Predicting Driving Fitness in a Low Vision Clinic: Correlating Two Tasks

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Abstract:

Predicting Driving Fitness in a Low Vision Clinic: Correlating Two Tasks

Purpose: The Useful Field of View (UFOV) computer task is a visual processing assessment tool used to aid in predicting driving fitness in low vision patients. The Dynavision 2000 board tests visuomotor reaction time, and also has been investigated for training skills pertinent to driving. However, very few studies to date have investigated Dynavision scores with relation to criteria for determining driving fitness, and standard normative scores have not yet been established. This study investigated the correlation between performance on the UFOV and Dynavision tasks, as the tasks could be used interchangeably if the correlation were strong. Performance data on both tasks were gathered for normal-vision adults and low vision patients of driving age. The effect of age and gender on subject performance on each task also was analyzed.

Methods: Fifty-one normal-vision adults and 17 low vision patients participated on the UFOV and the Dynavision Mode A tasks. Each subject completed one UFOV computer trial, which measures visual processing speed (ms) as flashed images must be identified and located on the screen, and three 60-s trials on Dynavision Mode A, which determines visuomotor reaction times as a random sequence of illuminated buttons are struck on a large wall-mounted board. The UFOV Selective Attention task (Task 3) was analyzed in isolation because most normal subjects achieved the optimal threshold for Task 1, Processing speed (100% normal vision vs. 59% low vision) and Task 2, Divided Attention (84% normal vision vs. 6% low vision).

Results: UFOV and Dynavision scores correlated positively and significantly ($p<0.05$) in normal adult ($r^2 = 0.392$) and low vision subjects ($r^2 = 0.479$). Increasing age was associated with poorer scores on both the UFOV and Dynavision tasks in the normal adult and low vision cohorts. Gender effect on performance was significant only for Dynavision performance in normal vision subjects, as males performed with shorter reaction times. Gender did not significantly affect performance on UFOV or on Dynavision for low vision patients.

Conclusion: Performance on the UFOV and Dynavision tasks correlate moderately in both low vision and normal vision adult subjects. The amount of variability on one task accounted for by the other (39% for normal-vision adults and 48% for low vision patients) is not enough to support the interchangeability of the two tasks clinically. Dynavision should be further and more specifically investigated for its individual cutoffs, sensitivity, and specificity for identifying driving candidates and correlating to crash risk. If found to be related to driving capability, the results of both UFOV and Dynavision tasks could be combined to improve the recommendations concerning driving by low vision patients.

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INTRODUCTION:

This study aimed to address the general problem of how a low vision clinic can use easily conducted visual tests to predict aspects of visual performance, such as fitness to drive, in low vision patients.

By definition, "low vision" occurs when chronic vision loss or impairment is not correctable by traditional means such as conventional glasses, contact lenses, surgery, or other medical treatments. An estimated 3.5 million Americans have low vision, and 80% of these patients are over age 65. Leading causes for visual impairment include age-related macular degeneration (AMD), diabetic retinopathy, glaucoma, and other retinopathies and optic neuropathies [1]. Low vision is most commonly thought of as reduced visual acuity, or an impaired ability to read small letters on the eye chart; however, the definition of low vision or visual impairment also includes persons with reduced ability to perceive contrast, and/or a reduced field of view or blind spots within the field of vision [1]. As, by definition, low vision is not correctable or curable, rehabilitation to assist with the patient's daily needs and tasks is the only vision care option. Low-vision rehabilitation assesses a patient's remaining visual function and implements training and/or the use of optical devices or assistive technology in order to improve quality of life and independence.

One common concern for low vision individuals is the impact of visual impairment on the ability to drive a vehicle. This is true both for younger low vision patients wanting to learn to drive for the first time (i.e., those with congenital etiologies of decreased vision) and for older low vision patients wanting to continue or return to driving after becoming visually impaired. Thus, a method to predict a visually-impaired person's potential driving performance is a sought-after element in clinics that care for low vision patients. The optometric low-vision clinician does not make a final legal determination of driving eligibility, as patients with low vision have to meet state-

mandated standards for visual acuity during their licensure test. The state of Texas Medical Advisory Board also has a minimum requirement for the visual field (140 degrees of continuous horizontal visual field), but DPS neither tests driver license applicants for visual field, nor designates a testing method for clinics to use [2]. However, even though low vision practitioners do not issue or withhold driver licenses, they can and should use DPS guidelines to give counseling and recommendations for or against patients attempting to drive or continue driving. The clinician also needs to advise the patient regarding attempting the driving test outright, investigating the potential benefit in fitting a bioptic telescope for meeting the licensure requirements, referring for occupational therapy assistance for training pre-driving skills, or referring to driving rehabilitation specialists for on-road training and testing. Thus, it is important for a low vision optometric practitioner to be knowledgeable in counseling the patient, setting expectations, and being realistic with the patient's time, money, and effort put toward attempts at driving training and testing. To fill this role, the low vision clinician needs to be able to obtain and analyze useful and reliable data about the patient's visual and motor capabilities, with respect to their ability to drive, during their examination.

When evaluating driving fitness in low vision patients, a clinic will assess a few important aspects of visual function, such as visual acuity, visual fields, and the ability to discern color/contrast. However, because driving is a complex task, these few measures cannot paint the entire clinical picture for evaluating that patient's fitness to drive. Driving requires levels of visual processing and attentional speed to spot landmarks, other vehicles or obstacles, and traffic signs and signals as they rapidly enter and transit through a moving driver's visual scene. Driving, as a physical task, also requires an ability to scan the environment and the vehicle's mirrors with the driver's head and/or eyes. In fact, The National Highway Traffic Safety Administration's National Motor Vehicle Crash Causation Survey found that, among older drivers, inadequate surveillance of the visual driving scene (i.e., for oncoming vehicles or pedestrians) caused 33% of the

recorded at-fault crashes [3]. Another critical visual skill was found to be the misjudgment of the time gap between oncoming vehicles, i.e., while waiting at an intersection to turn left [3,4]. In addition, physically maneuvering a vehicle, or hitting the brakes, in a swift and appropriate manner in response to visual input requires a level of motor capability and a reasonable visuomotor reaction ability. A patient's capabilities with regard to these skills should be assessed prior to referring the patient for their on-road driving training and/or test. Again, this is efficient because training and testing for driving with an occupational therapist and/or driving rehabilitation specialist would be a costly and time-consuming endeavor. Thus, an appropriate testing protocol should be created and validated in low vision clinics for measuring skills relevant to patients' driving capabilities.

Currently, The University Eye Institute Center for Sight Enhancement (CSE) low vision clinic administers the Useful Field of View (UFOV) computer test to assess attention skills and visual processing speed. The UFOV test is a heavily researched and validated measure of visual processing as it relates to driving fitness (see pg. 12). The CSE also has access to a Dynavision 2000 board, and the clinic administers the Dynavision exercise in mode A (see pg. 24) most commonly to patients in order to assess scanning and visuomotor capabilities. However, there is much less information on the Dynavision task's sensitivity to predict driving fitness (see pg. 17). Doctors in the CSE often use the information obtained from UFOV and Dynavision scores in conjunction with examination findings to construct a clinical picture of the patient's driving fitness. As of now, there are no widely accepted normative or cutoff scores that can appropriately be used for identifying "acceptable" Dynavision scores for patients of different ages and genders, with regard to what level of reaction time must be achieved for safe driving. Thus, the question arose as to whether a patient's scores on Dynavision would correlate with their scores on UFOV, for which there are clinically accepted cutoffs for driving fitness. It is of interest clinically to know the normative values for the Dynavision task

by age and gender so that the performance of low vision patients on the task can be conceptualized by comparison to these norms. It is also of interest whether UFOV and Dynavision scores are correlated, such that either task could be used interchangeably by clinics possessing only one instrument or the other.

Two specific experimental questions were posed. (1) How do the scores for the Selective Attention subtest of the Useful Field of View (UFOV) computer task relate to the average score for the Dynavision 2000 board visuomotor 60-second task in Mode A, as a function of age (from ages 8-100) and gender, both in the normal and low vision populations? (2) How does the performance of age-and gender-matched patients with various etiologies of low vision compare to the normative values on both tasks?

The specific purpose of this study was to gather normative data for adults on the UFOV computer task and the Dynavision board, and to investigate the presence of a correlation between UFOV and Dynavision scores in normally-sighted and low vision adults. As mentioned above, the significance of a correlation between UFOV and Dynavision scores lies in determining whether performance on one task is indicative of performance on the other, for utility in better tailoring the administering of Dynavision as an assessment tool for patients wishing to drive—a purpose for which UFOV is already an accepted test with well-known cutoffs and indications [5]. A strong correlation between the two would allow the tasks to be used interchangeably. Additionally, this study analyzed the relationship between scores on the two tasks with regard to gender and age, for subjects with normal vision and low vision. The presence and nature of a relationship between these subject characteristics and UFOV and/or Dynavision scores would allow for better clinical conceptualization and application of these scores in different patient populations.

Additionally, both UFOV and Dynavision data were collected on normally-sighted children in order to investigate normative data and age-matched expectations, against which the University Eye Institute Center for Sight Enhancement (CSE) can

compare performance of low-vision children on the two tasks. The purpose of this comparison and the testing of children is not so much for the assessment of their current or future driving ability, but rather for to measure children's current functional visual and visuomotor processing and, thereby, better tailor their assistive and rehabilitative care.

While the clinical significance of obtaining an accurate predictor of driving capability is easily appreciated, it also should be noted that a proper, thorough, and reliable assessment of driving fitness can have a profound effect on each patient and the community. Because UFOV and Dynavision can be used in conjunction with clinical examination findings when recommending or withholding recommendation of on-road driving training and tests, their capability to evaluate each patient's driving fitness can have significant repercussions for patient independence and lifestyle. This consideration highlights the necessity of task-normative score cutoffs and conceptualizations that are adjusted for factors like age and gender. A thorough evaluation of the UFOV and Dynavision tests themselves is a necessary precursor to evaluating the patient with those measures.

Anticipated results:

Based on clinical observation of patient performance, it was hypothesized by the CSE clinicians that UFOV and Dynavision scores would positively correlate in normal-vision adult and child, and low vision subject populations, such that subjects who perform well on one test would generally perform well on the other, and those with more average or poorer scores on one task will similarly score average or poorly on the other. It was similarly hypothesized that, in the aggregate, low vision patients would perform with significantly poorer scores (slower processing speeds and longer reaction times) than adults with normal vision on both tasks.

Possible interpretations:

If, as hypothesized, a correlation between UFOV and Dynavision were found to exist and each task's score serves as a strong predictor of performance on the other, a low vision clinic seeking to predict a patient's driving potential could administer only one of the tasks, either UFOV or Dynavision, to obtain an assessment of visual skills used in driving. However, if the two tasks do not significantly or strongly correlate, or if there is highly variable relationship between UFOV and Dynavision scores among subjects, then further research is indicated for the Dynavision apparatus and the relationship between Dynavision scores and crash risk/driving performance. The possibility of an independent link between Dynavision and driving performance would indicate that both UFOV and Dynavision could be administered to potential drivers to increase sensitivity and specificity of the evaluation of potential driving candidacy. In that case, UFOV and Dynavision would separately test visual processing and visuomotor abilities to get a more holistic prediction of driving risk. If a significant change in performance on either task occurs as subject age increases, then clinicians should consider age differences when creating performance expectations for older patients. Similarly, if significant performance differences exist for males versus females, or middle-aged versus older adults on these tasks, then different clinical criteria may need to be implemented for these patient subgroups.

To date there has not yet been any research comparing the scores on these two tasks to determine their correlation, or for their possible interchangeability.

REVIEW OF LITERATURE:

On Low Vision Drivers:

Driving is a common topic of concern and discussion in low-vision assessment and rehabilitation clinics. The determination of the most sensitive and specific predictors of on-road driving capability is of paramount importance, as refusal to recommend a patient for on-road driving due to a low score on one or more tasks that predicts driving performance can be life-changing for the patient. Driving for many individuals is a symbol of independence as well as a necessary means of transportation. Of the 3.5 million Americans with low vision, approximately 80% of those are over age 65; the prevalence of low vision in our population is about 1% for people in their sixties and increases to about 20% for people in their nineties. Thus, most low vision patients do not become visually disabled until later in life [1]. Because many low vision patients are elderly, driving ability holds particular importance because of its implications on the patients' ability to be independent, including care for themselves. Furthermore, the unfortunate reality is that losing the ability to drive can be socially isolating, and limits the patient's access to healthcare and employment [6]. In fact, cessation of driving has even been linked to increased depressive symptoms for the elderly population [6,7].

Due to the threat that low vision poses on the ability to safely operate a motor vehicle, assessing crash risk is a common topic of research for low vision clinics. Many studies have investigated correlations between characteristics of low vision drivers and their risk of being involved in a motor vehicle crash. For instance, it has been shown that age and visual impairment correlate positively with motor vehicle crash risk [8]. In fact, the Overview of Injury in Texas and Role of EMS/Trauma Registry found that in 2004, motor vehicle injuries were the leading cause of injury-related death in adults aged 65 to 74; motor vehicle crashes were the second leading cause of injury-related death (after falls) in adults over 75 [9]. Additionally, in 2014, more than 5,700 older adults were killed and more than 236,000 were treated in emergency departments for motor vehicle

crash injuries. This means approximately 16 older adults are killed and 648 are injured in crashes on average every day [10,11]. Other studies, however, found that presence or absence of previous driving experience, or increased numbers of miles driven, correlated more with crash risk than increased age did for low vision drivers [12,13].

While many different characteristics of low vision drivers can factor into their crash risk, potential drivers must first be assessed individually for their capabilities, ideally with an objective measurement test, in the clinical setting or closed-road setting, and in a manner that is most sensitive and specific at determining skill level for the task in question: on-road driving.

2) On Useful Field of View (UFOV) (See pg.18 for information on UFOV subtests and test administration).

One heavily researched and consistently described clinical test related to the visual demands of driving is the Useful Field of View computer task (UFOV). Research has shown that including UFOV in the pre-driving testing battery improves a vision exam's predictive power to appropriately assess driving performance [11]. As described above, The University Eye Institute Center for Sight Enhancement (CSE) low vision clinic administers the UFOV test to assess attention skills and visual processing speed. Assessing visual attention and processing capabilities in drivers is important because good visual acuity is not sufficient to ensure success with the complex visual components of driving; in fact, Rubin et al. found that, while UFOV was a significant predictor of crash involvement, visual acuity was not [13]. Thus, standard state driver licensing tests of acuity may not be sufficient to identify at-risk drivers.

Attentional capacity and the ability to quickly perceive, identify, and locate objects in the visual field are abilities tested by the UFOV program, and are crucial for motor vehicle drivers for safe navigation, because the appropriate deployment of visual attention allows a driver to extract relevant or salient information from a complex visual

scene very quickly, at a preattentive processing level [14]. For example, an unexpected traffic light change or approaching vehicle can catch the driver's attention, allowing them to safely maneuver or stop in time. According to Owsley et al., "Because driving is a complex visual/cognitive task, it is unlikely that the assessment of eye health and visual function alone would be sufficient to predict accident frequency. Eye health and visual function variables measure the quality of visual information available to the driver. Even if the incoming visual information is not degraded, different drivers may attend to different aspects of the scene as well as interpret the visual information in different ways. Thus, any model that attempts to predict accidents on the basis of visual input must include measures of information-processing skills. One such skill is visual attention" [14]. Tests of visual acuity and visual field alone fail to include such considerations, as "…standard clinical visual field tests may not fully describe the difficulties that may be encountered by people with visual impairment undertaking tasks in the cluttered environments and multiple demands of everyday life" [15]. Explicitly, the driver must be able to pay selective attention to salient information amidst a cluttered visual scene, at a very quick, even preattentive, speed of processing. This is the basis of UFOV's Task 3, Selective Attention (see pg.18).

UFOV scores have been linked consistently to primary visual processing and visual attention abilities [16]. A previous study by Ball et al. considered many aspects of the human visual information-processing system, including health of the eyes and vision, visual sensory function, visual attention including the Useful Field of View, and cognitive skills by a battery of neurocognitive tests, and related these to the subject's crash frequency [17]. This study found that the strongest predictors of vehicle accidents in the study were UFOV and mental status, which together accounted for 20% of accident variance. While eye health and visual sensory function did contribute to UFOV performance, these variables were not themselves found to be correlated to accidents [17]. Another study, by Owsley et al., found that tests of the Useful Field of View (including

processing speed, divided attention, and selective attention tasks) were the most predictive measure of motor vehicle accidents involving the participants during the previous five years [14]. In fact, another study by Goode et al. evaluated UFOV Tasks 1-3 scores and neuropsychological and cognitive test scores in relation to state-recorded at-fault crashes for the subjects; it was found that UFOV was the single most important crash predictor, with sensitivity and specificity of 86.3% and 84.3% respectively [18]. Persons whose UFOV scores were reduced by 40% or greater from normal values on all 3 UFOV subtests when combined were six times more likely to have been at-fault for an automobile crash in the previous 5 years, compared to persons with minimal or no reduction in UFOV performance [17]. For reference, a 40% or greater reduction in UFOV corresponds to a threshold value larger than or equal to 100ms on Task 2, and a threshold value larger than or equal to 350ms on Task 3 [5]. This outcome was supported by Ball et al., who reported that the UFOV had a sensitivity of 89% and a specificity of 81% in predicting which drivers had a history of automobile crashes [18].

Another study that investigated visual and medical characteristics of older drivers found that history of any falls and UFOV scores were most related to crash risk, finding that patients whose UFOV was reduced by $\geq$30% had more overall crashes as well as more at-fault crashes [19]. Rubin et al. reported that a reduction in overall score on a composite of the 3 UFOV Tasks along with glare sensitivity and visual field loss were significant predictors of automobile crash involvement, while visual acuity, contrast sensitivity, and stereoacuity did not correlate with crashes [16]. However, it has also been proposed that many drivers with low contrast sensitivity self-limit or even cease driving, so crash risk alone may not be an appropriate indicator of driving impairment [20]. A study by Owsley et al found that contrast sensitivity impairment, specifically in cataract patients, was in fact associated with crash risk [21]. Even so, no state currently administers tests of contrast sensitivity prior to motor vehicle licensure.

For UFOV test administration:

UFOV has been shown to have good reliability coefficients between the first test and a retest; the correlation coefficient for the 3 composite UFOV subtests was shown to be 0.88 in a group of 70 participants taking all 3 UFOV subtests approximately 2 weeks apart [5]. Although some studies have shown that UFOV testing shows some learning effect, with test-retest measures showing less processing time needed for subjects on their second UFOV attempt (with scores remaining statistically constant after the second attempt, [22] I deemed it impractical to rely on low vision patient and normal-vision subject return for retest, and time constraints during the low vision exam are prohibitive to repeating UFOV twice in one visit for a test-retest measure. Thus, I decided to administer one UFOV trial, including all 3 subtests, to both the normal vision and low vision cohorts for this study.

Anticipated Results for UFOV:

UFOV scores have been analyzed in relation to subject characteristics like age, gender, race, visual acuity, education, mental status, etc. Increased age has been consistently related to poorer baseline UFOV scores and a larger rate of decline in UFOV performance over time, unrelated to the aforementioned covariant factors [23]. UFOV scores (in this study, the sum total of the thresholds for all tasks) were found to follow a curvilinear pattern, with threshold decreasing (scores improving) and then increasing (scores declining) over a five-year period in control adults over age 65 [23]. The initial improvement represents the learning effect seen with UFOV, and the subsequent worsening is attributed to increasing age. Other studies have shown that UFOV performance improves in children until about age 14, when adult levels are generally reached [24]), and that performance in individuals above age 40 declines (longer processing thresholds for UFOV in older adults [25, 26]. Thus, we hypothesized that we

also would see this age effect in UFOV testing. There was no expected gender difference on the UFOV task.

3) ON DYNAVISION: (See methods pg. 24 for Dynavision task descriptions and test administration).

There is much less evidence in the literature that explicitly correlates Dynavision scores with assessments of driving performance or crash risk. Only one previous study by Klavora et al, which investigated a small cohort of 10 post-stroke patients, found post-hoc that a threshold score of 50 hits in 60 seconds on the Dynavision Mode A task was a significant differentiator between subjects who passed and failed an on-road driving test [27]. However, this score was achieved in these patients after a 6-week Dynavision training program. Then, a single follow-up study, also by Klavora et al, found that this 50 hit threshold had a 66% accuracy for predicting pass/fail outcomes on an on-road driving test in 56 participants [28]. No research explicitly links Dynavision scores with crash record.

However, the the Dynavision 2000 board does test skills related to the complex visual and physical requirements of operating a motor vehicle. Dynavision is "…an apparatus designed to test and train visual scanning, peripheral visual awareness, visual attention, and visuomotor reaction time across a broad, active visual field. Dynavision also requires execution of visuomotor response sequences, basic cognitive skills (short-term memory), and physical and mental endurance" [27]. Peripheral visual field awareness and the ability to scan with the head and eyes for salient information in the visual periphery (i.e., an illuminated light in the Dynavision task, versus vehicles, obstacles, and pedestrians in a driving visual scene) are critical for safe driving [3]. Similarly, Dynavision has been shown to be a reliable indicator of a person's visuomotor reaction time [29], which is a skill necessary for driving, as drivers need to quickly observe relevant changes in their surroundings and physically react to their visual

environment by rapid adjustments in controlling the vehicle, i.e. pressing the pedals or turning the steering wheel. As the skills tested by Dynavision appear to be related to those required in driving, it is plausible that Dynavision scores are related to on-road driving capabilities, although that link should be explored further.

Dynavision has also been tested for its efficacy in training skills for driving, as some small studies and case reports of post-stroke patients who received Dynavision training improved their reaction time and concurrently had better overall on-road driving test scores [27, 30]. Another study by Crotty et al., however, showed that the benefits of Dynavision training are limited to the Dynavision task and do not significantly aid persons in passing an on-road driving test [31].

On Administration of the Dynavision task:

The Dynavision task shows good repeatability, with a test-retest correlation coefficient of 0.71 – 0.73 [32]. Another study by Klavora et al. showed an intraclass reliability coefficient of .88 on multiple (five) trials for the subject-paced Mode A Dynavision task*. Some of the variance among trials is accounted for by a learning effect, as subjects' performance improves with practice; however, scores appear to level off after 2 trials, as all significant differences in scores were found to occur between trials 1 and 2 in this study [33].

For these reasons, I administered the Dynavision task 4 times, allowing the subject to practice during the first trial, and averaged the subsequent 3 trials to obtain their recorded score. Reaction time and visuomotor capabilities as measured by the Dynavision apparatus also appear to depend upon a subject's age and gender, with older persons and females exhibiting longer reaction times than younger persons or males [34]. Thus, we recorded and analyzed age and gender with respect to performance on the tasks.

* The intraclass correlation coefficient describes the assessment of consistency of a measurement made multiple times; a value between 0.75 and 1.0 is considered to display excellent agreement.
[Cicchetti, Domenic V. (1994). "Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology". *Psychological Assessment*. **6** (4): 284–290.].

Anticipated Results for Dynavision:

Although there exists no aggregate normative data for Dynavision performance, I hypothesized that, like the UFOV, Dynavision scores would show a non-linear age effect; specifically, an increase in successful hits per minute (decreasing reaction time) from childhood until maturity is reached, and then a decline in performance (increase in reaction time) for subjects beyond the age of approximately 40. It was hypothesized that males would perform the visuomotor Dynavision task with shorter reaction times than females, as indicated by previous literature [34]. It was similarly expected that low vision patients would perform with longer reaction times on average than the control population, across all ages and both genders.

METHODS AND SPECIFICATION OF EXPERIMENTAL SUBJECTS:

The goal of this project was to gather normative data for the Dynavision board for men and women with a range of ages, and to compare each subject's UFOV score to his or her Dynavision score. Two principal populations were sampled: normal-vision adults (subjects without any uncorrectable vision loss), and low vision adults.

Normal-Vision Subjects:

Normal-vision adult subjects for this study were recruited from available University of Houston College of Optometry students, faculty, and staff, as well as the friends and family of the aforementioned. Study recruitment flyers were posted in meeting areas and on visible bulletin boards around the College. Additionally, much of the recruiting was performed via word-of-mouth in the classroom and at the offices of faculty and staff. Before the start of data collection, the experimental protocol and recruiting procedures were reviewed and approved by the University of Houston Committee for the Protection of Human Subjects.

Fifty-one (51) normally-sighted (non-low vision) adults (29 F, 22 M, average age 43.67$\pm$14.74, range 21-73) were recruited to participate in the UFOV computer task and on the Dynavision 2000 board test. Inclusion of subjects for the normal adult cohort was based on adult status (all over 18 years of age), and the verbal denial of any uncorrectable visual impairment or physical impairment that would hinder the ability to complete the tasks. No persons under the age of 18 or with any uncorrectable visual impairment or any motion-limiting physical disability were included in the sample.

Normal-vision adult subjects attended one session, of approximately 30 minutes, without any other follow-up. Subjects were given the informed consent document to read, and the purpose and method of testing was described; all subjects were offered an

opportunity to ask questions, and each subject was required to sign and date the consent document, and verbally deny visual or physical impairment in order to participate.

After granting informed consent, each subject was administered both the UFOV and Dynavision tasks. Each subject completed one trial of the UFOV computer task, including the Processing Speed, Divided Attention, and Selective Attention tasks (see pg. 20), and one practice trial and three recorded 60-second trials in Mode A of the Dynavision 2000 board. A Microsoft Excel Random Number function, which generated a random decimal between 0 and 1, designated which task each subject completed first: if the number generated was below 0.5, the Dynavision trials were done first; if the generated number was above 0.5, the UFOV trial was done first.

Low Vision Subjects:

Low vision population subjects consisted of patients seen for a low vision examination by appointment at the University Eye Institute Center for Sight Enhancement, and analysis included only those patients willing to participate and fill out an informed consent document during their exam, to allow for the inclusion of their scores. These patients participated on both UFOV and Dynavision tasks as part of their clinical examination, and they were included in this study only if they had no physical impairment that would hinder performance on the tasks.

Seventeen (17) low vision patients of driving age (9 F, 8 M, aged average 33.35±17.82, range 16-83) agreed to participate, and performed both UFOV and Dynavision as part of their examination. These patients performed the study tasks during their appointments of varying lengths, and the appointments may have included a variety of other testing procedures before and/or after UFOV and Dynavision were administered. In the Center for Sight Enhancement, low vision patients are administered UFOV and Dynavision during their examination if the patient is currently driving or expresses interest in learning to drive or returning to driving. Inclusion of low vision study subjects

was based upon driving-age status (16 or over) and denial of any physical impairment that would hinder performance on the tasks.

Low vision patients were given (and as needed, aided through) a large-print copy of the informed consent document, and were counseled on the purpose of the study and allowed to ask questions. After providing informed consent, the UFOV and Dynavision tasks were administered to the patients in a pseudo-random order, per preference of the examining clinician. Like the subjects with normal vision, the patients completed one trial of the UFOV computer task, including the Processing Speed, Divided Attention, and Selective Attention tasks (see below), and one practice and three recorded 60-second trials in Mode A on the Dynavision 2000 board. Scores for UFOV and Dynavision, as well as the age, gender, and etiology of low vision were recorded for these subjects. A table of these characteristics for the low vision subjects is seen in Appendix A.

Additionally, a pilot study was initiated to gather normative data for children on the UFOV and Dynavision tasks. While there has been one investigation of normative performance on the UFOV test in children, there exists no study to date that displays expected or normative values for a child on any Dynavision task [12]. It was thought that data obtained on children with normal vision would be helpful to the CSE clinic for conceptualizing the visuomotor capabilities, peripheral visual awareness and scanning capacity of children with low vision. Eight normal-vision children were recruited.

UFOV Task Details:

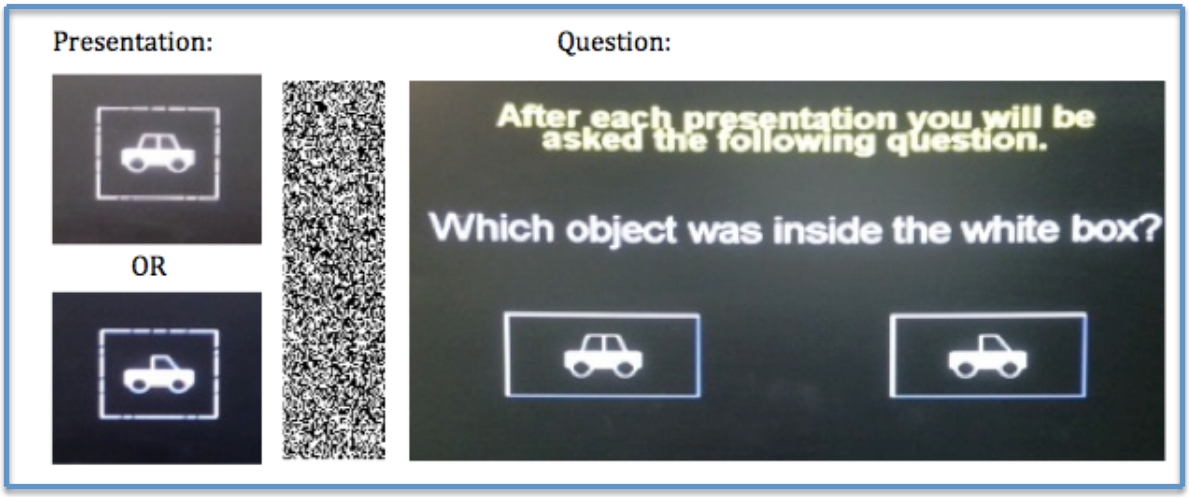
The Useful Field of View (UFOV) task is administered by a computer program, and tests visual processing abilities of the subject. It has three subtests: Processing Speed, Divided Attention, and Selective Attention.

The computer program was designed to present stimuli on a 17-inch computer monitor, and our clinic's newest version of the software was compatible with the Windows 7 operating system. The refresh rate of the computer monitor must be

appropriate to display the targets with the appropriate presentation speed. We set the refresh rate to 75 Hz to allow the fastest programmed flash presentation, 14.8 milliseconds, to display correctly. The output of a photocell with a rapid response time was displayed on an oscilloscope to verify the duration of the stimulus presentation, which was found to be accurate. Recommended viewing distance from the computer monitor while performing the UFOV task is 18-24 inches, as indicated by the UFOV User's Guide [5]. At this viewing distance, each presented car and truck stimulus (i.e., the central car/truck target in each task, and each peripheral target for tasks 2 and 3) is approximately 1 inch wide, corresponding to a visual angle of 2 to 3 degrees. The subject views the computer screen binocularly, with his or her habitual vision correction if used for that working distance. The UFOV User's Guide indicates that best spectacle correction is recommended, but small refractive inaccuracies should not interfere with testing as even "…a substantial degree of blurred vision" does not degrade performance on the three tasks [5]. The subject operated a computer mouse during each task and responded by clicking on one of the answer choices presented on the screen.

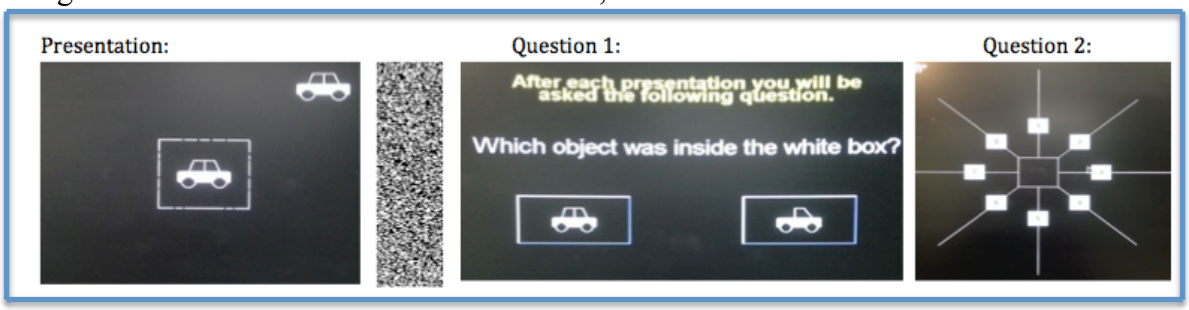
The first task, Processing Speed, involves a central fixation box and a brief flash of either a simple car shape or a simple truck shape, which is presented for a variable number of milliseconds (Figure 1). After the brief presentation and a second of entire-screen visual noise, the subject was asked to identify which vehicle (car or truck) flashed in the fixation box by clicking on the appropriate icon on the computer screen. Presentation time varies from 500 ms to 14.8 ms; two successive correct answers cause the computer program to shorten the duration of the car or truck presentation on the next trial, whereas an incorrect response lengthens the subsequent presentation time. This program uses the staircase method to estimate the 71% correct threshold, to determine the threshold processing speed for correct image identification [5].

Figure 1: Presentation of UFOV first task: Processing Speed.



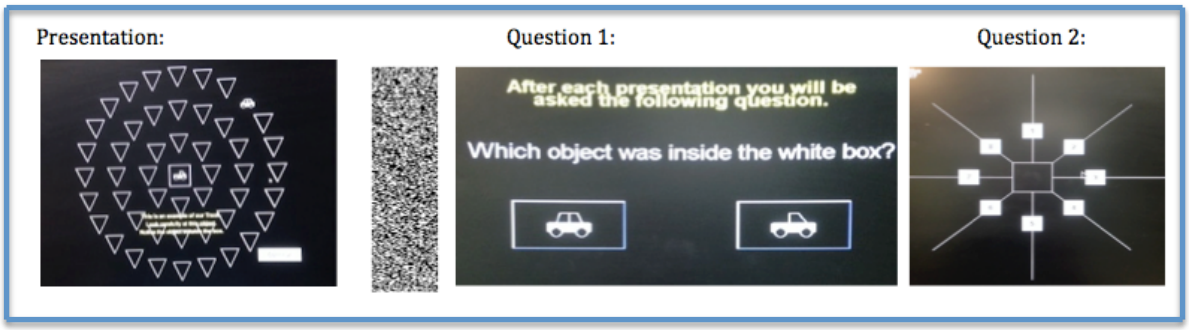
The second UFOV task, Divided Attention, is similar to the first task, but with an added level of difficulty: the flashed image still presents either the car or the truck shape in the center fixation box, but now also simultaneously includes a car in the periphery along one of 8 meridians (Figure 2). The subject must answer two questions for this task: 1) What was the image in the center box (car or truck)? And, 2) Along which one of the 8 meridians was the peripheral car located? The correct answers are selected by clicking on the central object seen and then clicking on the meridian on which the peripheral object was seen. Once again a two-down, one-up staircase method controls the duration of successive presentations to find the subject's threshold duration, at 71% correct, for the divided attention task.

Figure 2. Presentation of UFOV second task, Divided Attention.



The third UFOV task, Selective Attention, is similar to the second task, in that either a car or the truck flashes in the center fixation box, and a peripheral car simultaneously flashes along one of 8 meridians; however, this task also features 47 distractor triangles arrayed around the fixation box to obscure the location of the peripheral car (Figure 3). Subjects were asked the same two questions as in the Divided Attention task: 1) What was the image in the center box (car or truck)? And, 2) Along which one of the 8 meridians was the peripheral car located? The subject's threshold is again determined by varying the presentation duration, with every two correct answers prompting the program to decrease the presentation time, and each incorrect answer producing an increase in the presentation time.

Figure 3. Presentation of UFOV third task, Selective Attention



Subjects completed each of the three UFOV subtests once, in the order presented above. After each subtest, the UFOV computer program displays the subject's threshold, in milliseconds, for the target duration corresponding 71% correct identification for each task [5].

For scoring, the computer program calculates and displays the subject's threshold in milliseconds for each task; based on these results, the program classifies each subject into one of 5 categories for driving crash risk based on the estimated values of visual processing speed: Category 1 being Very Low Risk to Category 5 being Very High Risk

for a motor vehicle crash. See Appendix B for the table of cutoff threshold values for each category [5].

Dynavision Task Details:

The Dynavision 2000 is a 120x120 cm square board with 64 square button lights (each 2x2 cm) arranged in 5 concentric rings that are centered vertically and horizontally on the board (Figure 4). Slightly above the geometric center of the board is a LED screen, which is not illuminated in Mode A (although it can be used in other Dynavision tasks) that can serve as a height landmark. In this study, the apparatus operated in the "subject-timed" Mode A as follows: for 60 seconds, the board randomly illuminates single buttons in succession; subjects were instructed to press each illuminated button one at a time, as quickly as possible. Each time after a button is correctly struck, the apparatus advances to illuminate a new randomly selected button, which the subject then has to find and strike, and so on. The goal of the exercise is to obtain as many hits of the lit buttons as possible in the 60-second time frame. Other, more complicated tasks on the Dynavision board include the apparatus-paced mode, in which the buttons remain illuminated for a set duration, such as 1 second, and will advance to light the next button whether or not the subject makes a correct hit. Even more complicated tasks include numbers displayed on the LED screen (from one to many digits, displayed from less than a second to longer periods of time) that the subject has to recite while pursuing illuminated buttons in the aforementioned manner. Again, for this study, the Dynavision task was performed on the subject-timed Mode A only.

Subjects were encouraged to stand at arm's length from the Dynavision board, with the board adjusted on the wall so that the height of the LED screen, which is slightly above the geometric center of the board, was approximately at eye level, and the uppermost and lowermost buttons were all within reach. To locate the lit buttons, subjects were permitted to scan all areas of the board by moving their head and eyes (i.e., the subjects did not have to fixate at the center and use only peripheral vision to hit the

peripheral buttons), and they could use any part of their hand or any strategy to hit the buttons. Scanning is permitted because peripheral visual awareness leading to head and eye scanning, along with the visuomotor reaction ability, are the tested skills that are assumed to be most pertinent to driving ability. These testing conditions were applied as outlined in the Dynavision's manual [35].

Additionally, the Dynavision manual outlines testing conditions that call for dim room illumination. Dim illumination is necessary because complete darkness in the testing area allows each illuminated button to very quickly and saliently catch the subject's attention, with essentially no scanning required. A room that is too brightly lit, on the other hand, causes the illuminated button to be distinguished from the unlit buttons only with great difficulty. In our testing room, one set (half) of the overhead fluorescent lights were turned off to decrease ambient room lighting and reduce glare on the board itself. For reference, we used a photometer to assess the luminance of different regions of the Dynavision board (the gray background upon which the lights are mounted) and the lit red buttons themselves. As the partial room lighting cast slightly more light on the lower half of the board, it was found that the upper gray of the board had a luminance value of about 3.4 cd/m^2, whereas that of the lower portion of the board was 9.4 cd/m^2. The lit buttons on all regions of the board had a luminance of approximately 30 cd/m^2. Although the Dynavision manual does not specify recommended luminances, or a contrast value, for the background board and the lit buttons, the illumination in our experimental condition was deemed to adhere appropriately to the manual's recommendations. The difference in luminance between the top and the bottom of the background board was the same for all subjects and was deemed negligible, as the Weber contrast of all the illuminated buttons was greater than 200%.

As mentioned above, we elected to administer 1 practice and 3 trials of the Dynavision task in Mode A to assess, and potentially account for a learning effect. Subjects completed the first 60-second practice trial and were offered an additional

practice trial, in case the subject did not grasp the premise of the task, before the three recorded trials were completed. No subject elected to take the extra practice trial.

For scoring, the Dynavision apparatus tabulates the number of successful hits that a subject acquires in the 60 second run time. There are then two ways that one can calculate a reaction time. One way, performed by the Dynavision apparatus, is by recording the amount of time that elapses between each hit (inter-hit interval), and then averaging those across the 60 second trial. This average reaction time, in "seconds" (i.e., the number of seconds the subject requires, on average, to make a proper hit) is displayed with the results after the trial is over. A second way to calculate the subject's estimated reaction time would be to take the inverse of the number of hits in 60 seconds; i.e., 120 hits in 60 seconds gives an estimated reaction time of 0.50 seconds per hit. These two determinations of reaction time are not precisely equal, particularly if a subject exhibits great variability in the elapsed time between successive hits. However, across subjects, the (inverse) correlation between the number of hits in 60 seconds vs. the Dynavision-calculated average inter-hit reaction time in seconds (per hit) has been shown to be nearly perfect ($r = -0.997$) [36]. For this study, I elected to analyze performance using the apparatus-calculated average of the time in seconds for each hit, considering this to best represent each subject's average reaction time. After the initial practice trial, these apparatus-provided reaction times for the subsequent 3 Dynavision trials were averaged to give that subject's score, and are reported below as average "reaction time," in units of seconds (per hit).

Figure 4: Image of the Dynavision 2000 board.

The 120x120cm Dynavision 2000 board, with 64 buttons, is wall-mounted on a set of rails that allows its vertical position to be adjusted to each subject's height. Subjects could stand at any distance, scan with head and eyes, and use any part of the hand or any strategy to hit the successively illuminated buttons.

Modes of Analysis:

The primary goal of this investigation was to correlate UFOV scores, which measure the processing speed (in milliseconds) at which the subject can properly identify/locate the stimulus, to Dynavision scores, which measure average visuomotor reaction time (in seconds per hit). Thus, the two tasks have different outcome measures. As the investigation was concerned with how each subject's UFOV score compared to their Dynavision score (i.e., if a subject scores well versus poorly on one task, does their relative success on the other task correlate), I compared UFOV vs. Dynavision scores within subject groups (i.e., normal group or low vision group) via correlation and linear regression.

Determination of sample size for this investigation had to involve the expected correlation coefficient, as there was no calculable intervention or effect size; there was only observation of the subjects' scores on the two tasks. The sample size was calculated using a formula from Hulley and Cummings et al.[37], which gives the sample size needed to determine whether a correlation coefficient is significantly different from zero

for the expected correlation[†]. The primary question of this investigation was the correlation between UFOV vs. Dynavision scores, and there exists to date no prior knowledge of an expected linear relationship, or correlation coefficient, between the two tasks. Thus, I determined that a meaningful correlation coefficient would be r = 0.707, such that $r^2 = 0.50$ and 50% of the variance in scores on one task (UFOV or Dynavision) would be accounted for by the other. However, for the "expected correlation coefficient" in the sample size calculation, I chose a lower value of r = 0.5, so that the sample size would be sufficiently large to find a correlation coefficient statistically significant from zero, even if the coefficient of determination were found to be weak ($r^2 = 0.25$). This is because, the weaker the expected correlation coefficient, the larger the calculated required sample size. The secondary questions for this investigation, such as the effect of age on the scores for each task, were accounted for with the expectation that an appropriate sample size for the UFOV vs. Dynavision correlation would allow for enough confidence for the determination of a relationship between each task and age. The sample size was calculated to be 29 subjects for each group: normal vision and low vision.

When correlating UFOV vs. Dynavision scores, only the scores on the third and most difficult UFOV task, Selective Attention, were used. This is possible on the new UFOV software, whereas the old iteration of the program often cited in the literature [10, 14, 15] gathered data on all 3 tasks and provided the score as a percent reduction in performance from the minimum threshold performance. Conversion for scores from the old to new scoring and iteration of the UFOV program is provided by the creators of the program (The Visual Awareness Group) and is seen in Appendix B. I chose to analyze Task 3, Selective Attention in isolation because, particularly for the normal subject group, most subjects reached the ceiling of performance on the easier Tasks 1 and 2,

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[†] For a two-tailed hypothesis and p = 0.05 significance level, the standard normal deviate for $\alpha = Z_\alpha = 1.960$; for a power of 80% ($\beta = 0.20$, the standard normal deviate for $\beta = Z_\beta = 0.842$; then, $C = 0.5 * \ln[(1+r)/(1-r)] = 0.549$. Sample Size N calculated by: **Total sample size = $N = [(Z_\alpha + Z_\beta)/C]^2 + 3 = 29$**

successfully identifying (in Task 1, Processing Speed) and identifying and locating (in Task 2, Divided Attention) the stimuli at the fastest computer flash presentation of 14.8 ms. In fact, 100% of normal subjects hit this performance ceiling on Task 1, and 84.3% (43 of 51) did for Task 2 [see Appendix C for raw data]. In the low vision cohort, 59% (10 of 17) hit the performance ceiling for Task 1, and 6% (1 of 17) did for Task 2. Thus, the most significantly differentiating indicator of performance was UFOV Task 3, for which only 17.6% of normal subjects (9 of 51) and one low vision subject successfully identified and located the stimuli at a duration of 14.8ms. The range of normal adult subject processing speeds for Task 3 was 14.8 ms to 211.8 ms, while the range for low vision subjects was 14.8 ms to 431.5 ms.

In addition to using correlation and linear regression to assess the relationship between UFOV vs. Dynavision scores across normal subjects [Figure 5] and low vision subjects [Figure 6], the relationship between age and performance on the UFOV and Dynavision tasks also was analyzed using correlation and linear regression, to observe how scores vary with subject age for the normal vision adults and children for UFOV [Figs. 7-9] and for Dynavision [Figs. 11-13]. The effect of age on UFOV and Dynavision scores was analyzed for the low vision population as well [Figs. 10, 14]. The role of gender on scores was analyzed using independent t-tests for the means and standard deviations of male versus female performance for normal and low vision cohorts [Figs. 15-18].

Also, it was of interest to investigate test-retest reliability of the Dynavision board task. Because I expected a learning effect for the first few trials [32, 33], I compared the outcome of repeated Dynavision attempts through a series of paired-sample t-tests, comparing trial 1 vs. 2 and trial 2 vs. 3 to investigate a statistically significant difference in scores as subjects advanced sequentially through their 3 attempts. A two-tailed paired t-test was conducted with a Bonferroni correction for multiple (i.e., 2) tests. The Bonferroni correction indicated that the critical p value for this analysis would be 0.05/2

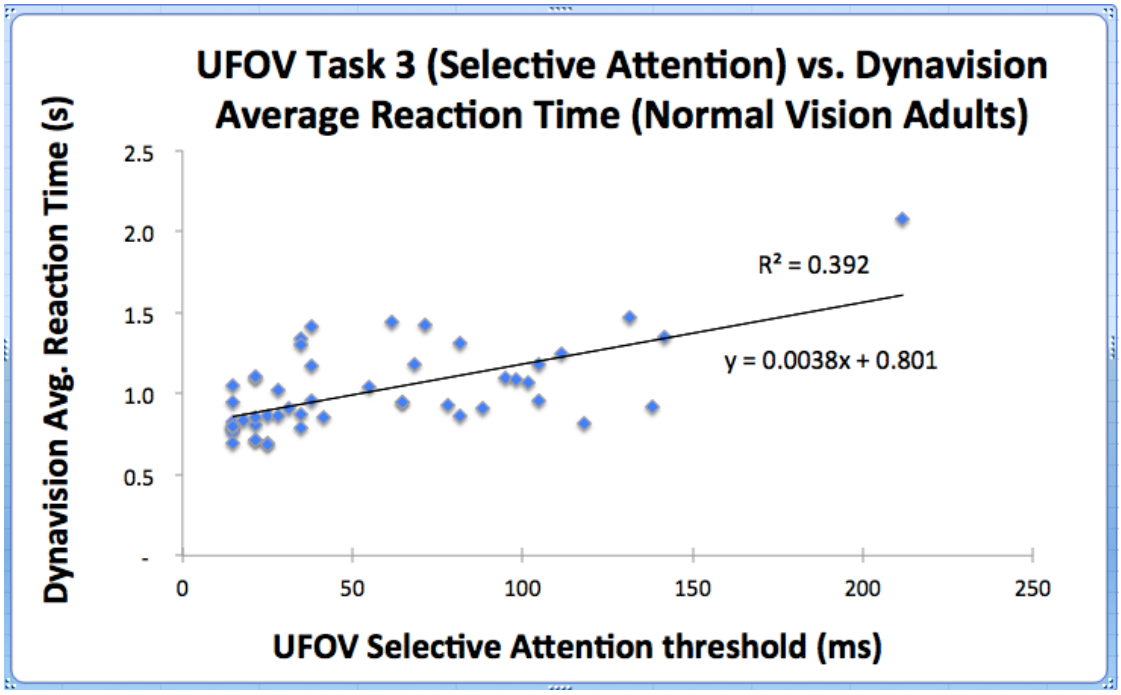
= 0.025. The mean subject scores for each Dynavision trial and respective standard error are shown below for the normal vision and low vision groups. Bland-Altman plots for agreement are provided for those trials that did not display a significant difference [Fig. 19-23].

Additional analyses were performed on the data from the pilot study, which obtained normative results for children on the UFOV and Dynavision tests. The raw data for this sub-study are found in Appendix C, and the linear regression for UFOV vs. Dynavision is discussed in Appendix D. The normative child data were also included in the analyses that considered age vs. UFOV and age vs. Dynavision scores in Figures 8, 9, 12, and 13 below.

RESULTS:

The correlation UFOV vs. Dynavision scores:

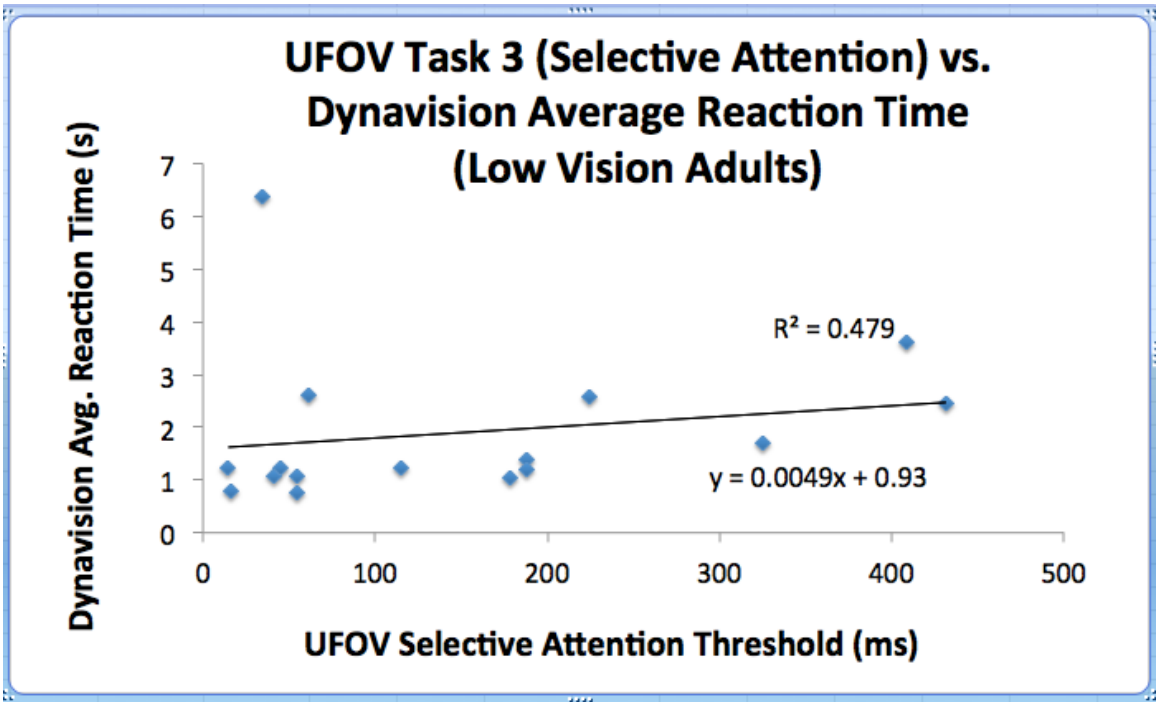
Fig. 5: UFOV vs. Dynavision correlation and linear regression for normal adult subjects



As seen above, UFOV and Dynavision scores correlate positively in the normal subject group, with a correlation coefficient r = 0.626, and coefficient of determination r^2 = 0.392 such that approximately 39% of the variability on one task was accounted for by the score on the other task. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 51 and using a 2-tailed t test, t[df=49] = 5.62, p = 8.9 x 10^{-7}. Thus, the correlation between UFOV and Dynavision scores in normal adult subjects is found to be statistically significant. However, the value of r^2 does not meet my desired level of clinical significance, which sought r^2 = 0.5, or 50% of variability on one task accounted for by the score on the other task. The 95% confidence interval for the correlation coefficient r = 0.626 gives an upper limit r = 0.768 and lower limit r = 0.424, so with a two-tailed p-value of 0.155, the

correlation coefficient found is not statistically significantly different from the desired r = 0.707 [38].

Fig. 6: UFOV vs. Dynavision correlation and linear regression for low vision subjects



UFOV and Dynavision scores correlate positively in the low vision patient subject group with $r^2 = 0.479$; thus, about 48% of variability on one task was accounted for by the score on the other task. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 17 and using a 2-tailed t test, t[df=15] = 3.716, $p = 2.07 \times 10^{-3}$. Thus, the correlation between UFOV and Dynavision scores in low vision subjects is found also to be statistically significant. This correlation is very close to my desired level of clinical significance of 50% of variability on one task accounted for by score on the other task. The 95% confidence interval for this correlation coefficient provides upper limit r = 0.813 and lower limit r = 0.515. With a

two-tailed p-value of 0.419, the found correlation coefficient 4 = 0.692 was not statistically significantly different from the target r value 0.707 [38].

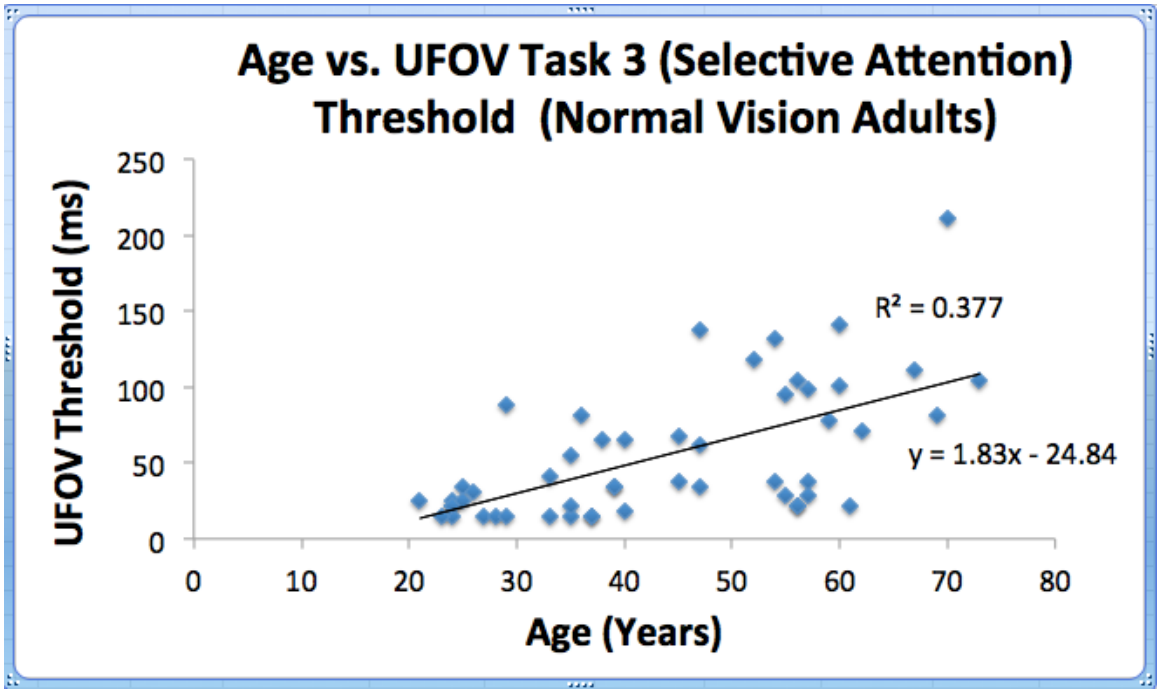
When correlating UFOV vs. Dynavision, it is of interest to compare whether the linear regression and correlation data, including the best-fit lines, are similar between the normal adult and low vision data for patients of driving age. This comparison addresses the question of whether the low vision patient data conform to the same relationship as that of the normal vision adults. Concerns include whether the y-intercepts are different (i.e., shifted to higher values for UFOV threshold or Dynavision reaction time), and whether the slopes are quantitatively different (i.e., different rate of change of scores). When tested with multiple regression and interaction analysis, testing between the interaction of the outcome variables (scores) and group designation (normal vision vs. low vision) revealed that the slopes of the two regressions were not statistically significantly different from each other, with a two-tailed p-value = 0.702. When testing the intercepts, they were statistically significantly different with p = 0.019, showing that low vision patients performed more poorly on both UFOV and Dynavision (had different score intercept values), but the relationship between performance on the two tasks was quantitatively similar between normal and low vision groups.

As discussed in the modes of analysis section above, only the Task 3 UFOV threshold scores were analyzed for their correlation to the Dynavision task as well as with regard to age and gender. While this is somewhat different from many previous studies in which the scores on all 3 subtests were added or averaged to give the UFOV score, analyzing Task 3 in isolation allows for better differentiation between subjects because many subjects, even in the low vision cohort, achieved the threshold ceiling of 14.8 ms on Task 1, whereas only one subject in the low vision cohort reached the ceiling threshold on Task 3. Thus, Task 3, being the most difficult, had the largest range of scores and the data differentiates performance among subjects most appropriately. Additionally, although only one low vision subject reached the performance threshold on

Task 2 as well, the best comparison between low vision and normal vision adults is still achieved by comparing Task 3 because of the fact that more than half of normal vision adults reached the 14.8ms on Task 2. Of the 17 low vision subjects, 14 placed in UFOV Category 1, two placed in Category 2, and one placed in Category 4. Thus, an analysis of the Category results alone would not provide much ability to analyze threshold trends on UFOV for this low vision cohort.

The effect of age:

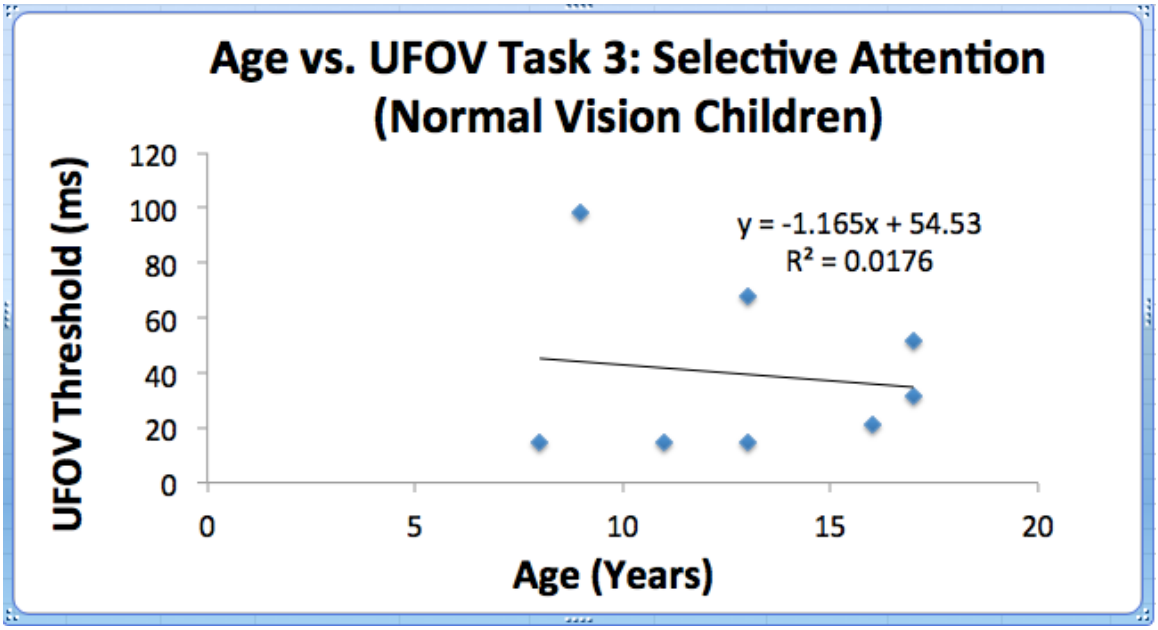
Fig. 7: Age vs. UFOV correlation and linear regression for normal adult subjects



As seen in Figure 7, age and UFOV scores correlated positively in the normal vision subject group with an r^2 value = 0.377; thus, about 38% of variability on the UFOV task was accounted for by age in adults with normal vision. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 51 and using a 2-tailed t test = t[df=49] = 5.450, p = 1.63 x

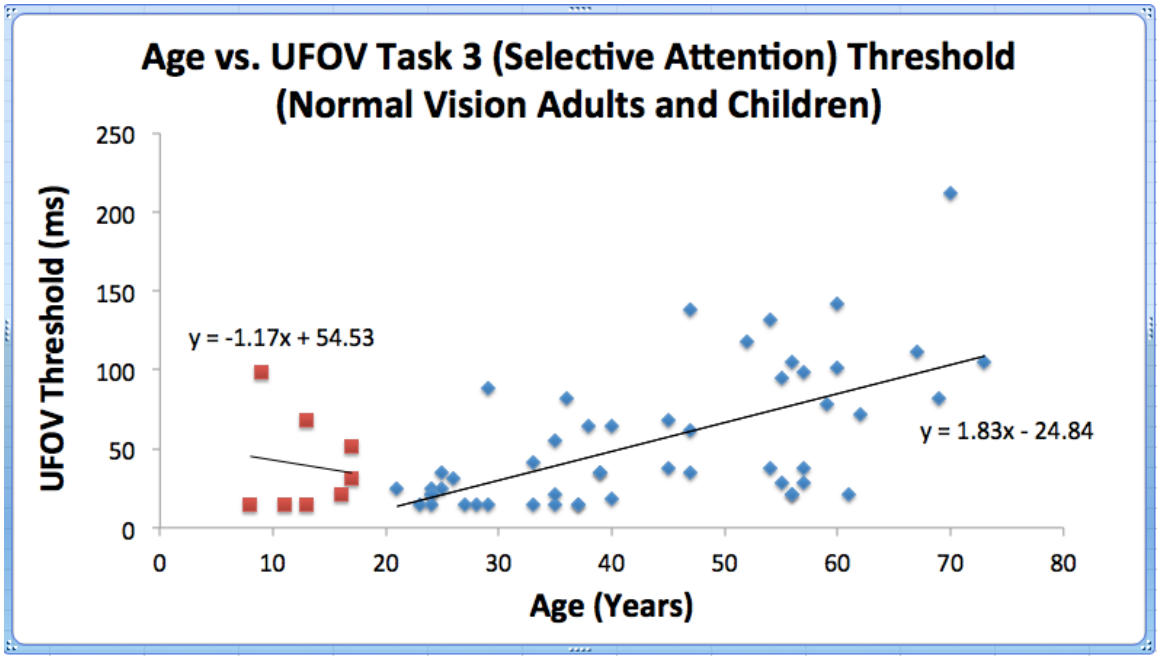
10^{-6}. Thus, the correlation between age and UFOV in normal-vision adult subjects is found to be statistically significant; with increasing age, performance on UFOV Task 3 declines, as evidenced by longer threshold durations.

Fig. 8: Age vs. UFOV correlation and linear regression for normal vision children



On the other hand, age and UFOV scores did not show a significant correlation in the normal vision children, with an r^2 value = 0.0176 (Figure 8). Thus, only about 2% of the variability on the UFOV task was accounted for by age in children with normal vision. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 8 and using a 2-tailed t test, t[df=6] = 0.328, p = 0.754. Thus, the correlation between age and UFOV in normal-vision child subjects is not found to be statistically significant.

Fig. 9: Age vs. UFOV, correlation for normal vision adults and children



A combined plot of UFOV performance over the full range of ages in normal-vision subjects is presented in Figure 9. As reported above, the data for children with normal vision did not exhibit a significant correlation between age and UFOV threshold. The data suggest that performance on the UFOV test becomes adult-like at approximately age 21, the youngest in the adult sample, although there was not a strong enough relationship in the children's data to identify the intersection between the lines fit to the children's and adults' performance with any confidence.

Fig. 10: Age vs. UFOV correlation and linear regression for low vision subjects

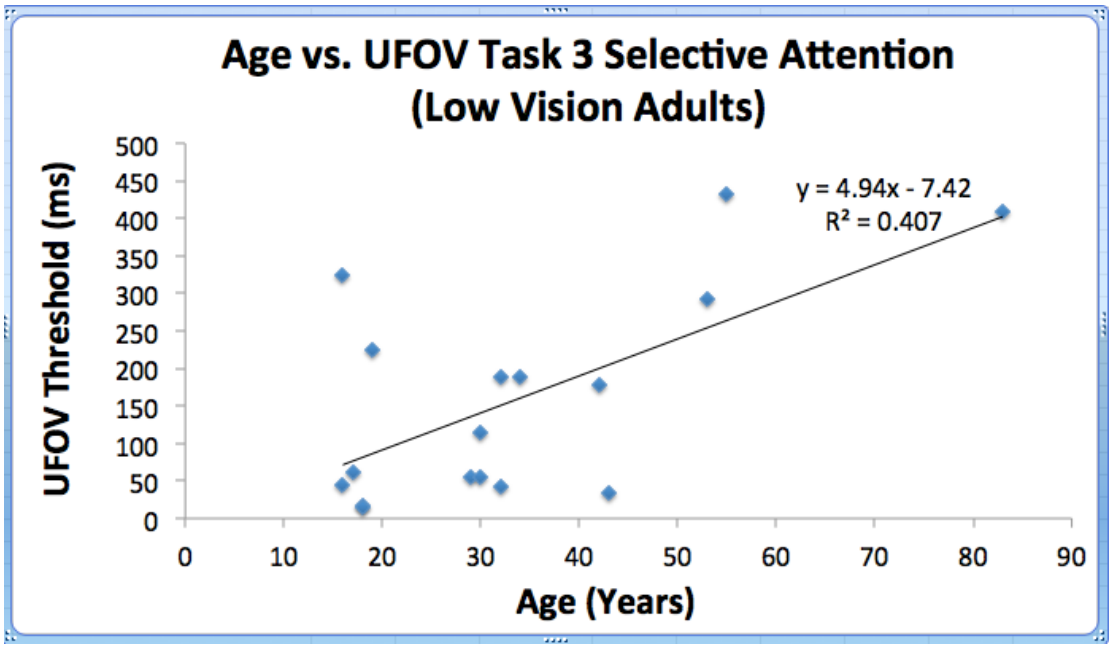
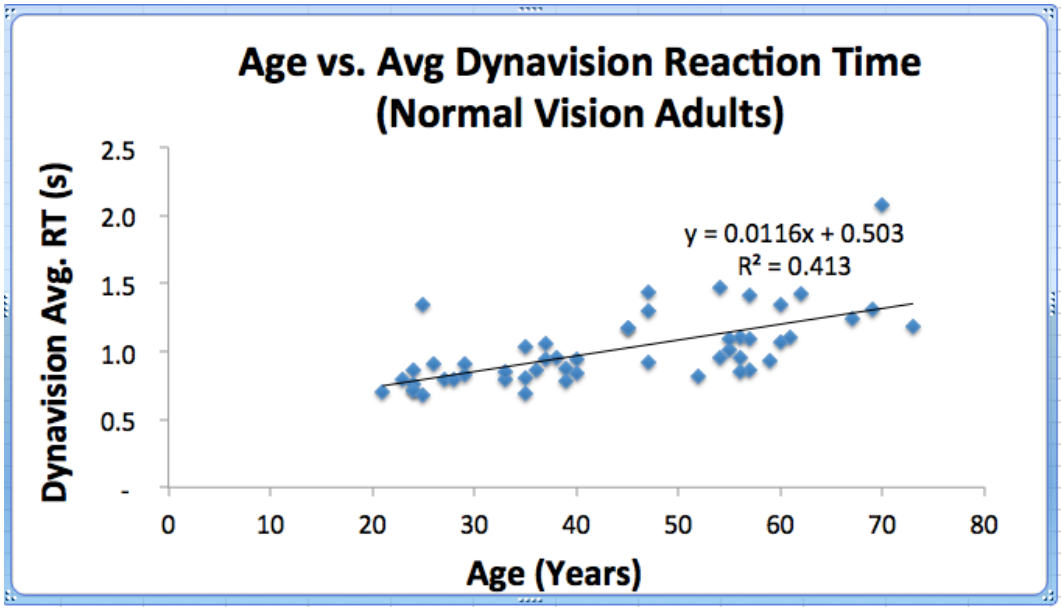


Figure 10 shows that age and UFOV scores correlated positively in the low vision subject group with $r^2 = 0.407$; thus, about 41% of variability on the UFOV task was accounted for by age in the adults with low vision. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 17 and using a 2-tailed t test = t[df=15] = 3.209, p = 5.85 x 10^{-3}. Thus, the correlation between age and UFOV in low vision adult subjects is found to be statistically significant.

When analyzing the effect of age on UFOV scores, I was interested in comparing whether the best-fit regression lines are similar for the normal adult and low vision adult data. This addresses the question of whether the low vision patient data conform to the same relationship as that of the normal vision adults. Concerns include whether the y-intercept is different (i.e., shifted to higher UFOV thresholds in the low vision patients), and whether the change in UFOV scores with age is quantitatively different (i.e., different rates of change of scores with increasing subject age). When tested with multiple regression and interaction analysis, testing the interaction of age and group designation

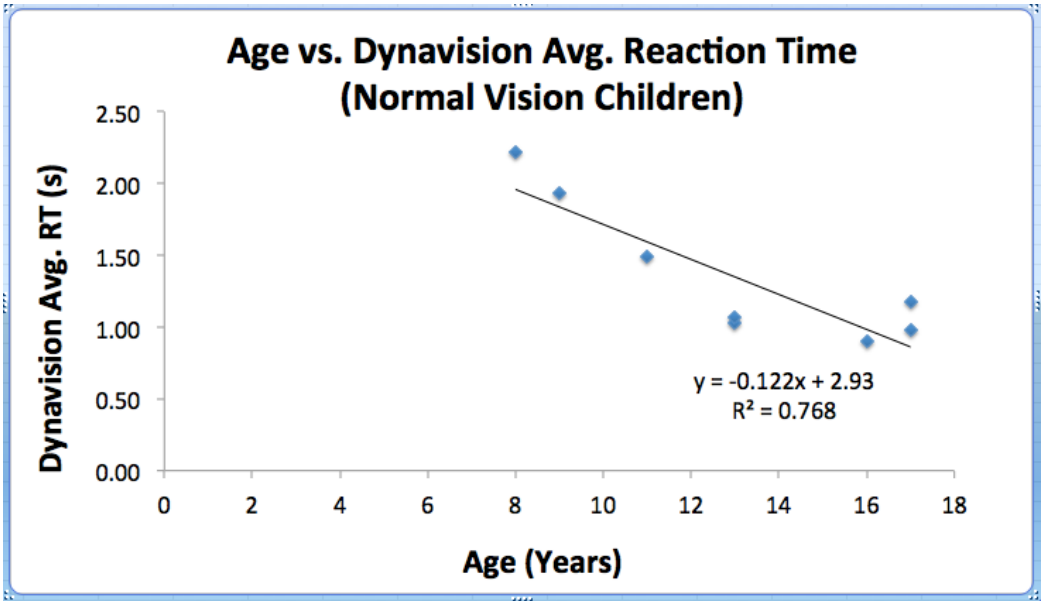
(normal vision vs. low vision) in relation to the outcome measure for UFOV revealed that the slopes of the two regressions (age vs. UFOV for normal-vision and age vs. UFOV for low vision cohorts) were statistically significantly different from each other, with a two-tailed p-value = 0.004. When testing the intercepts, they were not statistically significantly different with p = 0.681, showing that in relation to age, performance deteriorates more with increasing age in low vision than in the normal vision subjects. Intercept may not be relevant here because it corresponds to an age of 0 years, which is not clinically relevant, and is extrapolated heavily from this adult data set. However, solving the linear regression equations to calculate a predicted UFOV score for a patient of adult age [age 18] provides a predicted threshold of 8.1ms for a normal vision subject, and 81ms for a low vision subject. Again, interaction analyses did not find these intercepts to be statistically significantly different.

Fig. 11: Age vs. Dynavision correlation and linear regression for normal vision adult subjects.



Age and Dynavision scores correlate positively in the normal vision subject group with an r^2 value = 0.413; thus, about 41% of variability on the Dynavision task was accounted for by age in adults with normal vision. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 51 and using a 2-tailed t test = t[df=49] = 5.867, p = 3.74 x 10^{-7}. Thus, the correlation between age and Dynavision in normal-vision adult subjects is found to be statistically significant; with increasing age, performance on Dynavision declines, as evidenced by longer reaction times.

Fig. 12: Age vs. Dynavision correlation and linear regression for normal vision children



On the other hand, age and Dynavision scores correlate negatively in the normal vision child subject group with r^2 coefficient = -0.768 (Figure 12). Thus, about 77% of variability on the Dynavision task was accounted for by age in children with normal vision. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 8 and using a 2-tailed t test =

t[df=6] = 4.457, p = 4.3 x 10^{-3}. Thus, the correlation between age and Dynavision in normal vision child subjects was found to be statistically significant. The data show that, through childhood, increasing age correlates with improved performance (faster reaction times) on the Dynavision apparatus.

Fig. 13: Age vs. Dynavision average reaction time for all ages

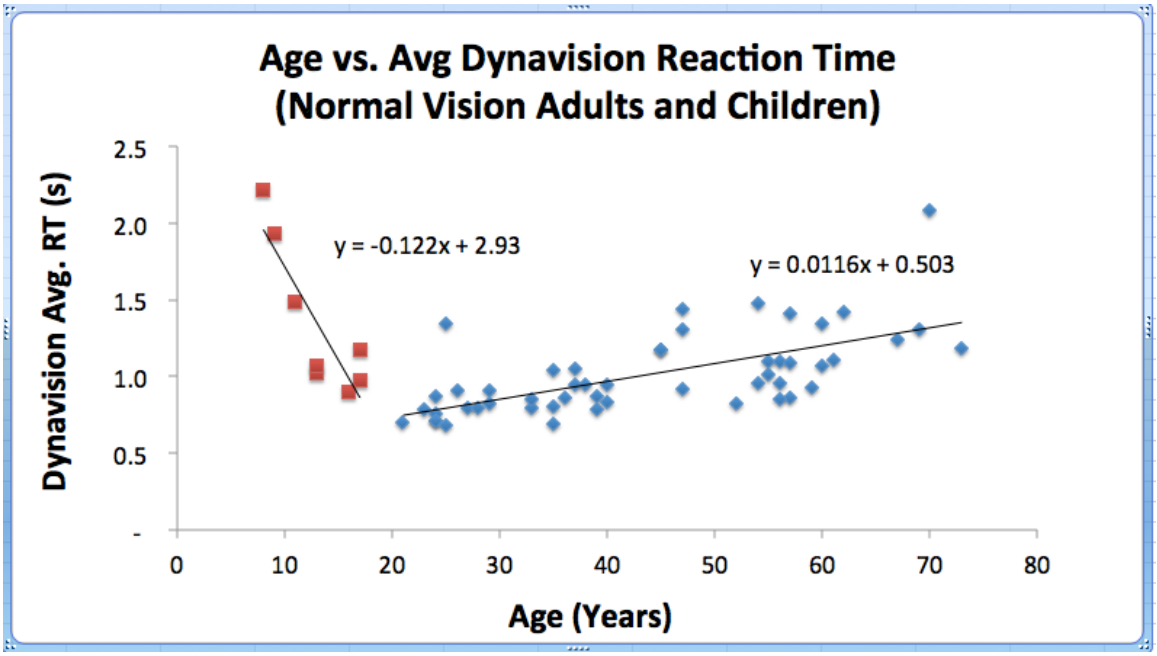
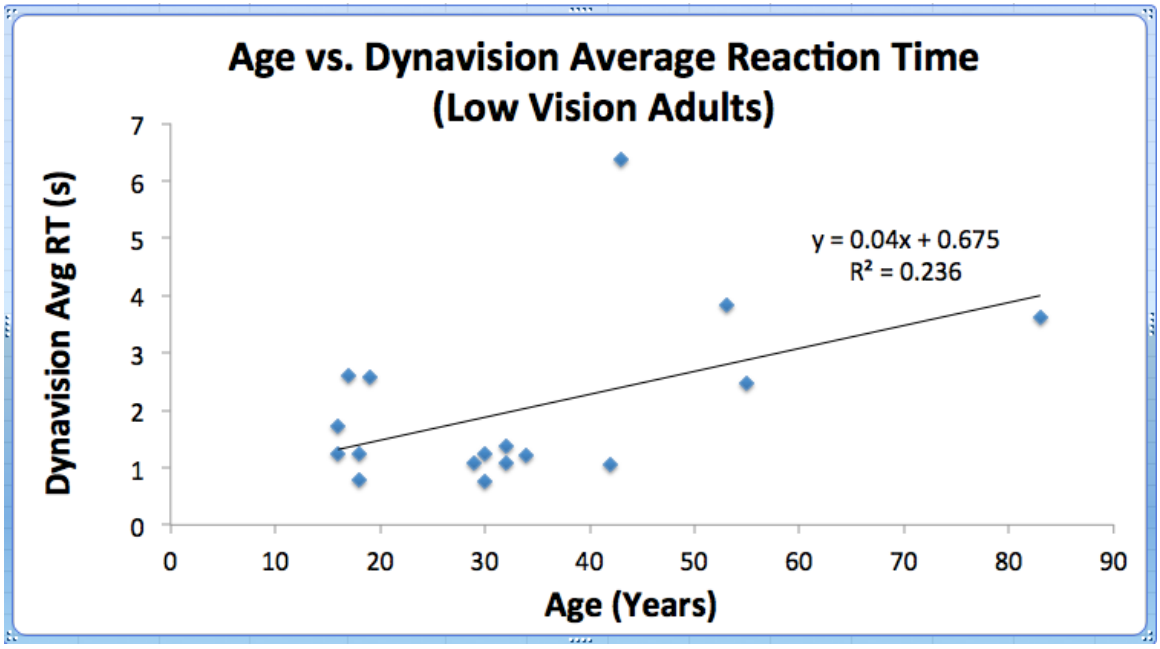


Figure 13 presents a combined plot of Dynavision performance over the full range of ages in normal-vision subjects. As seen above, the data for normal vision children indicate a significant negative relationship between age and Dynavision reaction times, whereas a positive correlation between age and Dynavision reaction times exists for the normal adult population. Solving for the intersection of the linear regression lines fit to the child and adult data (-0.12x + 2.88 = 0.012x + 0.503) suggests that the age at which performance on the Dynavision task becomes adult-like, is approximately age 18.

Fig. 14: Age vs. Dynavision linear regression and correlation for low vision adults



As in the adults with normal vision, age and Dynavision scores correlate positively in the low vision subject group with an r^2 value = 0.236 (Figure 14). Thus, about 24% of variability on the Dynavision task was accounted for by age in adults with low vision. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 17 and using a 2-tailed t test = t[df=15] = 2.153, p = 0.048. Thus, the correlation between age and Dynavision in low vision adult subjects is found to be statistically significant.

When analyzing the effect of age on Dynavision scores, I was again interested in comparing whether the linear regression fits are similar between the normal adult and low vision subjects of driving age, to determine whether the low vision patient data conform to the same relationship as that of the normal vision adults. Concerns include whether the y-intercept is different (i.e., shifted to longer Dynavision reaction times in the low vision patients), and whether the slopes are qualitatively different (i.e., whether reaction time changes at different rates with increasing subject age). When tested with multiple regression and interaction analysis, testing the interaction of age and group designation

(normal vision vs. low vision) in relation to the outcome measure for Dynavision revealed that the slopes of the two regressions (age vs. Dynavision for normal-vision and age vs. Dynavision for low vision cohorts) were statistically significantly different from each other, with a two-tailed p-value = 0.015. When testing the intercepts, they were not statistically significantly different with p = 0.709, showing that in relation to age, performance deteriorates more with increasing age in low vision than in the normal vision subjects. Intercept may not be relevant here because it corresponds to an age of 0 years, which is not clinically relevant, and is extrapolated heavily from this adult data set.

As seen above in Figures 11 and 14 and based on the best-fit values of slope and intercept, it appears that only the slope of the regression line (but not the y-intercept for Dynavision reaction times), differs quantitatively between the low vision patients (0.04 s/year) and the normal vision cohort (0.012 s/year). Thus, while Dynavision reaction times are approximately the same in young adult low vision patients and normal adults, the low vision patients' performance deteriorates more rapidly with increasing age as compared to normal vision subjects. This outcome differs from the effect of subject group on both the slope and intercept of the lines fit to the UFOV data.

Fig. 15: Performance by gender on UFOV: Normal vision adults

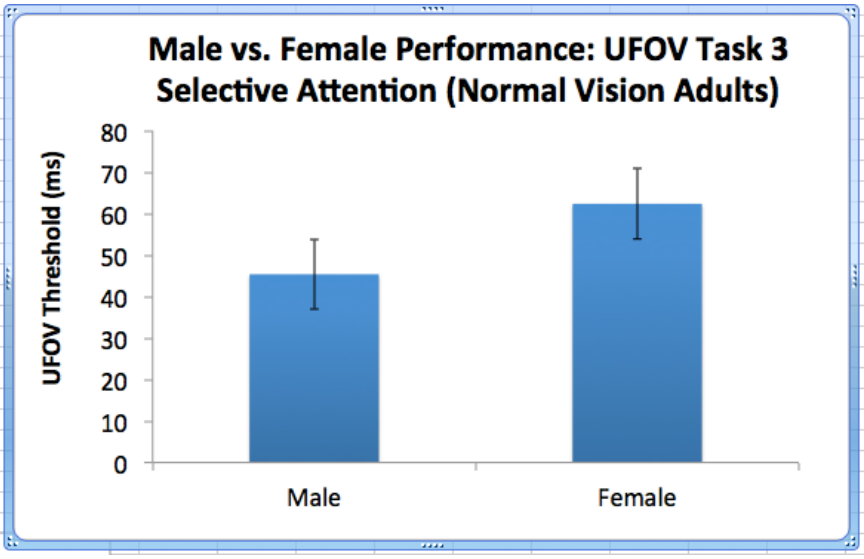


Fig. 15 shows the average performance for males and for females with normal vision on the UFOV Task 3, Selective Attention. Error bars indicate ±1 standard error of the mean. To compare UFOV performance by gender in normal vision adult subjects, an independent t-test [39] was performed for 22 males, with an average threshold score = 45.39 ms, and standard deviation = 34.40 ms and 29 females, with an average threshold score = 62.389, and standard deviation = 49.25; t = 1.38, df = [51 – 2] = 49. The two-tailed P value = 0.173. Thus, UFOV threshold scores for men and women with normal vision were not found to be statistically significantly different.

However, I also investigated age as a possible confound, as it appeared that females had a higher average age in the normal vision group than males. Using an un-paired t-test with df = 49, t = 2.38, and the two-tailed p-value = 0.021. Thus, the female and male ages were statistically significantly different, with female age being higher by an average of ~9.5 years. Thus, I estimated a correction using the regression line fit to Age vs. UFOV Task 3 scores (Figure 7). With a slope of +1.83x, I would estimate that the mean female UFOV score would be 1.83*9.5 = 17.385 ms higher due to the difference in group age alone. Then, recalculating the t-test to analyze for a difference in performance due to gender on UFOV, adjusting the mean female score by this factor (the adjusted mean female Task 3 threshold score = (62.386 – 17.385 =~45 ms). The new unpaired t-test with df = 49 reveals t = 0.032, and the two-tailed p-value = 0.975. Thus, accounting for the sampling age differences between the normal vision male and female groups showed that age did have an effect on the non-statistically significant difference in performance between males and females on the UFOV task.

Fig. 16: Performance by gender on UFOV: Low vision adults

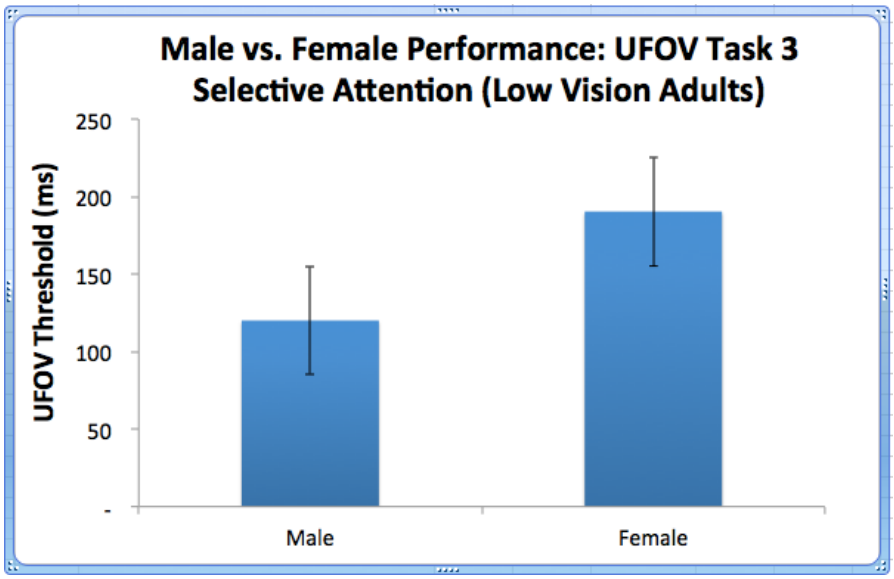


Fig. 16 shows the average performance for males and for females with low vision on the UFOV Task 3, Selective Attention. Error bars indicate ±1 standard error of the mean. To compare UFOV performance by gender in low vision adult subjects, an independent t-test was performed for 8 males, with an average threshold score = 120.05 ms, and standard deviation = 160.60 ms and 9 females, with an average threshold score = 190.37 ms: and standard deviation = 120.42; t = 1.03, df = [17 – 2] = 15. The two-tailed P value = 0.3197. Thus, UFOV threshold scores for men and women with low vision were not found to be statistically significantly different.

As seen in Figs. 15 and 16, normal vision and low vision cohorts exhibit the same gender effect with respect to scores on UFOV; in each group, males performed with lower (faster) Selective Attention thresholds, but the effect was not statistically significant in either group.

Investigation revealed that age was not a confound in the analysis of UFOV performance by gender for low vision patients, as an unpaired t-test comparing group ages for the males and females revealed t=0.69 and with df = 15, the two-tailed p-value = 0.499; thus, there was no statistically significant different in ages between the male and

female low vision groups. Therefore, age difference did not affect the relationship between gender and performance for low vision patients.

Fig. 17: Performance by gender on Dynavision: Normal vision adults

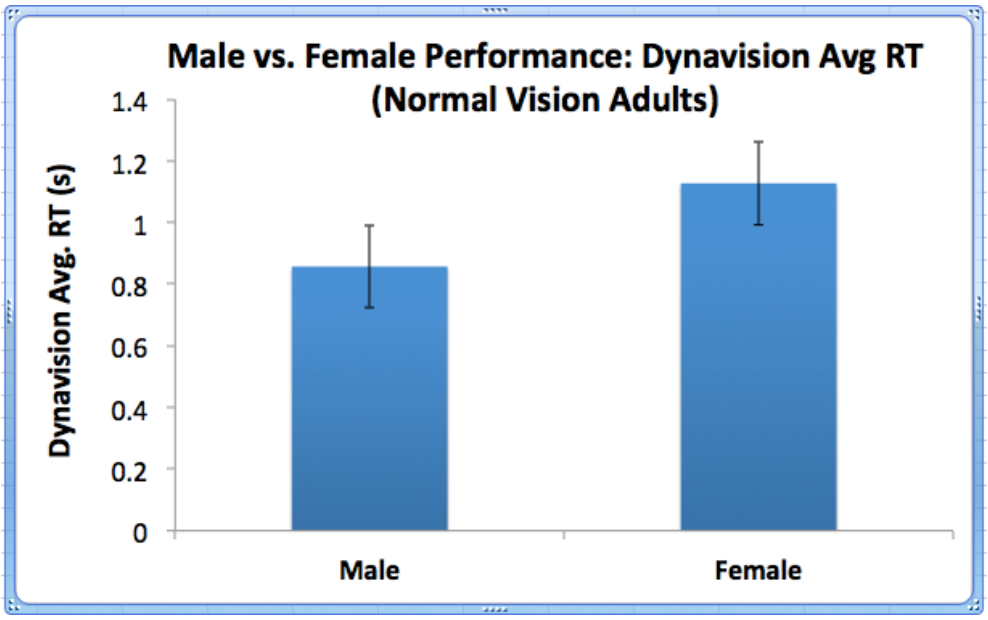


Fig. 17 shows the average performance for males and for females with normal vision on the Dynavision Mode A task. Error bars indicate ±1 standard error of the mean. To compare UFOV performance by gender in normal vision adult subjects, an independent unpaired t-test was performed for 22 males, with an average reaction time score = 0.857 s, and standard deviation = 0.124; and 29 females, with an average reaction time score = 1.127 s, and standard deviation = 0.288; t = 4.12, df = [51 – 2] = 49. The two-tailed P value = 1.0×10^{-4}. Thus, Dynavision reaction times for men and women were found to be statistically significantly different, with males performing with shorter reaction times than females.

As with the analysis for the effect of gender on UFOV performance, I investigated age as a possible confound when analyzing Dynavision performance by gender in normal vision subjects, as females had a higher average age in the normal vision group than

males. Using an un-paired t-test with df = 49 to compare average ages between the female and male normal-vision cohorts, t = 2.38, and the two-tailed p-value = 0.021. Thus, the female and male ages were statistically significantly different, with female age being higher by an average of ~9.5 years. Thus, I estimated a correction using the regression line fit to Age vs. Dynavision reaction time scores for normal vision adults (Figure 11). With a slope of +0.0116x, I would estimate that the mean female Dynavision reaction time score would be 0.0116*9.5 = 0.11 s longer due to the difference in group age alone. Then, I recalculated the t-test to analyze for a difference in performance due to gender on Dynavision, adjusting the mean female reaction time score by this factor (the adjusted mean female score = (1.128 – 0.11 =~ 1.018 s). The new unpaired t-test with df = 49 reveals t = 2.447, and the two-tailed p-value = 0.018. Thus, accounting for the sampling age differences between the normal vision male and female groups showed that age did have an effect on the difference in performance between males and females on the Dynavision task, but that even accounting for this age difference, there was still a statistically significant difference in performance between males and females, with males performing with shorter reaction times.

Fig. 18: Performance by gender on Dynavision: Low vision adults

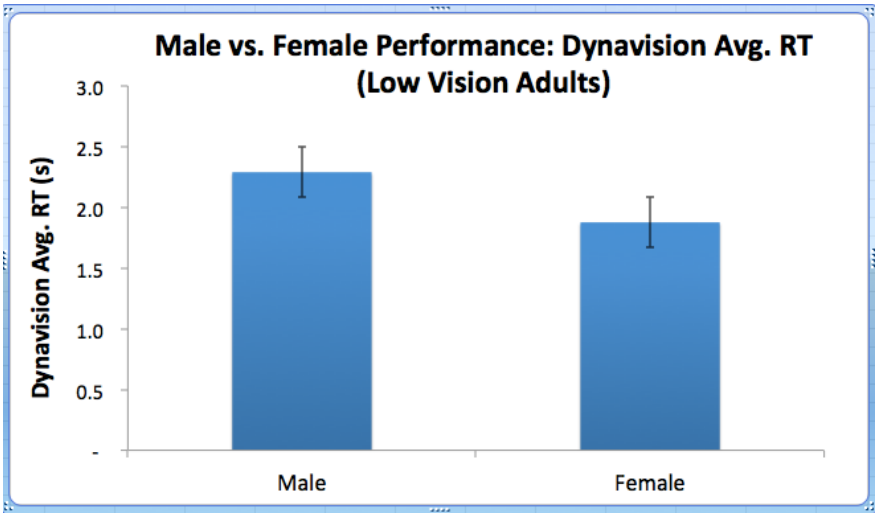


Fig. 18 shows the average performance for males and for females with low vision on the Dynavision board Mode A task. Error bars indicate ±1 standard error of the mean. When comparing Dynavision performance by gender in low vision adult subjects, an independent t-test was performed for 8 males, with an average reaction time = 2.29 s, and standard deviation = 1.91 and 9 females, with an average reaction time = 1.88 s, and standard deviation = 0.98; t = 0.566, df = [17 – 2] = 15. The two-tailed P value = 0.579. Thus, Dynavision reaction times for men and women with low vision were not found to be statistically significantly different. As with low vision performance by gender on UFOV, investigation revealed that age was not a confound in the analysis of Dynavision performance by gender for low vision patients, as an unpaired t-test comparing ages in the male and female groups revealed t=0.69 and with df = 15, the two-tailed p-value = 0.499; thus, there was no statistically significant different in ages between the male and female low vision groups.

As seen in Figs. 17 and 18, normal vision and low vision cohorts did not exhibit the same gender effect on Dynavision performance. Whereas the males perform statistically significantly better in the normal vision cohort (lower reaction times and faster performance), even when the effect of age is accounted for, the females perform statistically insignificantly better in the low vision cohort.

Fig. 19: Mean reaction times across the 3 Dynavision trials for normal vision adults:

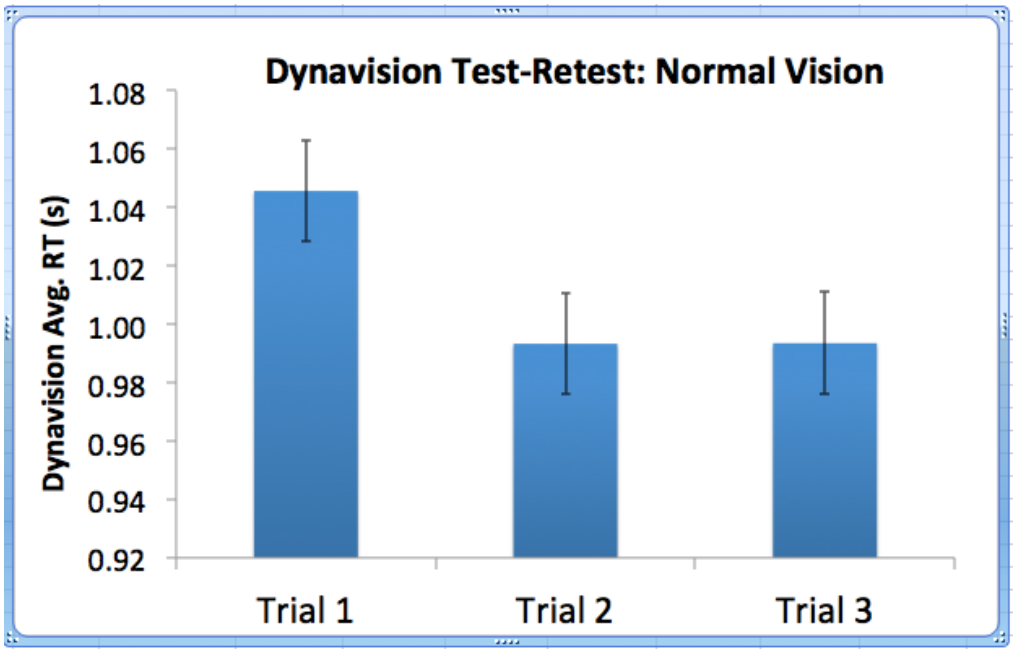
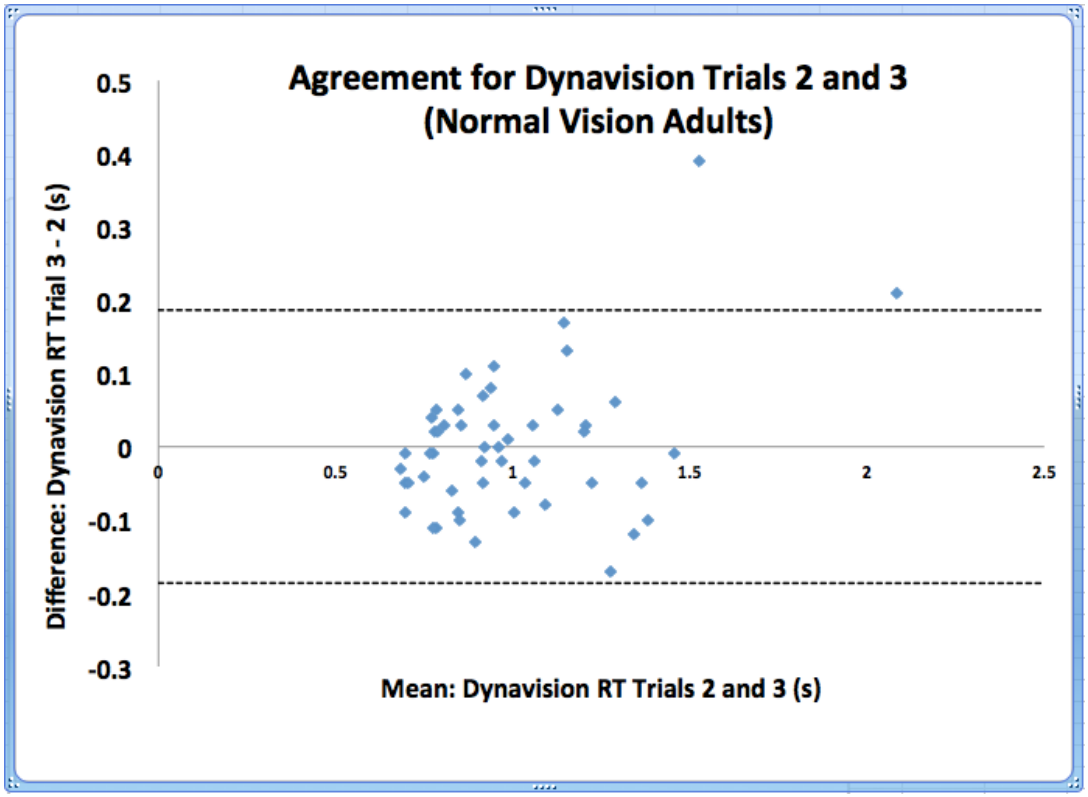


Figure 19 shows the mean reaction times for normal vision subjects on 3 attempts at the Dynavision task. Error bars show ±1 standard error of the mean. The individual trials for each subject were compared via paired t-tests [39], (Trial 1 vs. Trial 2 and Trial 2 vs. Trial 3), and a Bonferroni correction was applied for the 2 comparisons, such that an alpha level of $p \leq 0.025$ was applied. For the analysis of Trial 1 vs. Trial 2, $t = 3.567$, $df = [51 - 1] = 50$. The two-tailed P value = 8.0×10^{-4}. Thus, performance on Trial 2 was statistically significantly faster than on Trial 1. When comparing Trial 2 vs. Trial 3, $t = 0.0147$, $df = [51 - 1] = 50$. The two-tailed P value = 0.988, which is not statistically significant.

Because Trial 2 and Trial 3 were not found to be statistically significantly different, agreement between the Dynavision results on these two trials is represented below on a Bland-Altman plot [40].

Figure 20: A Bland-Altman plot of Agreement on Dynavision Trials 2 vs. 3 in Normal Vision Subjects



As seen in Figure 20, a Bland-Altman plot illustrates agreement between Dynavision trials 2 and 3 in normal vision subjects, for which there was no statistically significant difference in scores across subjects (Figure 19). In normal vision adult subjects, Dynavision trial 2 and 3 upper and lower limits of agreement for the 95% confidence interval were specified by Limit = Bias ± 1.96 * Standard Deviation, where the bias is the mean of the differences between trial 2 and 3 scores for each subject, and the standard deviation is calculated for the mean scores for trials 2 and 3. In this case, the 95% confidence interval limits of agreement for Dynavision trials 2 and 3 were ± 0.186 seconds.

Fig. 21: Mean reaction times across the 3 Dynavision trials for low vision adults:

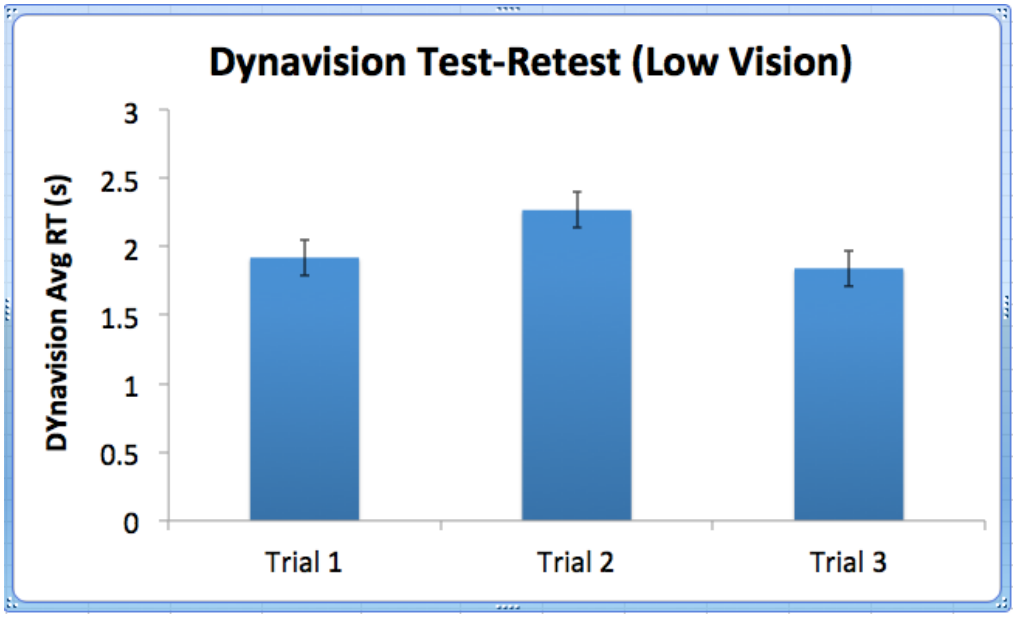
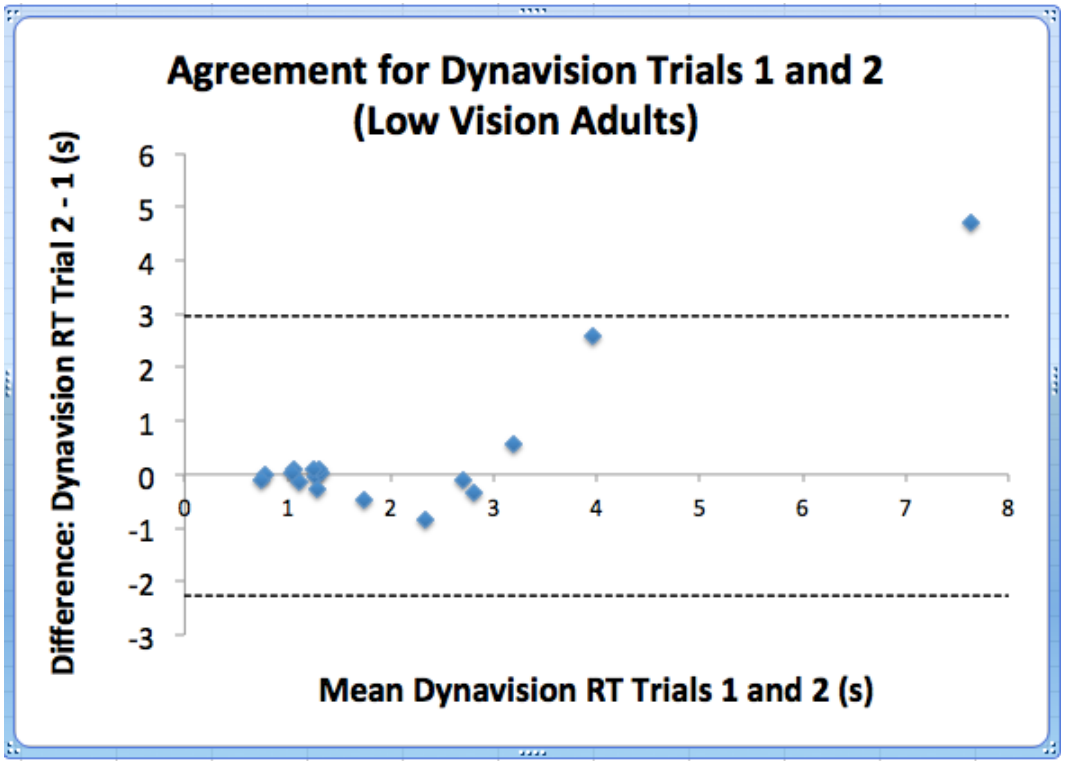


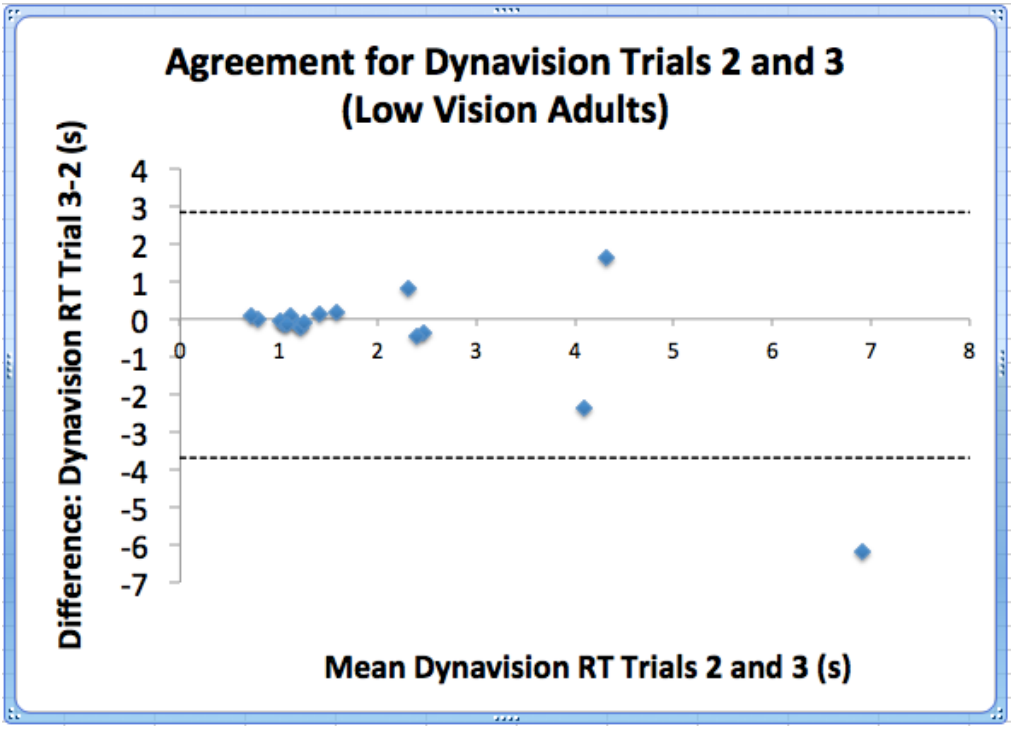
Figure 21 shows the mean reaction times for low vision subjects on 3 attempts at the Dynavision task. Error bars show ±1 standard error of the mean. The individual trials for each subject were compared via paired t-tests [39] (Trial 1 vs. Trial 2 and Trial 2 vs. Trial 3), and a Bonferroni correction was applied for the 2 comparisons, such that an alpha level of $p \leq 0.025$ was applied. For the analysis of Trial 1 vs. Trial 2, $t = 1.07$, $df = [17 - 1] = 16$. The two-tailed P value = 0.299. Thus, performance on Trials 1 and 2 was not statistically significantly different. When comparing Trial 2 vs. Trial 3, $t = 1.05$, $df = [17 - 1] = 16$. The two-tailed P value = 0.307; thus, performance on Trials 2 and 3 also is not found to be statistically significantly different.

Fig. 22: Bland- Altman plot for Dynavision Trial 1 vs. Trial 2 for Low Vision Subjects



Here, a Bland-Altman plot [40] illustrates agreement between Dynavision trials 1 and 2 in low vision subjects, for which there was no statistically significant difference in scores across subjects (Figure 21). In low vision subjects, Dynavision trial 1 and 2 upper and lower limits of agreement with a 95% confidence interval were specified by Limit = Bias ± 1.96 * Standard Deviation, where the bias is the mean of the differences between trial 1 and 2 scores for each subject, and the standard deviation is calculated for the mean scores for trials 1 and 2. Here, the 95% confidence limits of agreement were +3 and -2 seconds.

Fig. 23: Bland- Altman plot for Dynavision Trial 2 vs. Trial 3 for Low Vision Subjects



In Figure 23, a Bland-Altman plot shows the agreement between Dynavision trials 2 and 3 in low vision subjects, for which there was no statistically significant difference in scores across subjects (Figure 21). Dynavision trial 2 and 3 upper and lower limits of agreement were specified as was done for trials 1 and 2 in Figure 22; in this case, the upper and lower limits of agreement for the 95% confidence interval were +3 and -4 seconds, respectively.

DISCUSSION:

This study sought to investigate the correlation between the Useful Field of View (UFOV) and Dynavision 2000 tasks. If there were a clinically significant correlation between the two tasks, the tasks could be interchangeable when clinically assessing the visual driving fitness of low vision patients. It was decided that a clinically significant correlation between the tasks would have at minimum a correlation coefficient $r = 0.707$, such that $r^2 = 0.5$ and 50% of the variability on one task would be accounted for by the score on the other task. This investigation revealed that the correlation between UFOV and Dynavision did not meet our desired level of clinical significance for either normal vision or low vision patients.

In normal vision adult subjects, the correlation between the two tasks was significantly different from zero, but as only about 39% of the variability on one task was accounted for by the scores on the other, this does not support the clinical interchangeability of the two tasks. Similarly, in the low vision cohort, there was a statistically significant correlation, but with only approximately 48% of the variance on one task accounted for by the scores on the other, I cannot confirm that the tasks could be clinically interchangeable in the low vision cohort. However, the obtained value of r^2 in the low vision cohort is very close to the desired level of clinical significance. As more low vision patients participate on both UFOV and Dynavision tasks in the CSE clinic as part of their examination and as the sample size increases, a clinically significant relationship may be achieved. The data are sufficient to support my hypothesis that UFOV and Dynavision correlate in both normal and low vision subjects, but the notion of interchangeability is not supported.

The sample size for this study was calculated based on the presumed or anticipated correlation coefficient of $r = 0.5$, which gave a required sample size of 29 subjects for each group (normal vision and low vision). The data in fact show a correlation coefficient stronger than $r = 0.5$ in each of the cohorts (normal vision and low

vision). Post-hoc, with the correlation coefficient for normal adult subjects found to be r = 0.626, again using the formula by Hulley, Cummings et al [37], a sample size of 18 subjects would actually be required to show that a correlation for that r value is statistically different from zero; this was more than met with the 51 normal vision subjects enrolled in this study. For low vision subjects and an obtained r = 0.692, post-hoc calculation provides that a sample size of 14 would be sufficient to support a statistically significant correlation for this r value, which was met with our low vision adult study sample size of 17 patients. However, as already noted above, although the observed correlations in both groups are statistically significant, they did not support an interchangeability between UFOV and Dynavision. Additionally, the low vision sample size was sufficiently small that different characteristics of low vision subjects, such as etiology of vision loss, could not be analyzed separately with large enough representative subgroups. Thus, I cannot make distinctions for different types of low vision (i.e., central vs. peripheral vision loss) or individual etiologies when comparing UFOV to Dynavision scores, nor can I relate particular ocular diseases or low vision etiologies to scoring trends on either task separately. Further data collection to increase the sample size would be necessary to analyze the relationship between UFOV and Dynavision scores in subgroups of low vision patients.

Subject traits such as age and sex were also analyzed for their effect on performance. Previous literature indicated that UFOV scores should improve in young children until about age 14, when adult levels would be reached [23]. In the pilot data I gathered, I did not see a significant correlation, or even any trend, for a relationship between age and UFOV score in subjects under 18 years of age. I propose that my sample size of only 8 children was simply not sufficient to support the hypothesized age effect, because the UFOV data were highly variable in the child subjects. For the adult subjects, performance showed a significant linear trend toward poorer scores (longer threshold time) with increasing age, beginning with better scores for the youngest adult

subjects enrolled in the study. This outcome does not necessarily support the previous literature that suggested that UFOV performance begins to deteriorate after age 40 [24, 25]. The relationship I found instead is consistent with a gradual and continuous decline, beginning earlier in adulthood. This trend was also present and amplified for low vision subjects of driving age, whose UFOV performance showed an even stronger correlation and steeper rate of change (deterioration) of performance (longer threshold times) with increasing age. Thus, it appears that the normal-vision and low vision cohorts exhibited similar relationships between age and UFOV, and that UFOV performance deteriorates with age beginning in early adulthood.

On the Dynavision test, the normal-vision child subjects in the pilot study showed a strong significant negative correlation between age and reaction time, indicating that the youngest subjects perform more poorly on the task, and that performance improves in children from age 8 to 17. Combining this linear regression line with that fit to the data for normal adult subjects on Dynavision suggests that best performance (shortest reaction time) occurs around age 18, after which the reaction time increases approximately linearly (scores deteriorate) with increasing age. This relationship between age and Dynavision performance found in normal adults was seen to be amplified in the low vision adults, as Dynavision scores worsened with increasing age at a statistically significantly faster rate than in subjects with normal vision. Thus, it can be stated that the low vision patients exhibited exaggerated age effects as compared to the normative cohort on both UFOV and Dynavision.

When gender was considered for its effect on UFOV and Dynavision scores, it was found that men trend toward better scores on UFOV in both normal vision and low vision driving-age adults, but neither of these trends are statistically significant. This absence of a significant gender effect agreed with the expectation from previous literature [22]. When investigating age as a potential confound in the analysis of scores by gender, it was found that the female normal-vision cohort was statistically significantly older than

the normal-vision male group by an average of 9.5 years; this accounted for some of this (statistically-insignificant) difference in gender performance. There was no age-gender confound in the low vision group, as the mean ages of the male and female low vision subjects did not statistically significantly differ. However, I had hypothesized, based on previous studies [33, 34], that there would be a statistically significant difference between male and female performance on Dynavision performance in adult subjects. This was found to occur only for normal-vision subjects, and the effect was present and statistically significant even when adjusting for the fact that the normal-vision females in this study were older on average. However, female low vision subjects were found to have better scores than males on the Dynavision task, although there is no statistically significant difference. Hence, the low vision cohort does not exhibit the same relationship between gender and performance on the Dynavision task that is observed in the normal-vision adults' data. A larger sample size for the low vision cohort might reveal more about the relationship between Dynavision performance and gender.

During administration of the UFOV and Dynavision tasks to the subjects, I became aware of other factors, which were not included in my analyses, which could possibly affect subjects' performance on the tasks. For instance, subject arm length (or "wingspan") is a trait that appeared to grant an advantage to taller and longer-armed subjects when performing the Dynavision task. This is because these subjects' arms, when extended, could more easily and quickly reach outer buttons on the Dynavision board that would require a longer transit time from a short-armed subject. Additionally, longer-armed subjects were able to stand at a slightly further working distance than shorter subjects and still be within arm's reach of the board, allowing for a decreased need for scanning the board for each illuminated button, as more of the board would fall within the central visual field from a further distance. Subject height and arm length may have, at least in part, contributed to the inverse correlation between age and Dynavision scores for children ages 8 to 17, as the youngest children were much smaller, and this

could have factored into the child taking longer to reach the outer buttons. This same effect could also have contributed to the finding that males performed with shorter reaction times than females in the normal-vision adult group; as on average males are taller than females, height as a characteristic could be a confound in the analysis of the relationship between gender and reaction time on the Dynavision task. Another factor that was not analyzed but may contribute to task performance is subject personality with regard to competitive nature and motivation, particularly for the Dynavision task. While some subjects appeared highly motivated to beat their previous score on each new trial, or to perform their absolute best, others struck the buttons with less sense of urgency. By my observation, there were subjects across age and gender who displayed the full spectrum of motivation, from competitive to nonchalant. However, the most competitive and highly motivated subjects appeared to be toward the younger end of the cohort, both in the normal and low vision groups. Thus, level of motivation could possibly have contributed in part to the age effect seen on the Dynavision task.

Conversely, fewer confounding or interfering subject characteristics seemed relevant with regard to the UFOV task. Aside from the subject's ability to direct attention appropriately to the computer task (which is, in fact, a relevant part of the UFOV assessment rather than a confounding factor), there did not appear to be any factors related to a subject's physical or personality traits that would affect UFOV scores. For these reasons, I note that UFOV scores appear more representative and specific to the intended assessment, and less likely to be affected by incidental subject characteristics that may influence performance on the Dynavision task.

For each of the tasks, it should be noted that the different etiologies of low vision could have contributed to differences and variability in performance on the tasks in the low vision subject cohort. As all subjects with uncorrectable vision loss ("low vision") were included in the study regardless of whether the vision loss included decreased acuity, loss of central or peripheral field, or some combination of the above, it is possible

that differences in capabilities for a given patient could lead to differences and variability of performance on one task or the other, or both. This notion highlights that further research would be necessary to analyze performance on these tasks for persons with specific etiologies of low vision, to better estimate their driving potential on the basis of these clinical scores.

Test-retest reliability was also of interest for the 3 Dynavision trials in this investigation. I hypothesized based on previous literature that the Dynavision task would display a learning effect for the first two trials, after which I expected performance to level off [33]. My data support this hypothesis in the normal vision cohort, in which there was a statistically significant improvement of performance between attempts 1 and 2 of the Dynavision task, but not between attempts 2 and 3. However, low vision subjects did not show any statistically significant difference between any of the 3 trials and, in fact, as a group the cohort performed slightly worse on trial 2 than on trial 1 or 3. This outcome might imply that the learning effect on this task is less pronounced in the low vision group, compared to that of the normal vision cohort. However, it could instead be an indication of the increased variability in the scores for low vision subjects. When analyzing agreement between scores for trials 1, 2, and 3 of the Dynavision task, the limits of agreement for the 95% confidence interval were considerably larger for the low vision population (ranging from +3 to -2 and -4 seconds), than for the normal vision population (approx. $\pm$0.2 seconds). The lack of a clear learning effect or significant difference in scores between trials on the Dynavision task for low vision patients may appear to preclude the need for averaging multiple trials. However, given the large size of the limits of agreement for reaction time on multiple Dynavision trials for low vision subjects, averaging results on 3 trials may still provide a more representative estimate of performance compared to the results of a single trial because of the increased variability in scores. Additionally, it was not recorded in the clinical records whether or not each subject had attempted Dynavision during a previous low vision exam. Some low vision

subjects in this study were new to the Dynavision task and others were not; thus, investigation into this variable may further explicate the learning effect for low vision patients on the Dynavision Mode A task.

The trends seen above can be employed when considering low vision patients' performance on the UFOV and Dynavision tasks as part of a pre-driving assessment exam; i.e., these trends may help tailor the analysis of each individual patient's case in the context of their cohort. For instance, elderly patients may not be held to the same expectations as young adults for the UFOV or Dynavision tasks, given the tasks' significant correlations with age. That being said, all but two of the subjects in the normal vision cohort landed within the UFOV Category 1: Very Low Risk. Thus, while UFOV scores deteriorate approximately linearly with increasing age for patients with normal vision within the sampled age range (age 21-73), subjects even toward the top of this age range can be expected to score in Category 1. Additionally, the UFOV scores of 14 of 17 low vision subjects also fell within Category 1, so a level of functional impairment corresponding to Categories 2 and above should be carefully analyzed as potentially significant. Similarly for Dynavision testing, elderly patients and children should not be expected to reach similar reaction time values as young adults of driving age. Score adjustment or extra consideration is not necessary for assessing the effect of gender on performance on UFOV and Dynavision, as low vision subjects did not show a significant gender difference on either task. Characteristics such as subject height may need to be taken into consideration when interpreting Dynavision scores.

Conclusions:

In summation, performance on the UFOV and Dynavision tasks correlate in both normal and low vision adult subjects, but the observed correlation is not strong enough to warrant interchangeability of the two tasks when assessing low vision patients for driving fitness. It is possible that the skills tested individually in UFOV (visual processing speed and attentional capacity) and Dynavision (visuomotor reaction time and scanning) are not

related enough to correlate strongly across all subjects. Because UFOV is a well-researched and reliable indicator of driving performance and crash risk, it remains a relevant and utile mainstay in the low vision clinic for use in the pre-driving examination. The Dynavision 2000 task, however, requires further investigation into its own independent correlation with on-road driving safety and crash prediction and risk. If Dynavision were found to have cutoff or threshold scores that correlate independently with potential driving fitness including on-road assessment pass or failure, or recorded crash risk, and if UFOV and Dynavision performance fail to correlate strongly because the traits that each test assesses are qualitatively different and individually related to driving, then administering both tasks (UFOV and Dynavision) could increase sensitivity and specificity for improving driving fitness prediction.

Appendices:

Appendix A:

Characteristics of low vision patients recruited as subjects for this study.

Age	sex	etiology of LV
16	M	Left homonymous hemianopsia
16	M	ONH hypoplasia/Septo-optic dysplasia
17	M	Cone-rod dystrophy
18	M	Oculocutaneous Albinism
18	M	Oculocutaneous Albinism
19	F	ROP; Corneal scarring
29	F	Bilateral RD repaired; CME
30	F	Stargardt Disease
30	M	Congenital Nystagmus
32	F	Oculocutaneous Albinism
32	F	ONH swelling and CME (OD only; no vision OS)
34	F	Stargardt Disease
42	F	Pars Planitis
43	M	Congenital macular degeneration
53	F	Sturge-Weber; end-stage glaucoma
55	F	Proliferative Diabetic Retinopathy OU
83	M	Age-related Macular Degeneration

Appendix B:

Category cutoff scoring for the Useful Field of View task:

Scores for Subtests 1-3	Category Level	Risk Statement
Subtest 1 > 0 but <= 30, and Subtest 2 > 0 but < 100, and Subtest 3 > 0 but < 350	1	Very Low
Subtest 1 > 0 but <= 30, and Subtest 2 > 0 but < 100, and Subtest 3 >= 350 but <= 500	2	Low
Subtest 1 > 0 but <= 30, and Subtest 2 >= 100 but < 350, and Subtest 3 > 0 but < 350	2	Low

Subtest 1 > 0 but <= 30, and Subtest 2 >= 100 but < 350, and Subtest 3 >= 350 but <= 500	3	Low to Moderate
Subtest 1 > 0 but <= 30, and Subtest 2 >= 350 but <= 500, and Subtest 3 >= 350 but <= 500	4	Moderate to High
Subtest 1 > 30 but <= 60, and Subtest 2 > 0 but < 100, and Subtest 3 > 0 but < 350	2	Low
Subtest 1 > 30 but <= 60, and Subtest 2 > 0 but < 100, and Subtest 3 >= 350 but <= 500	3	Low to Moderate
Subtest 1 > 30 but <= 60, and Subtest 2 >= 100 but < 350, and Subtest 3 > 0 but < 350	3	Low to Moderate
Subtest 1 > 30 but <= 60, and Subtest 2 >= 100 but < 350, and Subtest 3 >= 350 but <= 500	4	Moderate to High
Subtest 1 > 30 but <= 60, and Subtest 2 >= 350 but <= 500, and Subtest 3 >= 350 but <= 500	5	High
Subtest 1 > 60 but < 350, and Subtest 2 >= 100 but < 350, and Subtest 3 > 0 but < 350	3	Low to Moderate
Subtest 1 > 60 but < 350, and Subtest 2 >= 100 but < 350, and Subtest 3 >= 350 but <= 500	4	Moderate to High
Subtest 1 > 60 but < 350, and Subtest 2 >= 350 but <= 500, and Subtest 3 >= 350 but <= 500	5	High
Subtest 1 >= 350 but <= 500, and Subtest 2 >= 350 but <= 500, and Subtest 3 >= 350 but <= 500	5	Very High

Comparison of new UFOV program scores, and the scoring (by percent decrease) previously cited in the literature:

Original UFOV (% Reduction)	**New PC UFOV (Speed in msec)**
< 22.5	< 100 Task 2 and < 350 Task 3
23.0 - 39.5	Task 2 >= 100 or, Task 3 >= 350
40 - 60	>= 100 Task 2 and >= 350 Task 3
> 60	>500 Task 2 and >500 Task 3

Appendix C: Raw data for all subject groups

Normal Vision Adults:

Age	Sex	Dyna1 Hits	Dyna 1 RT	Dyna 2 Hits	Dyna 2 RT	Dyna 3 Hits	Dyna 3 RT	Avg Dyna RT	UFOV1	UFOV2	UFOV3	Category
24	F	70	0.86	71	0.82	65	0.92	0.87	14.80	14.80	24.80	1
24	F	77	0.78	78	0.77	82	0.73	0.76	14.70	14.70	14.80	1
24	F	81	0.74	83	0.72	89	0.67	0.71	14.80	14.80	21.40	1
24	F	82	0.72	82	0.73	88	0.68	0.71	14.70	14.70	21.40	1
25	F	41	1.44	47	1.26	45	1.32	1.34	14.80	14.80	34.80	1
26	F	70	0.84	67	0.89	59	1.00	0.91	14.80	14.80	31.40	1
37	F	55	1.09	56	1.06	59	1.01	1.05	14.80	14.80	14.80	1
37	F	59	1.01	68	0.88	62	0.95	0.95	14.70	14.80	14.80	1
40	F	60	1.00	63	0.94	67	0.89	0.94	14.80	14.80	64.80	1
45	F	54	1.10	49	1.19	49	1.22	1.17	14.70	14.80	38.10	1
45	F	41	1.42	56	1.04	56	1.07	1.18	14.80	14.80	68.10	1
47	F	40	1.46	48	1.25	50	1.20	1.30	14.80	14.80	34.80	1
47	F	61	0.96	61	0.96	70	0.83	0.92	14.80	14.80	138.20	1
47	F	41	1.41	41	1.46	41	1.45	1.44	14.80	14.80	61.40	1
54	F	56	1.04	65	0.92	65	0.92	0.96	14.80	14.80	38.10	1
54	F	43	1.37	45	1.33	34	1.72	1.47	14.80	131.50	131.50	2
55	F	53	1.13	62	0.96	62	0.96	1.02	14.80	18.10	28.10	1
55	F	51	1.17	56	1.07	57	1.05	1.10	14.80	28.10	94.80	1
56	F	56	1.05	53	1.10	52	1.15	1.10	14.80	14.80	21.40	1
56	F	65	0.92	60	0.98	61	0.96	0.95	14.80	104.80	104.80	2
57	F	67	0.89	66	0.89	75	0.80	0.86	14.80	14.80	28.10	1
57	F	38	1.55	42	1.40	47	1.28	1.41	14.80	14.80	38.10	1
60	F	57	1.03	52	1.13	57	1.05	1.07	14.80	14.80	101.50	1
60	F	39	1.49	43	1.36	50	1.19	1.35	14.80	141.50	141.50	1
61	F	58	1.03	56	1.06	48	1.23	1.11	14.80	14.80	21.40	1
62	F	39	1.51	42	1.43	45	1.33	1.42	14.80	18.10	71.50	1
67	F	45	1.33	50	1.19	49	1.21	1.24	14.80	14.80	111.50	1
69	F	50	1.19	43	1.39	44	1.34	1.31	14.80	14.80	81.50	1
70	F	28	2.07	30	1.98	27	2.19	2.08	14.80	31.50	211.80	1
21	M	85	0.70	85	0.70	87	0.69	0.70	14.80	14.80	24.80	1
23	M	72	0.83	79	0.75	76	0.79	0.79	14.80	14.80	14.80	1
25	M	92	0.65	81	0.74	91	0.65	0.68	14.80	14.80	24.80	1
27	M	73	0.82	71	0.84	81	0.73	0.80	14.80	14.80	14.80	1
28	M	73	0.82	78	0.77	76	0.79	0.79	14.80	14.80	14.80	1
29	M	65	0.91	78	0.76	74	0.81	0.83	14.80	14.80	14.80	1
29	M	70	0.83	64	0.93	62	0.96	0.91	14.80	14.80	88.10	1
33	M	72	0.83	77	0.78	78	0.77	0.79	14.80	14.80	14.80	1
33	M	68	0.87	73	0.82	69	0.87	0.85	14.80	14.80	41.40	1
35	M	86	0.70	85	0.70	89	0.67	0.69	14.80	14.80	14.80	1
35	M	74	0.81	76	0.79	73	0.82	0.81	14.80	14.80	21.40	1

35	M	54	1.11	57	1.05	62	0.96	1.04	14.70	14.70	54.80	1
36	M	67	0.89	67	0.90	75	0.80	0.86	14.80	14.80	81.50	1
38	M	61	0.97	67	0.90	61	0.98	0.95	14.80	14.90	64.80	1
39	M	66	0.91	71	0.84	68	0.87	0.87	14.80	14.80	34.80	1
39	M	72	0.83	78	0.77	79	0.76	0.79	14.70	14.70	34.80	1
40	M	70	0.85	69	0.86	75	0.80	0.84	14.80	14.80	18.10	1
52	M	66	0.91	72	0.83	80	0.72	0.82	14.80	94.80	118.10	1
56	M	61	0.98	76	0.78	75	0.80	0.85	14.70	14.70	21.40	1
57	M	46	1.30	61	0.98	60	0.99	1.09	14.80	14.80	98.10	1
59	M	61	0.97	65	0.92	66	0.90	0.93	14.80	14.80	78.10	1
73	M	48	1.24	55	1.09	48	1.22	1.18	14.80	18.10	104.80	1

Normal Vision Children:

Age	Sex	Dyna1 Hits	Dyna 1 RT	Dyna2 Hits	Dyna2 RT	Dyna3 Hits	Dyna 3 RT	Avg Dyna RT	UFOV1	UFOV2	UFOV3	Category
9	F	33	1.81	30	1.92	29	2.06	1.93	14.80	28.10	98.20	1
17	F	64	0.93	56	1.06	64	0.94	0.98	14.80	14.80	51.50	1
17	M	46	1.26	50	1.16	54	1.10	1.17	14.80	14.80	31.50	1
16	F	67	0.89	64	0.94	68	0.88	0.90	14.80	14.80	21.40	1
11	F	41	1.44	38	1.50	38	1.52	1.49	14.80	14.80	14.80	1
13	F	64	0.94	56	1.07	55	1.07	1.03	14.80	14.80	14.80	1
8	M	28	2.13	23	2.57	29	1.96	2.22	14.80	14.80	14.80	1
13	F	53	1.11	58	1.03	55	1.07	1.07	14.80	14.80	68.10	1

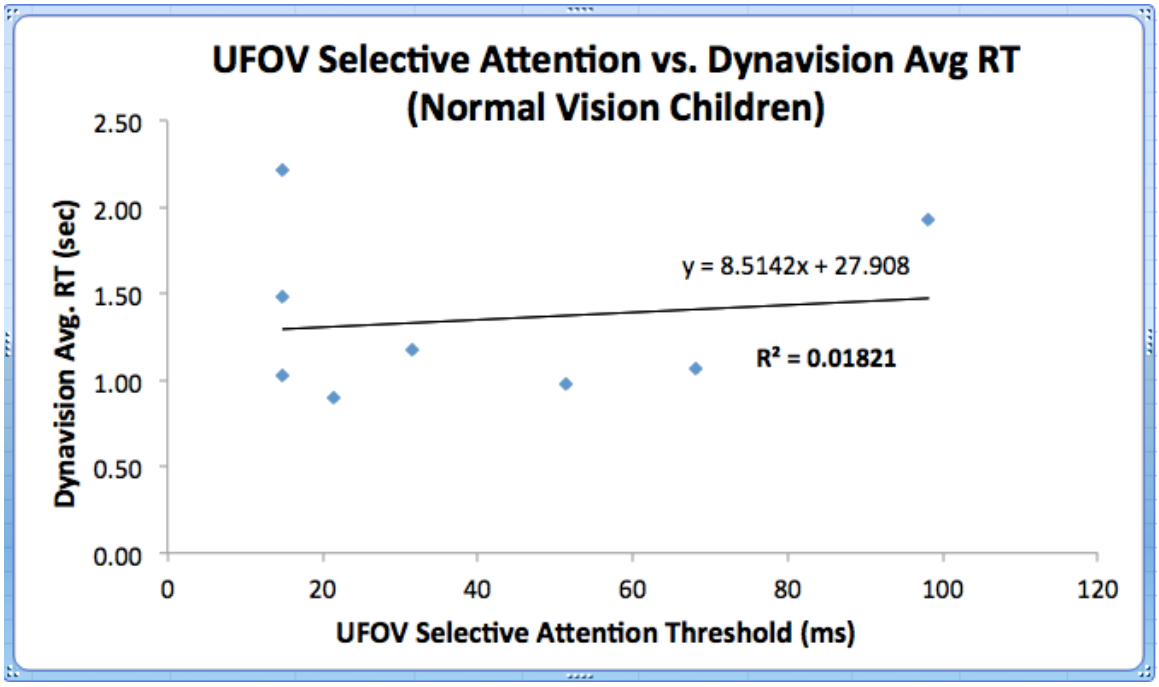
Low Vision Adults of driving age:

Age	Sex	Dyna 1 Hits	Dyna 1 RT	Dyna 2 Hits	Dyna 2 RT	Dyna 3 Hits	Dyna 3 RT	Avg Dyna RT	UFOV1	UFOV2	UFOV3	Category
30	F	46	1.30	48	1.25	53	1.13	1.23	21.50	74.80	114.80	1
42	F	58	1.02	54	1.11	60	0.99	1.04	14.70	34.80	178.10	1
32	F	51	1.18	57	1.05	61	0.98	1.07	14.70	14.70	41.40	1
32	F	46	1.30	44	1.34	40	1.48	1.37	14.80	18.10	188.20	1
19	F	21	2.75	22	2.65	26	2.30	2.57	18.10	18.10	224.80	1
29	F	58	1.03	56	1.07	52	1.15	1.08	14.80	38.10	54.80	1
55	F	21	2.76	29	1.91	21	2.70	2.46	178.20	178.20	431.50	4
53	F	20	2.91	17	3.49	11	5.13	3.84	25.80	151.50	291.50	2
34	F	41	1.43	51	1.16	58	1.02	1.20	24.80	48.10	188.20	1
18	M	76	0.78	77	0.78	76	0.79	0.78	16.70	16.70	16.70	1
30	M	74	0.81	86	0.69	78	0.76	0.75	14.80	14.80	54.80	1
16	M	47	1.26	44	1.34	54	1.10	1.23	14.80	44.80	44.80	1
43	M	9	5.28	5	9.99	13	3.82	6.36	14.80	21.40	34.80	1
83	M	21	2.67	10	5.27	20	2.92	3.62	41.40	19.50	408.20	2
18	M	49	1.21	45	1.31	49	1.21	1.24	14.80	14.80	14.80	1
16	M	30	1.98	40	1.50	35	1.66	1.71	14.80	78.10	324.80	1
17	M	20	2.98	22	2.64	27	2.17	2.60	14.80	14.80	61.50	1

Appendix D:

Pilot study for normal vision children.

i. Linear regression and correlation for UFOV vs. Dynavision in normal vision children



As seen above, there was no trend in the relationship UFOV vs. Dynavision results for the cohort of children ages 8 to 17. With an r^2 value = 0.018, only about 2% of variability on one task would be accounted for by score on the other task. The significance level for this correlation was calculated with a t-test (with N-2 df) = r / SQRT([1-r^2]/ [N-2]). With a sample size N = 8 and using a 2-tailed t test, t[df=6] = 0.334, p = 0.75. Thus, the correlation between UFOV and Dynavision scores in normal child subjects was not found to be statistically significant.

The effect of age on the UFOV task in this cohort of children is shown on pg. 35, and there was no significant correlation between age and performance. The effect of age

on the Dynavision tasks for children in this pilot study is shown on pg. 39, and there was found to be a statistically significant negative correlation between age and reaction times on Dynavision, such that scores improved (lower reaction times) with increasing child subject age.

As with the adult scores for both normal vision and low vision, a ceiling effect was seen for child performance on the UFOV task. For Task 1, 100% (8 of 8) child subjects reached the ceiling processing speed of 14.8 ms. For Task 2, 87.5% (7 of 8) children reached the 14.8 ms threshold. For Task 3, only 3 of the 8 subjects (37.5%) reached the 14.8 ms threshold score. Thus, as for adults and low vision patients, UFOV task 3 data were used when comparing UFOV to Dynavision scores.

To compare UFOV performance by gender in normal vision child subjects, an independent t-test was performed for the 2 males and 6 females; $t = 0.431$, $df = [8 - 2] = 6$. The two-tailed P value = 0.844. Thus, there was no significant gender difference in performance on UFOV for normal vision children. This could be in part caused by the very small sample size here, especially as there were only 2 males. Similarly for Dynavision, a t-test was performed for the 2 males and 6 females; $t = 1.218$, $df = [8 - 2] = 6$. The two-tailed P value = 0.269. Thus, there was no significant gender difference in performance on Dynavision for normal vision children; again, a larger sample size would allow more thorough investigation into this relationship.

Test-retest reliability for the Dynavision task in these children was performed; the individual trials for each subject were compared via paired t-tests [33], (Trial 1 vs. Trial 2 and Trial 2 vs. Trial 3), and a Bonferroni correction was applied for the 2 comparisons, such that an alpha level of $p \leq 0.025$ was applied. For the analysis of Trial 1 vs. Trial 2, $t = 1.57$, $df = [8 - 1] = 7$. The two-tailed P value = 0.159. Thus, performance on Trials 1 and 2 is not statistically significantly different. When comparing Trial 2 vs. Trial 3, $t = 1.01$, $df = [8 - 1] = 7$. The two-tailed P value = 0.346; thus, performance on Trials 2 and 3 also is not found to be statistically significantly different. Thus, there was no significant

learning effect shown for children when repeating trials on the Dynavision task. However, this does not necessarily imply that an appropriate approximation of reaction time can be made without repeating the task, because the children demonstrated a higher variability in performance than, for instance, the normal vision adult cohort. This was what led to the lack of statistical significance in improvement in scores between trials, and this variability indicates that an average of 3 Dynavision trials may still provide the best overall estimate of the subject's reaction time.

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