www.ies.org

Quoting Clayton Gordon <cgordon@ies.org>:
Hi Nick,
You have permission from the IES to use the figure in your thesis but we require a credit. Are you following a certain style with regard to Credits for other permissions?
Clay

Clayton Gordon
Marketing Manager
Illuminating Engineering Society
of North America
120 Wall Street, 17th floor
T 212-248-5000 x 110
F 212-248-5018
cgordon@ies.org
www.ies.org

APPLIED SCIENCE LABORATORIES

Excellent! Happy to hear the system worked well!

I did review with management and there is no problem using the picture with the citation for ASL.

Please let me know if I can be of any further assistance.

Have a great day!

Katie Anderson
Customer Relations Specialist
Applied Science Laboratories the authority on eyetracking
175 Middlesex Turnpike
Bedford, MA 01730
Phone: 781-275-4000 x27
Fax: 781-275-3388
Email: kanderson@asleyetracking.com