FUNCTIONAL VISION
A Call to Action

Dr. Melissa Hunfalvay
Melissa@righteye.com
“25% of all schoolchildren in the United States have functional vision problems.” (Zaba, 2011).

69% of adolescents with a concussion were shown to have one or more Functional Vision issues (Christina, Scheiman, Gallaway, 2015).

Up to 74% of adults with low levels of literacy have function vision problems (Zaba, 2011).

In any given year, approximately 30 percent of adults over age 65 will fall. Having impaired vision more than doubles this risk (Ehrlich, Hassan, Stagg, 2018).

About 50 percent of people who said they had trouble seeing were afraid of falling and as a result, limited their activity (Ehrlich, Hassan, Stagg, 2018).

More than one in four older adults with vision problems had recurrent falls in the year before they were surveyed (Ehrlich, Hassan, Stagg, 2018).
What is Functional Vision?

Functional Vision is the vision needed to live life successfully. Although a broad definition, functional vision effects an individual’s ability to successfully engage in Activities of Daily Living (ADL’s). Throughout the lifespan, activities such as reading, walking, driving, playing sports, even making a cup of coffee or peanut butter and jelly sandwich all begin with functional vision (Land, 2006; 2009).

To date, the term Functional Vision has been associated with low vision (Rosenthal & Cole, 1996) and vision impairment (Kaiser & Herzberg, 2017). However, Functional Vision has broader considerations for the overall health and wellness of individuals.

Many optometrists clinically assess some components of a Functional Vision assessment, most commonly these include visual acuity and refraction. However, a comprehensive Functional Vision assessment includes more than “seeing clearly.” According to the American Optometry Association (AOA), evidence-based clinical guidelines recommend a comprehensive exam to include acuity, refraction and ocular motility (the examination of the 12 extra-ocular muscles), binocular vision (the ability of the eyes to work together), accommodation (the ability of the eye to change focus), ocular and systemic health assessments and the patients visual function (AOA, 2015).

As part of the preliminary examination, the AOA recommends an initial evaluation of the patients’ functional vision by assessing, in part, the patients eye movements, ocular alignment, pupil size, pupil response, and near point of convergence (NPC; AOA, 2015).

Functional vision is not just eyesight, or even information from the eyes alone. Instead, functional vision is the eye-brain connection (see Figure 1). The eyes take in environmental
information, that is then transferred via the optic nerve to the cerebellum and then to the dorsal and ventral tracks within the brain. This information is processed in various ways and ultimately sent to the motor cortex and brain stem to “act” on the information. This continual circuit is collectively referred henceforth as Functional Vision. The purpose of which is to enable a person to see, process, and respond to an ever-changing environment. The individuals’ ability to do this reflects success (or failure) in ADL’s.

Diagram 3: Eyes-to-Action Process

New York, NY, p 59.

Figure 1:
The eyes are the only sense in the body to directly connect to the brain. The retina is part of the brain and initial brain processing. Therefore, to assess functional vision we need to assess the eyes, the brain, the motor response and the relationship between all three. In doing so, we will have a better understanding of functional understanding of how these components interact and affect our ability to live life successfully through functional optimization.

Functional Vision requires an understanding of research and clinical practice in areas that are often seen as disparate fields of both research and practice. These include optometry, ophthalmology, neurology, functional neurology, occupational therapy, physical therapy and kinesiology.

<table>
<thead>
<tr>
<th>Profession</th>
<th>Area of Specialty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optometry</td>
<td>Eyes</td>
</tr>
<tr>
<td>Ophthalmology</td>
<td>Eyes</td>
</tr>
<tr>
<td>Neurology</td>
<td>Nerves</td>
</tr>
<tr>
<td>Occupational Therapy</td>
<td>ADL’s</td>
</tr>
<tr>
<td>Physical Therapy</td>
<td>Actions</td>
</tr>
<tr>
<td>Kinesiology</td>
<td>Movement/actions</td>
</tr>
<tr>
<td>Chiropractic</td>
<td>Musculoskeletal</td>
</tr>
</tbody>
</table>

The purpose of this paper is to review relevant literature across these different domains as they relate to Functional Vision and include eye movements, the eye-brain-action connection. A further purpose is to create awareness, to provide a cohesive understanding and reference point for this important concept in the desire that researchers and clinicians from different fields may have a foundational model for working together to assist people in leading successful lives.
How prevalent are Functional Vision issues?

Children, aged 6-14 years, with reduced reading efficiency, defined as reading at least 2 grade levels below expected, presented with dysfunctional levels of Functional Vision. Specifically, abnormal binocular vision and/or accommodative results (Christian, Nandakumar, Hrynchak, Irving, 2017).

Since the 1960’s studies have shown the link between juvenile delinquency, learning disabilities and functional vision. Snow (1983), Bashara & Zaba (1978), Harris (1989), Stehli (1990) and Dzik (1966) have found that significant numbers of juvenile offenders had one of more visual deficiency. Since 80% of all learning involves the visual system, it would be expected that youth with functional vision deficiencies would experience frustration in school which may lead to disruptive behavior and in some cases delinquent behavior. The challenge has been to identify such issues early with functional vision examinations in order to identify and ameliorate such factors to reduce the increase of risk of delinquent behavior.

In a study by Johnson and Zaba (1998) the most significant finding was a high failure rate of juvenile offenders on tracking tasks. 80% of the children in the study failed the Developmental Eye Movement Test. This failure rate was “considered poor and represent(ed) a real dysfunction in a task or subject area” according to prior research by Solan & Suchoff (18).

Juvenile offenders who failed the visual tracking tasks had lower reading, language arts, and total achievement scores. Tracking accounted for 15% of the reading score variability, 18% of the language arts variability and 19% of the total achievement variability. Convergence explained an additional 6% of total achievement variance. Thus, tracking and convergence together accounted for 25% of the total variance for academic achievement. As stated previously,
80% of the juveniles failed one or more of these tasks. Such undetected visual problems are likely not only to frustrate but often can lead to a perception that the juvenile has an inability to perform the academic tasks because of learning or reading disorders.

Functional Vision issues are also very common after concussions. 69% of adolescents with a concussion were shown to have one or more Functional Vision issues (Christina, Scheiman, Gallaway, 2015). Specifically, accommodative disorders (51%), convergence insufficiency (49%), and saccadic dysfunction (29%). In all, 46% of patients had more than one vision diagnosis. 1.7 million people incur a traumatic brain injury (TBI) annually in the United States according to Centers of Disease Control and Prevention statistics (Faul, Likang, Coronado, 2012) The leading causes of TBI in the US population are falls, running into objects (struck by/against events), motor vehicle accidents, and assaults. Traumatic brain injuries can take place in any setting and can happen to anyone.

One component of functional vision is binocularity, being able to see in 3D. Approximately 12% of the population has binocular vision dysfunction.

What are the Consequences of Uncorrected Functional Vision issues?

When Functional Vision problems are not detected early in life they can negatively affect the individual throughout their lifetime. Undetected vision problems have been found at a significantly higher rate in Title 1 students, who are two to three times more likely than non-Title I students to have undetected functional vision problems (Johnson, Blair, & Zaba, 2000). Juvenile offers, illiterate adults, academically at-risk college students and academically/behaviorally at-risk public-school students all have significantly higher Functional Vision problems than other members of the US population (Zaba, 2001).
Between 1992 and 2003, according to the National Assessment of Adult Literacy (NAAL) there was a decline in the average prose literacy. Prose literacy is defined as the knowledge and skills needed to perform prose tasks, that is to search, comprehend, and use continuous texts (See figure 1). Furthermore, a significant number of undetected and untreated functional vision problems were found in adults at the lowest level of literacy (Thau, 1991). Up to 74% of these adults failed a functional vision screening (Johnson & Zaba, 1994). Many of these adults are the children of yesterday who had undiagnosed and untreated vision problems and grew up to become part of the adult literacy problem we face today in the United States.

Research has shown that, functional vision problems can lead to inadequate academic performance in school, low self-esteem, emotional issues and even anti-social behavior (Johnson & Zaba, 1999).

In the United States the incarceration of juvenile and adult offenders is the highest of any country in the world in numbers and cost. On any given day, nearly 60,000 youth under the age of 18 are incarcerated (ACLU: https://www.aclu.org/issues/juvenile-justice/youth-incarceration/americas-addiction-juvenile-incarceration-state-state). According to the 2017 Bureau of Justice Statistics, the imprisonment rate is 440 per 100,000 adults. Totaling over 2.2 million people. In 2000, previously undetected vision problems were found in populations of adjudicated adolescents, with percentages as high as 74% (Barber & Johnson, 2002). Criminality is obviously a complex social problem however, vision is often overlooked as a contributing factor, despite overwhelming evidence that it plays a critical role in development.

Better Functional Vision and vision care means a more literate and productive workforce. It has been estimated that “…a 1% rise in literacy scores translates into a 2.5% relative rise in labor productivity and a 1.5% increase in gross domestic product (GDP) per person.” 36 Today
the goal of almost all employers is “high performance workplaces that integrate technology, work process, and organization … practices that can adapt to changing business conditions.” 37 To achieve this goal, employers are spending billions of dollars to upgrade the basic skills of many employees. In fact, in 2006, US organizations spent an astounding $5.8 billion on basic skills such as remedial reading, writing, and math. 38 Smaller companies often do not offer basic skills training. The limited literacy skills of employees cost businesses and taxpayers $20 billion annually in low wages, profits, and productivity. 38, 39 One economist estimates the US “could reduce the number of crimes committed by 100,000 each year and save $1.4 billion annually, if 1% more males graduated from high school each year.” 40 Healthy vision is vital for a productive and efficient workplace. The US Census Bureau predicts that between 2000 and 2040, the number of Americans aged 65 and over will more than double to 77 million, while the number of prime working age adults between 25 and 54 will increase by only 12%. 41 Today’s children must have the necessary vision skills to perform successfully in school and in the workplace. A society with higher rates of functional vision is a more literate society and a stronger economic future. It is a simple as connecting the dots:

```
Better Vision Care
  ↓
Increased Literacy
  ↓
Fewer Societal Problems
  ↓
Stronger Economy
```

The economic theory for such an intervention is straightforward—identifying and remedying vision problems should increase students’ acquisition of human capital. If students cannot see, they cannot read (be it their textbooks or the writing on the board at the front of the
classroom), and if they cannot read they have little hope of keeping pace with the demands of school and will likely underperform relative to their full potential. By identifying and treating vision problems at an early age, students will acquire human capital at a faster rate, which will yield both private and social benefits. (Cunha et al. (2006), Heckman, Lochner, and Todd (2006), Lange and Topel (2006), Grossman (2006), and Lochner (2011) for reviews of the private and social benefits of education.)

We find that providing additional/enhanced screening alone (screen-only schools) is generally insufficient to improve student math and reading skills as measured by scores on the Florida Comprehensive Achievement Test (FCAT). Indeed, some estimates indicate possibly negative impacts of this intervention. However, averaging over all students (including those with good vision), the intervention that included not only screenings but also vision exams and free eyeglasses (full treatment schools) increased both the probability of passing the FCAT reading test and the probability of passing the FCAT math test by 2.0 percentage points, although the statistical significance of these results is strong only for the reading test. We also find suggestive evidence that sizeable positive spillovers may be accruing to students with good vision in the full treatment schools.

The Neurology and Neuroscience of Functional Vision

Functional Vision includes not only the eyes and eye movements, but also the brain, visual pathways and subsequent motor responses. Vision, specifically movements of the gaze and eyes, begin a sequence of events that allow us to locate the information needed by the motor system to execute movement (Land, 2006).

To successfully perform ADLs such as food preparation: making a cup of tea (Land et al., 1999) and making a peanut butter and jelly sandwich (Hayhoe, 2000; Hayhoe et al., 2003) eye
movements were recorded using eye tracking technology. Several distinct but interacting eye and brain systems were shown to be involved in such tasks. To pick up the mug to make tea, the mug must first be found, this is the job of the gaze system to initiate the movement of the eyes and usually the head and trunk as well. This brings the image of the mug onto the fovea of the eyes so it can be seen clearly. The information from the visual system is needed to check that the object fixated upon is, in fact, a mug. The visual system then provides directional guidance for prehension of the arm and hand toward the mug and finally, to check details of the mug such as the orientation of the handle to allow the hand to prepare the correct grip for picking up the mug successfully, without dropping it on the floor.

To perform the simple task of picking up a mug, three systems; the gaze, visual and motor systems are all involved. A fourth system, known as a “controller” has overall control of the three systems which create a “schema” or internal representation of a task directing gaze on where to look (Land, 2009).

The location of these systems in the brain are well known. In brief, the gaze system consists of the Frontal Eye Fields (FEFs; Leigh & Zee, 2015; p.486) and the lateral intraparietal are of the parietal lobe (Land, 2009). These are connected via neural pathways to the superior colliculus and ultimately to the oculomotor nuclei of the brain stem.

The visual system, in varies ways occupies much of the brain. In the specific action of picking up a mug the occipital lobe and much of the temporal lobe with extensive connections to the parietal and frontal lobes. The dorsolateral prefrontal cortex (DLPFC) is most associated with the purposeful action of picking up the mug. If the DLPFC is damaged initial steps or actions associated with picking up the mug will not be affected, however, the organization of this activity is impaired.
Movement is in the primarily motor cortex, the premotor cortex and various parietal areas known to be associated with the reach and grasp prehension motion of picking up a mug.

Therefore, although an action begins with gaze and eye movements, in order to complete the action, neural pathways, with interconnected brain regions and ultimately motor responses all combine to successfully (or not) pick up a mug. This simple act, that we do many times a day, requires all systems to work functionally. Without them this act, and many more complex acts are adversely affected. Dropping the mug, falling up or down stairs, driving accidents, dropping a catch can all be results of poor functional vision. Even sedentary activities such as reading, typing, and drawing are all adversely affected by poor functional vision.

To successfully perform ADLs we need our vision to be functional. Eye movements are one component of Functional Vision. The following section will focus on eye movements types, purpose and their role in ADLs.

Eye Movements: Human eye movements are of two main types according to Leigh and Zee (2015): those that stabilize gaze (fixations, vestibular, optokinetic and smooth pursuits) and those that shift gaze to redirect the line of sight to objects of interest (nystagmus quick phase, saccades and vergence).

Gaze stabilization

Fixations: Neural Pathways of fixations

Eye movements are designed to position our gaze and then fovea to objects of interest so we can clearly and with stability see our environment. The object should be positioned within 0.5 degrees of the center of the fovea for best clarity. Objects outside the fovea have reduced visual acuity by about 50% and lack fine detail (Leigh & Zee, 2015). Holding the image of a stationary object on the fovea (minimizing ocular drifts) is known as a fixation.
During purposeful behavior, such as preparing a sandwich, fixations, stopping points of the eye, are directed at task-relevant objects 84% of the time (Land, 2009). This indicates that fixations, allow the fovea to receive environmental information needed to complete the task. In other words, one can follow a visual scan path from fixation-to-fixation to understand the “thinking” of the person.

According to Land et al. (1999), during purposeful activities that include movement, fixations can be classified into four categories. Locating fixations are, as they suggest, concerned with location of objects, the mug in the above example was found via a locating fixation. Directing fixations function to provide fovea centered goal-position information to guide action. Guiding fixations are concerned with the manipulations involving more than one object, for example the kettle and its lid. Checking fixations determine when some condition is met, for example, the kettle is full, the water is boiling.

During human evolution the first threat to visual clarity came with locomotion. Our eyes are within our head and if we did not have the ability to move our eyes the visual world would “slip” on the retina with every head perturbation, resulting in blurred vision. To compensate for this and allow for images to be stabilized on the fovea during movement the vestibular ocular reflex and visually mediated reflexes were developed.

What happens when Gaze Stabilization is dysfunctional? If a person is unable to fixate their visual acuity is impaired, meaning that object may appear blurry. Depending on the fixation degradation (if a nystagmus) then the severity can range from mild blurring to rapid periodic jumps where the “world appear to move back and forth.” In some cases, objects in the periphery appear to move up and down, and in other cases object lying on the floor appear to move side to side (torsional oscillations).
If the eye fails to stabilize fixations during infantile and childhood development, then the child may fail to develop binocular vision. Consequences of such include a failure to perceive in three dimensions, failure to determine distances that objects are from oneself and from each other. Migraines, vertigo (sensations of spinning and dizziness) abnormal head posture and strain and symptoms such as ataxia (the loss of full control of bodily movements and coordination) can be symptoms of a failure to fixate.

Failure of Gaze stabilization on Functional Vision and ADL’s. Typical outcomes include increase risk of falling, clumsiness, inaccurate reach and grasp, impaired hand eye coordination. In a specific ADL example of walking up stairs and ringing a doorbell, the person who is unable to fixate may not see the steps clearly, they may misjudge the height of the stairs, the stairs may even appear to move making foot placement difficult. Halfway up the stairs they may feel dizzy, nauseous, nervous and anxious. Once making it to the top of the stairs they reach out to the doorbell and may find they misjudge the location of the bell and their hand hits the door as it appears closer than anticipated.

Findings indicate that some children with an identified reading problem also present with abnormal binocular test results compared to published normal values (Christian, Nandakumar, Hrynchak, Irving, 2017)

Therefore, we need to include fixations in oculomotor behavior and as part of a functional vision assessment. They should also be considered in the therapy.