

A Comparison of Two-Dimensional and Three-Dimensional Perceptual-Cognitive
Training in Concussed Populations

by

Erika Shaw
B.Sc., University of Washington, 2011

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF SCIENCE

in the School of Exercise, Physical and Health Education

© Erika Shaw, 2019
University of Victoria

All rights reserved. This thesis may not be reproduced in whole or in part, by photocopy
or other means, without the permission of the author.

Supervisory Committee

A Comparison of Two-Dimensional and Three-Dimensional Perceptual Cognitive Training in Concussed Populations

by

Erika Shaw
B.Sc., University of Washington, 2011

Supervisory Committee

Dr. Brian Christie, Department of Neuroscience
Supervisor

Dr. Lynne Stuart-Hill, Department of Exercise Science, Physical and Health Education
Departmental Member

Abstract

Supervisory Committee

Dr. Brian Christie, Department of Neuroscience

Supervisor

Dr. Lynne Stuart-Hill, Department of Exercise Science, Physical and Health Education

Departmental Member

The NeuroTracker (NT), a computerized three-dimensional multiple object tracking (3D-MOT) training device, has potential benefits for concussion assessment and management, as well as maintenance of cognitive function. Accessing 3D technology is a limiting factor for 3D-MOT, so we assessed the performance of MOT training in 2D and 3D environments in both healthy and concussed individuals (8-91 years of age). The participants (n=86) who completed all ten training sessions over the three-month period, were assigned to one of three different studies: (1) an environment comparison (2D versus 3D), (2) an age comparison (youth, young adult, and older adult), or (3) a concussed population comparison (non-concussed, recently concussed, and prolonged concussed). In all studies, performance increased with training, indicating all individuals could increase perceptual cognitive function in all environments. Significant differences were apparent when 2D and 3D environments were compared, with participants in the 3D environment outperforming participants in the 2D environment. Furthermore, switching from the 3D to the 2D environment was detrimental to learning performance. When comparing learning performance between different aged individuals, a linear regression demonstrated learning performance increased at a lesser rate with age ($p < 0.05$). Concussed populations also demonstrated correlative trends when comparing learning performance, as well as initial NT scores. The longer an individual was suffering from concussion symptoms, the lower the initial NT score was, but the higher the rate of

learning performance was through out training. Further investigation into attention, memory, and visual processing speeds in each population may help to better resolve the relationship between these domains and clarify if NT can serve as a means for concussion assessment and rehabilitation for individuals at any age in the future.

Keywords: NeuroTracker, 3D-MOT, Performance training, Perceptual cognitive training, Cognitive function, Aging, 2D versus 3D, mTBI, Concussion diagnosis,

Table of Contents

Supervisory Committee	ii
Abstract	iii
Table of Contents	v
List of Tables	vii
List of Figures	viii
Acknowledgments.....	ix
Dedication	x
Chapter 1: Introduction and Literature Review	1
1.1 Introduction.....	1
1.2 Literature Review.....	4
1.2.1 Vision and Perception.....	4
1.2.2 Two-Dimensional and Three-Dimensional Perception	8
1.2.3 Aging and Perceptual-Cognitive Function.....	11
1.2.4 Concussions and Perceptual-Cognitive Function	12
1.2.5 Visual and Perceptual-Cognitive Training.....	15
1.2.6 The NeuroTracker (3D-MOT device) as a Perceptual-Cognitive Training tool	18
1.3 Summary of Literature	20
1.4 Rationale, Research Questions and Hypotheses	23
Chapter 2: Methodology	25
2.1 Participants.....	25
2.1.1 A Comparison of 2D and 3D MOT training Population.....	27
2.1.2 A Comparison of 3D MOT training among Concussed Populations	28
2.1.3 A Comparison of 3D MOT training among Aging Populations.....	29
2.2 Experimental Design.....	30
2.3 Procedure	32
2.4 Materials (Equipment)	34
2.4.1 Initial Intake and Screening Tools	35
2.4.2 Three-Dimensional Multiple Object Tracking (3D-MOT)/The NeuroTracker	37
2.5 Analysis.....	38
Chapter 3: Results.....	41
3.1 A Comparison of 2-Dimensional and 3-Dimensional MOT Training.....	42
3.2 The Affect Age has on 3-Dimensional MOT Training.....	50
3.3 A Comparison of Concussed Populations using 3-Dimensional MOT Training ...	55
Chapter 4: Discussion and Conclusion	60
4.1 Discussion	60
4.1.1 A Comparison of 2-Dimensional and 3-Dimensional MOT Training.....	61
4.1.2 The Affect Age has on 3-Dimensional MOT Training.....	63
4.1.3 A Comparison of Concussed Populations using 3-Dimensional MOT Training	64
4.1.4 Implications of Research.....	65
4.1.4 Limitations	67
4.2 Conclusion/Summary.....	67

References.....	70
Appendix.....	77
Appendix A – Participant Consent Form.....	77
Appendix B – Participant Assent Form	86
Appendix C – Intake Form/ Medical History	87
Appendix D – Appointment History and Ongoing Consent.....	91
Appendix E – Godin Leisure Time – Exercise Questionnaire.....	92
Appendix F- Leisure Activity Questionnaire.....	94
Appendix G – International Physical Activity Questionnaire for the Elderly	95
Appendix H – Mini Mental Examination Scale.....	98
Appendix I – Memory Complaint Questionnaire	102
Appendix J – Geriatric Depression Scale	103
Appendix K – MOT and Related Concussion Assessment Form.....	106
Appendix L – Brian Injury Questionnaire	108
Appendix M - Sport Concussion Assessment Tool – 3 rd Edition	111
Appendix N – Child - Sport Concussion Assessment Tool – 3 rd Edition.....	113
Appendix O – Reaction Time Test (Ruler Drop).....	115
Appendix P – King-Devick Test.....	116
Appendix Q – Vestibular/ocular Motor Screen	118
Appendix R – Withdraw form	121
Appendix S – Instructions for Athletes in case of concussion.....	122
Appendix T – Certificate of Ethical Approval.....	123
Appendix U - Three-Dimensional Multiple Object Tracking/The NeuroTracker	124

List of Tables

Table 1. The Cognitive Functions Involved in 3D-MOT	19
Table 2. 3D-MOT as a Gold-Standard Cognitive Enhancer	20
Table 3. A Comparison of 2D and 3D MOT training population.....	27
Table 4. A Comparison of 3D-MOT training among Concussed populations	29
Table 5. A Comparison of 3D-MOT training among Aging populations.....	30
Table 6. Descriptive Statistics for all Dependent Variables used in Research:	41
Table 7. Correlations between Covariables and Dependant Variables in Research:	42
Table 8. Descriptive Statistics for all Dependant Variables used in the Comparison of 2D and 3D Representations of 3D-MOT Research, by Representation:	43
Table 9. Descriptive Statistics for all Dependant Variables used in 3D-MOT training among Aging populations Research, by Age Group:	50
Table 10. Correlations between Age and Dependant Variables in 3D-MOT training among Aging population Research:	51
Table 11. Descriptive Statistics for all Dependant Variables used in 3D-MOT training among Concussed populations Research, by Concussion Status:	55

List of Figures

Figure 1: The Main Visual Pathway.....	5
Figure 2: Visual Processing Pathways: Ventral-Recognition vs. Dorsal-Action	8
Figure 3: Monocular Cues..	11
Figure 4: Flow Chart of Separation of Participants into Testing Populations	26
Figure 5: A Visual Representation of 3D-MOT Training/A Single Trial of NeuroTracker Training.....	38
Figure 6: A Comparison of Learning Adaptations in 2D and 3D Environments	44
Figure 7: A Normalized Representation of Learning Adaptations in 2D and 3D Environments.....	45
Figure 8: A Comparison of Learning Adaptations in Groups that Switched 2D and 3D Environments after 5th Appointment.....	46
Figure 9: A Normalized Representation of Learning Adaptation in Groups that Switched 2D an 3D Environments.....	47
Figure 10: A Normalized Representation of Learning Adaptions in all Testing Environments.....	48
Figure 11: A Linear Regression of Learning Adaptations among all Ages.....	52
Figure 12: A Comparison of Learning Adaptions in Healthy Youth, Young Adults, and Older Adult Populations	53
Figure 13: A Normalized Representation of Learning Adaptation in Healthy Youth, Young Adults, and Older Adults..	54
Figure 14: A Comparison of Learning Adaptation in Symptomatic and Healthy Populations.....	56
Figure 15: A Normalized Representation of Learning Adaptation in Concussed and Non-Concussed Populations.	57
Figure 16: A Comparison of Learning Adaptations in Concussed and Prolong Concussed Populations.....	58
Figure 17: A Normalized Representation of Learning Adaptations in Concussed and Prolong Concussed Populations.....	59

Acknowledgments

Thank you to my lab mates and supervisor, I would not have been able to complete this thesis, if it wasn't for the help so graciously given to me by Stela Musteata, Caroline Spaner, and Dr. Brian Christie. Financial support was provided through awards to BRC by the Canada Foundation for Innovation and Cogisens Athletics for the equipment and materials used in this study.

Dedication

To my loved ones and anyone who has struggled with perceptual cognitive performance, and is looking for another way to assess and achieve higher levels of function.

Chapter 1: Introduction and Literature Review

1.1 Introduction

This research examines perceptual cognitive training in three-dimensional (3-D) and two-dimensional (2-D) representations of three-dimensional multiple object tracking (3D-MOT) training. It will also examine the relationship between perceptual cognitive performance and age, as well as the relationship between perceptual cognitive performance and concussion status.

To examine perceptual cognitive training and the systems it is engaging in the brain, one must first understand that all primates, including humans, rely heavily on their visual systems (Kaas, 2013). Visual perception is the brain's ability to interpret what the eyes see. Our eyes are only able to produce flat, 2-D images, but the brain is able to interpret these images as a 3-D picture. The perception of a 3-D environment occurs via binocular vision (Fahle, 1987).

The assessment tool is the NeuroTracker (NT), a computerized 3D-MOT training program that is used by a multitude of high-performance athletes to enhance perceptual cognitive skills. The NT provides a direct indicator of perceptual capabilities such as: complex motion integration, distributed attentional control, fluid-rapid processing and visual working memory. The NT also has potential benefits for concussion assessment and management, as well as maintenance of cognitive function (Beauchamp, & Faubert, 2011).

Aging is associated with declines in performance on a multitude of cognitive functions (Bherer L. et al., 2013), including attention, memory, and decision-making

processes (Hasher, & Zacks, 1988). These declines can impede their ability to live independently, and lower their quality of life. Prominent theories of age-related declines in memory have been linked to deficits in executive processes such as inhibitory functions (Hasher & Zacks, 1988), reaction time (Johnson, Reader, Raye, & Mitchell, 2002; Johnson, Mitchell, Raye, & Greene, 2004), and speed (Salthouse, 1996). Visual perceptual performance can be a means of diagnosing changes in these processes, making the NT an optimal assessment and training tool for an aging population.

A concussion is considered a mild traumatic brain injury (mTBI) and is defined as a traumatic brain injury induced by biomechanical forces (McCrorry, P., et al., 2017). Concussions can cause perceptual cognitive difficulties in the form of vestibular/ocular issues such as vertigo, dizziness, disequilibrium and much more. When it comes to these individuals the need for vision therapy, optokinetic exercises, and visual perceptual training (such as NT training) is increased.

The NT has demonstrated great perceptual cognitive training ability, however its use among an aging population (to assist in maintenance or improvement of cognitive function) or as a concussion diagnostics tool requires more research. Similarly, the effectiveness of the NT as strictly a 3D-MOT training device has yet to be proven. The performance of MOT training in 2D and 3D environments in both healthy and concussed individuals across an age span of 8-91 years of age has never been assessed.

This research aims to address questions such as “does a prolonged concussed population associate with lower threshold speeds (or performance) on the NT than a recently concussed, or non-concussed population?” and “can the NT be an effective tool for perceptual cognitive training in all populations?”. Similarly, “do older adult

populations associate with lower threshold speeds or learning adaptations on the NT?”.

Finally, the question of “ how might different perceptual cues (2D or 3D) affect cognitive function and the acquisition of higher threshold speeds in working memory, attention, and processing speeds?” or “will learning adaption occur at the same rate despite differences in perceptual cues?”, and “can one smoothly alternate between different environments and maintain similar learning adaptations to others who maintained training within the same environment?’ will be addressed in this research.

To answer these questions, this research is broken down into three studies. In the first study, an examination of perceptual cognitive training in young adults, there is a focus on determining if performance training in 3D has any advantages over 2D representations of 3D-MOT training. It is hypothesised that the brain will interpret the 3D representation more easily, because performing the task in the 2D representation will increase cognitive load, due to the need to interpret monocular cues. An inherent assumption in this study, is that 2D and 3D representations of a 3D environment are interpreted differently. In the second study, the relationship between perceptual cognitive performance on the NT and age will be determined. It is hypothesised that NT performance will decline with increasing age, and cognitive decline. In this study, it is assumed that cognitive decline is associated with age, and will produce changes in perceptual-cognitive performance on the NT. In the final study, a concussed population will be examined to determine if the NT can be an effective tool for diagnosing perceptual cognitive deficits and potentially even serve as a means for decreasing these deficits over a ten-session training regime. This final study is greatly dependant on the honesty of the participants. As all studies were completely anonymous and were strictly

for research purposes (not medical diagnostics), participants were expected to be honest about their symptoms or lack thereof (without fear of it affecting their lives). A limitation present in all studies, is the use of a convenient sample, allowing for only local comparison. Delimitations are the use of three separate studies, to ensure there would be no confounding of variables, thus allowing concussion status, age, and environmental cues all to be compared independent of each other. The null hypothesis to all studies is that no difference in perceptual cognitive performance between groups (2D versus 3D, youth versus adults, or concussed versus non-concussed) will be present.

1.2 Literature Review

1.2.1 Vision and Perception

Our brains are organized around vision. Vision involves the interpretation of light stimuli by the brain. Light enters the eye via the cornea, the anterior cavity, through the pupil (a hole in the center of the iris), to the lens, which focuses the light on the retina (the inner most layer of the eye), where the visual information is transduced into neural impulses (Stanfield, 2011). The retina is composed of neural tissue, which contains photoreceptors (rods and cones), cells that detect the light and movement of detail and color (Tyler, J., 2015). When light waves reach the photoreceptors, they are transformed from light energy into electrical energy, which is conveyed to bipolar cells, triggering a pattern of action potentials that ganglion cell axons, otherwise known as the optic nerve, convey to the visual centers in the brain (Purves, D., et al., 2012).

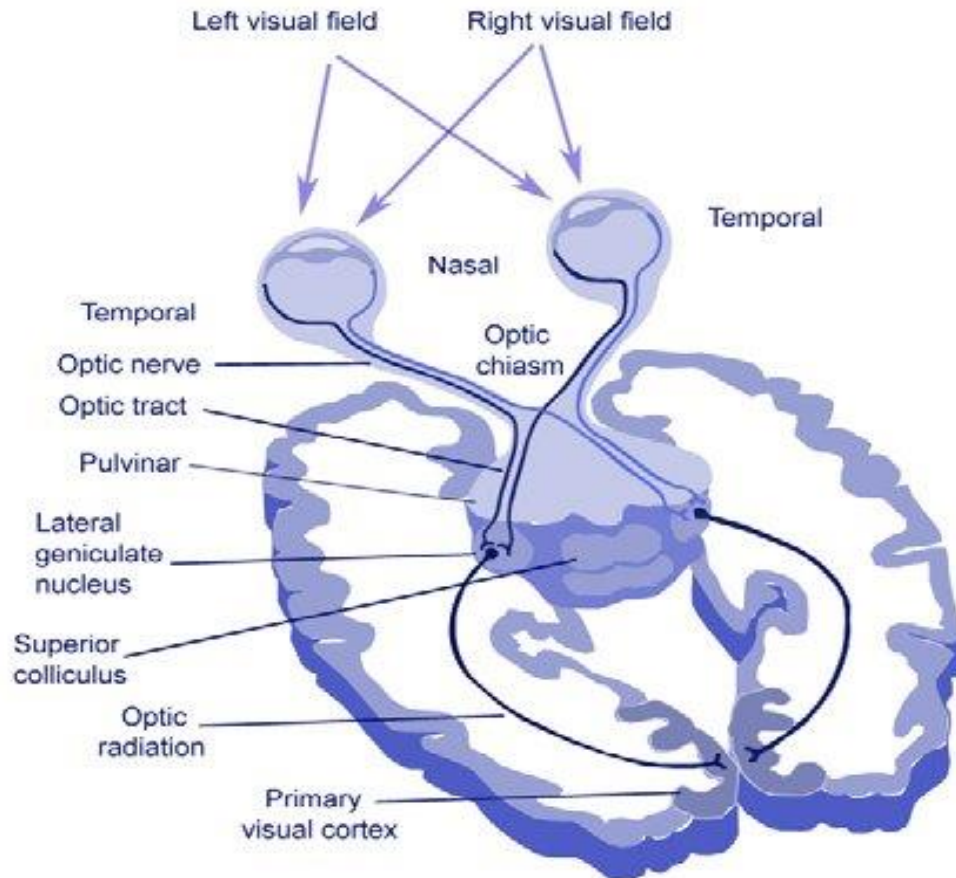


Figure 1: The Main Visual Pathway (Georgiev, D., 2011). An image of the brain (sliced along the horizontal plane) with the visual pathway represented as initiating at the eyes (their visual fields) intake of light stimuli, continuing along the optic nerve, crossing over at the optic chiasm, through the optic tract, to the lateral geniculate nucleus, where it synapses with optic radiations, to terminate at the primary visual cortex.

The two optic nerves exit each eye at the optic disk and combine at the base of the brain just in front of the brainstem to form the optic chiasm. In the optic chiasm, half the axons from each eye cross over to the other side of the brain, resulting in all input from the right visual field traveling in axons in the left side of the brain, and vice versa (Stanfield, 2011). The ganglion cell projections continue through the optic tract, to terminate in the lateral geniculate body (a nucleus in the thalamus), where they form synapses with neurons that radiate to the primary visual cortex in the occipital lobe (Refer to Fig.1). Signals continue from the primary visual cortex to other visual areas in the

occipital lobe (extrastriate area), the parietal lobe (purveying information concerning motion), and the temporal lobe (involved in object recognition). Normal vision depends on the integration of information in all of these cortical areas.

Visual perception is the brain's ability to interpret what the eyes see. The primary visual cortex (striate cortex or V1) is laid out in a manner that mirrors the back of the retina, allowing for image reconstruction (Tyler, J., 2015). Much of our current understanding of the functional organization of the visual cortex is thanks to David Hubel and Torsten Wiesel, who anesthetized animals to examine the responses of individual neurons to various patterns of retinal stimulation. It was found that neurons selectively respond to different light orientations. Brodmann's studies on the monkey cortex also aided in an initial understanding of the topographical organization of the different structures of the brain and the respective functions. From there, it was found that outside the striate area lies a broad cortical zone, the extrastriate cortex of the occipital lobe. This region receives inputs from the striate cortex, is primarily visual in function, and is believed to be involved in a higher or more abstract level of analysis than that carried out by the striate cortex (Van Essen, D., 1979). The functional organization of the extrastriate visual area, the concept of cortical processing streams, and the idea that different visual areas constitute highly specialized representations of visual information, was further developed thanks to studies conducted by Maunsell and Newsome in 1987, and Felleman and Van Essen in 1991, on the macaque monkey. Felleman and Van Essen suggested a distributed hierarchical process of visual information, with multiple parallel and interconnecting pathways at each level. As a result of this work, specialized structures

such as the middle temporal area, V1, V2, V3, and V4 were identified as being involved in vision.

V1 is the primary vision area, it is the first processing level in the hierarchy. V1 and V2 are heterogeneous, they take part in color, form and motion perception. They are often referred to as the striate cortex, because when stained with cytochrome oxidase stripes are revealed. The thin stripes take part in color perception, the thick stripes have roles in form and the pale stripes in motion perception (Kolb, B., & Whishaw, I. Q., 2009). V2 is the second level in the hierarchy, it projects to all other occipital regions. V3 is concerned with the shape of objects in motion. V5 (also known as middle temporal or MT) is specialized to detect direction, motion and depth (Born, R., & Bradley, D., 2005). V4 and V8 are color regions. Interestingly, color vision is integral to the analysis of position, depth, motion, and the structure of objects (Tanaka, et al., 2001).

After V2, three distinct, parallel pathways emerge exiting the occipital lobe. The parietal pathway, or the dorsal stream, has a role in visual guidance of movement (Milner, D., & Goodale, M., 2006), the inferior temporal pathway or ventral stream, which is concerned with object perception, including color (Ungerleider, L., & Haxby, J., 1994), and the superior temporal sulcus or STS stream, is important in visuospatial functions and in the perception of certain types of movements (biological motion) (Kolb, B., & Whishaw, I. Q., 2009).

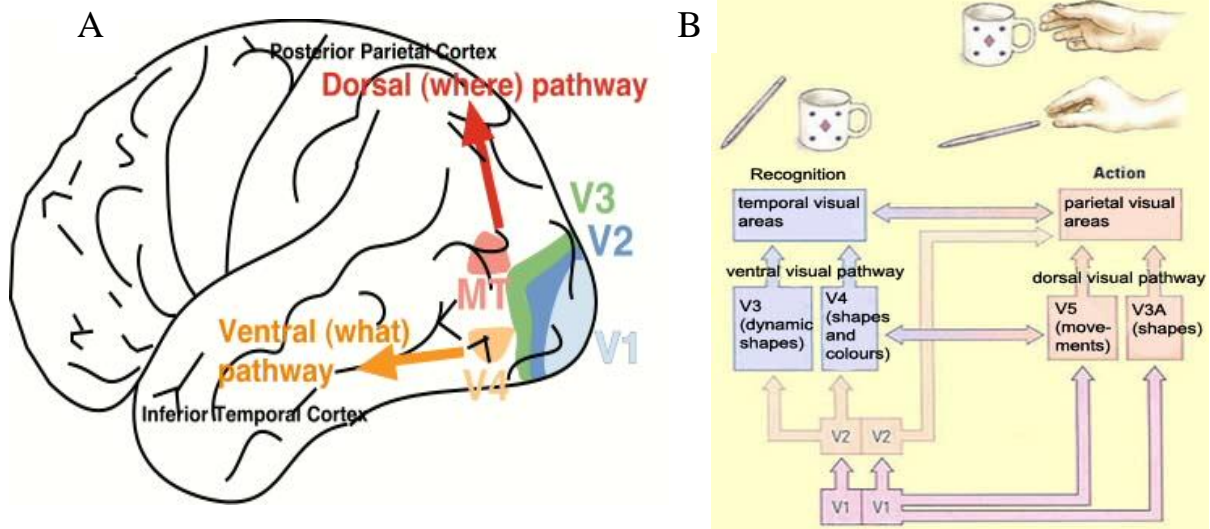


Figure 2: Visual Processing Pathways: Ventral-Recognition vs. Dorsal-Action. **A:** an image of the left external view of the brain, depicting the specialized visual structures (V1, V2, V3, V4, V5(MT)) in occipital cortex and their main projections (from Dubuck, 2002). **B:** A diagram showing the pathways visual information travels along, starting at the bottom (V1), and moving upwards via V2 - V5 (and the ventral or dorsal visual pathway), to terminate at the temporal or parietal visual area, with an image at the top of what these visual areas process. The ventral pathway recognizes what the object is, the dorsal pathway locates the object and its movement (from Lloyd, 2007).

1.2.2 Two-Dimensional and Three-Dimensional Perception

Our eyes are only able to produce flat, two-dimensional (2-D) images, but the brain is able to build these images into a three-dimensional (3-D) picture. The perception of a 3-D environment occurs via binocular vision, the use of two eyes (Fahle, M., 1987). Our eyes are positioned approximately five centimetres or two inches apart, so each sees its surroundings from a slightly different angle or view point (Tyler, J., 2015). These view points overlap, as a result, binocular disparities in vision provide information that the brain can use to calculate depth (Blake, R., & Sekuler, R., 2006), otherwise referred to as stereopsis.

While binocular disparities are naturally present when viewing a real 3-D scene with two eyes, they can also be simulated by artificially presenting two different images separately to each eye using a method called stereoscopy. The perception of depth in such cases is also referred to as "stereoscopic depth" (Howard, I. P., & Rogers, B. J., 1995). Differences in object size and motion parallax (differences in the image of an object over time with observer movement) aid in the discernment of depth and 3-D structure (Howard, I. P., & Rogers, B. J., 2012). Binocular disparity and image motion are important sources of information for the perceptual recovery of 3D shape from two-dimensional (2D) retinal projections (Julesz, 1971; Wallach & O'Connell, 1953).

There are two distinct aspects to stereopsis: coarse stereopsis and fine stereopsis, each provide depth information of different degree of spatial and temporal precision (Barry, S. R., 2012). Coarse stereopsis (also called gross stereopsis) appears to be used to judge stereoscopic motion in the periphery. It provides the sense of being immersed in one's surroundings and is therefore sometimes referred to as qualitative stereopsis. Fine stereopsis is mainly based on static differences. It allows the individual to determine the depth of objects in the central visual area (Panum's fusional area) and is therefore also called quantitative stereopsis (Barry, S. R., 2012).

How the brain combines the different cues – including stereo, motion, vergence angle and monocular cues – for sensing motion in depth and 3D object position is an area of active research in vision science and neighboring disciplines (Barry, S. R., 2012). Current forms of monocular cues for a 3D perception include: linear perspective, interposition, height in the plane, texture gradients, relative size, light and shadow (Landy, 1995) (Refer to Fig. 3). To elaborate, linear perspective is a depth cue

that utilizes the fact that lines converge in the distance (Cutting, & Millard, 1984). Interposition or occlusion, involves the overlap of objects and the perception of the object between the viewer and the other object to be closer, or in front of the other object (Gibson, 1950; Kaufman, 1974). Height in the plane is the use of a set horizon (generally the top of image) with objects that are further away appearing higher up on the image, or closer to the horizon. Texture gradients are the use of small details to make areas closer to the viewer appear courser, and areas farther away appear plain or undetailed. Relative size is the enlargement of closer objects in comparison to objects further away from the viewer to illustrate their position (Cutting, & Millard, 1984). Light and shadow is a depth cue that utilizes patterns to create the illusion of a 3D figure, in respect to a designated light source (Gibson, 1950; Kaufman, 1974). According to the modified weak fusion model for how humans calculate a 3D depth perception, all these monocular cues are

combined using a dynamic weighted average, which is dependant on the reliability of each cue and its discrepancies from other cues (Landy, 1995).

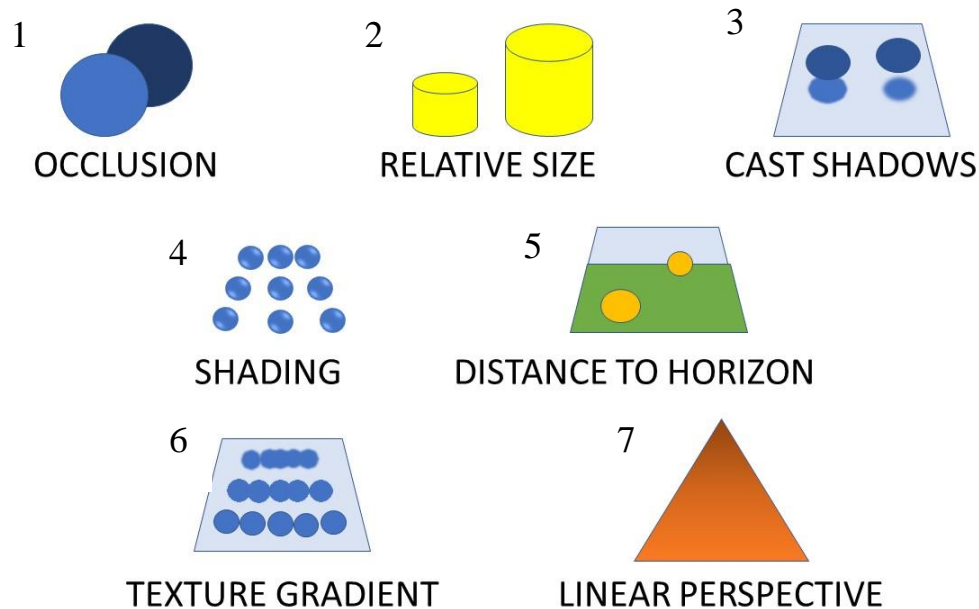


Figure 3: Monocular Cues. Images of monocular cues are shown. These include: **1:** occlusion (circles overlapping); **2:** relative size (the same shape in different sizes); **3:** cast shadows (circles with shadows larger or smaller, closer or farther away from said circle). **4:** shading (the use of darkness of light to give the illusion of a 3D ball, based on a source); **5:** distance to horizon ('farther' circle is on the horizon, 'closer' circle is below the horizon); **6:** texture gradient ('closer' circles have more defined outlines/ textures, 'farther' circles are hard to define), and **7:** linear perspective (the converging of lines as they move up the page, or 'farther' away).

1.2.3 Aging and Perceptual-Cognitive Function

A decline in perceptual-cognitive function has been inversely related to aging.

Aging has been associated with several different cognitive changes, ranging from relatively little cognitive decline, to severe cognitive deficits that impede the ability to live independently. Like many other medical conditions, age-related cognitive decline is also associated with a large inter-individual variability. (Bastin, C., et al., 2012)

Moreover, cognitive decline rarely occurs in the same fashion; for instance, some older

adults may maintain good episodic memory, but have impaired short term memory or decision-making processes. (Thoene, A. L., & Glisky, E. L., 1995) Attention, memory, and decision-making processes are cognitive functions consider to be the most susceptible to aging related decline. (Hasher, & Zacks, 1988)

Executive functions are an example of a broad attentional mechanism involved in higher-level cognitive tasks. These cognitive tasks may include skills such as planning, problem-solving, and cognitive flexibility (Banich, 2009). Prominent theories of age-related declines in memory have been linked to deficits in executive processes such as inhibitory functions (Hasher & Zacks, 1988), reaction time (Johnson, Reader, Raye, & Mitchell, 2002; Johnson, Mitchell, Raye, & Greene, 2004), and speed (Salthouse, 1996). All these aging associated difficulties evolve and culminate into obstacles with processing complex visual information (J. Faubert, 2002; A. Bertone, Guy J., J. Faubert 2011; K. & R. Ball Sekuler, 1986).

Declines in perceptual cognitive function among aging populations are best treated through cognitive training. Cognitive training would bring about higher cognitive flexibility, greater information processing, and more effective coping with failure (The International Handbook of Psychology, Kurt Pawlik & Mark Rosenzweig, 2000).

1.2.4 Concussions and Perceptual-Cognitive Function

Deficits in perceptual-cognitive function are commonly observed among individuals who are considered concussed and/or suffering from post-concussion syndrome. An individual is considered concussed, when they have sustained a concussion, or mild traumatic brain injury (mTBI). In the *Consensus statement on*

concussion in sport- the 5th edition, the Berlin expert panel modified the previous Concussion in Sport Group (CISG) definition of a sport related concussion to the following, “Sport related concussion is a traumatic brain injury induced by biomechanical forces” (McCrory, P., et al., 2017). Several common features that may be utilised in clinically defining the nature of a concussive head injury include: it may be caused from an impulsive force transmitted to the head, it typically results in short-lived impairment of neurological function, it may result in neuropathological changes due to functional disturbances (not structural injury to the brain), and loss of consciousness, and resolution of said changes or impairments typically follows a sequential course, but may be prolonged (McCrory, P., et al., 2017). Another non-sport related definition of a concussion or mTBI is defined as a traumatically induced transient disturbance of brain function and involves a complex pathophysiological process (Harmon, K. G., et al., 2013). A concussion is considered complex, when symptoms without exertion lasts for more than 10 days and requires neuropsychological testing (Covassin, T., Elbin, R., & Stiller-Ostrowski, J. L., 2009). Neuropsychological testing is required for several reasons, one of which is that traumatic brain injuries often involve damage to the prefrontal cortex, ventral frontal lobe and anterior temporal lobe. These areas are highly implicated in the recognition of, and reaction to emotionally relevant stimuli, making it logical that depression and anxiety like symptoms are observed following a mTBI (Kennedy, J. E., et al., 2007). These symptoms can further cognitive compromise (beyond those accounted for by the concussion) by suppressing attention, mental efficiency, learning and memory (Kay, T., et al., 1992). Diagnosis of a concussion requires that the clinical signs and symptoms cannot be explained by medication use, other injuries (such as cervical

injuries, or peripheral vestibular dysfunction), or other comorbidities (psychological factors or coexisting medical conditions) (McCrory, P., et al., 2017).

When a person becomes concussed and symptoms persist past the expected recovery period (typically no more than 10 days), the individual may be suffering from post-concussion syndrome (Clarke, L. A., Genat, R.C., & Anderson, J. F. I., 2012). The term post-concussion syndrome (PCS) refers to a range of symptoms associated with a concussion or mTBI. These symptoms include: headaches, fatigue, vertigo/dizziness, irritability, emotional lability, cognitive deficits, sleep disturbance, and/or depression and anxiety. These symptoms are most likely due to physiological differences, such as constricted or debilitated activity in specific regions of the brain, namely: the dorsolateral prefrontal cortex, the dorsal anterior cingulate cortex, the insular cortex, the thalamus, and the striatum. Chen also noted that depressive symptoms post-concussion/ post injury could be attributed to medial prefrontal dysfunction (Chen, J. et al., 2008).

Declines in perceptual-cognitive function, specifically visual spatial and vestibular ocular deficits, are commonly observed among concussed and PCS individuals.

In a study by Brosseau-Lachaine, O., et al., it was concluded that visual deficits are demonstrated among children (ages 6 to 16 years) who sustained a mTBI. When they were processing higher-order information (complex stimuli such as radical optic flow) over relatively long periods post injury (at least 12 weeks), they were still affected by the mTBI (Brosseau-Lachaine, O., et al., 2008).

The link between vestibular/ocular deficits and concussions was well demonstrated in *A Brief Vestibular/Ocular Motor Screening (VOMS) Assessment to Evaluate Concussion* (Mucha, A., et al., 2014). It was found that all VOMS items

correlated with concussion symptoms, with the vestibular ocular reflex (VOR) and the visual motion sensitivity (VMS) being most predictive of identifying concussed individuals.

Three possible reasons were identified as the cause for the vestibular deficits among concussed individuals. The first two are the result of trauma to the peripheral vestibular system or the central nervous system. This can be either in the form of diffuse axonal injury and other microstructural disruptions, or via trauma induced migraines and headaches. The third possible cause of vestibular problems, is psychological factors and behavioral factors including anxiety, depression, panic, and posttraumatic stress disorder (PTSD) (Fifel, T. D., Kalra, D.), all of which have been linked to concussions and PCS.

Some studies have suggested an association between prior concussions and chronic cognitive dysfunction (Harmon, K. G., et al., 2013). as well as increased risk of depression and dementia (Gilchrist, J., et al., 2009). Additional research is required to clarify risk factors and causes of any long-term neurological impairment.

Since deficits in perceptual cognitive function has been so strongly linked to concussions, diagnosis and treatment of concussions favor tests and training regimes that incorporate perceptual cognitive function, such as: visual, vestibular, and cognitive tests and training regimes.

1.2.5 Visual and Perceptual-Cognitive Training

Visual and perceptual-cognitive testing and training have been used to aid in diagnosis of concussions and other cognitive deficits and declines, to treat concussion symptom, and to enhance perceptual-cognitive performance among many populations.

It has been found that impaired eye movements in concussed individuals indicates poor brain function. As cognitive load increases, deficits become more pronounced. Thus, visual testing aids in differentiate between symptoms caused by the physical trauma of the concussion or the psychological factors that have developed since. It was found that the PCS participants performed worse on all eye-movement functions, and on neuropsychological function. “Compared with neuropsychological tests, eye movements were more likely to be markedly impaired in PCS cases with high symptom load. Poor eye movement function, and particularly poor subcortical oculomotor function, are correlated with post-concussive symptom load and problems on activities of daily living” (Heitger, M. H., et al., 2009). This indicates ongoing cerebral impairment and supports the notion that PCS can be assessed via visual testing.

Vision therapy, or optokinetic exercises can also be used to train the brain and rehabilitate it to a higher functionality. For example, it was determined that optometric vision therapy in patients with either mTBI or cerebrovascular accident (CVA) experiencing oculomotion disorders, was very effective (Ciuffreda, K. J., et al., 2008). Through a retrospective computerized based query, it was found that 90% of those with mTBI and 100% of those with CVA were deemed to have treatment success. Proving various forms of vision therapy to be an effective method of rehabilitation of concussion symptoms.

Vestibular rehabilitation with an exposure to optokinetic (OK) stimuli “showed significant within-group improvements for vestibular, visual vertigo, and autonomic symptoms”, with the supervised and full-field visual environment groups improving the most on postural stability, gait, and decreased depression (Pavlou, M., et al., 2013).

Therefore, OK stimuli incorporated in to vestibular rehabilitation was successful in decreasing vestibular and visual deficits among concussed individuals.

Similar to the optokinetic (OK) stimuli used by Pavlou in the 2013 publication, the new technology (NeuroTracker) is meant to enhance perceptual-cognitive skills. The NeuroTracker uses an intelligent staircase procedure to push perceptual-cognitive thresholds and achieve maximal stimulation. It also provides a direct indicator of perceptual capabilities such as: complex motion integration, distributed attentional control, fluid-rapid processing and visual working memory. Perceptual-cognitive training can be done using this technology (Beauchamp, P., & Faubert, J., 2011).

The NeuroTracker enhances cognitive ability and improves analytical behaviors such as problem solving, comprehension speed and learning ability (Parsons, B., et al., 2016). That is to say, training with the NeuroTracker results in direct benefits to activities that require the integration of simultaneous inputs such as driving, crossing busy streets, or engaging in sports activities (Faubert, J., 2013). Demonstrating that improved cognitive functions (attention, processing speed and working memory) can be translated into everyday life (Parsons, B., et al., 2016). So, no matter the population, the NeuroTracker has demonstrated improved cognitive abilities for young, older adults, healthy, and/or pathological samples such as concussion or autism (D. Tullo et al., pre-publication; Kowalski, K. et al., pre-publication). Using this tool could be a new means of training older adults and/or concussed populations, however evidence is lacking to support this assertion.

1.2.6 The NeuroTracker (3D-MOT device) as a Perceptual-Cognitive Training tool

Perceptual-Cognitive Training of Athletes (Faubert, J., & Sidebottom, L., 2012) gives a great outline of how the NeuroTracker can be used to train athletes. In sport, often dynamic scenes requiring integration of simultaneous visual cues are present. The ability to perceive and integrate complex moving patterns, while allocating attention resources in different key areas of the dynamic scene, is critical to high-performance sports (Williams, et al., 2006; Faubert, 2001). For example, when a defender is blocking an oncoming attacker in possession of the ball/puck, they must anticipate the space between them, the possibility of passing, and whether other defenders will intercept. This ability is called Player Movement Dynamics. To train this perceptual-cognitive ability a successful program must integrate the following tasks: Isolation/breakdown and overload of attention, multiple object tracking (MOT), large visual fields, speed thresholds, and binocular 3D visual stereoscopy. The NeuroTracker was developed to include all of these aspects and thusly can be used to train perceptual-cognitive skills (Faubert, J., & Sidebottom, L., 2012).

In 2013, 308 observers (professional athletes (n=102), elite amateur athletes (n=173), and non-athlete university students (n=33)) trained up to 15 times (separated over a minimum of 5 different days, with no more than 3 sessions in a given day). The initial results were proven to be very successful.

There are several ways one can go about testing and training on the NeuroTracker. Studies have shown that the condition of testing can influence the learning curve produced through training. For example, if a player is standing rather than sitting, his/her growth curve from the initial visit will be reduced. For this reason, it can be

expected that other sensory, physical, and psychological factors may affect performance. Nevertheless, “results do suggest that rapid learning in complex and unpredictable dynamic contexts is one of the critical components for elite performance” (Faubert, J., 2013). Enhancing Cognitive Function Using Perceptual-Cognitive Training (Parsons, B., et al., 2014) is an article that helps address optimal testing/training frequency while using the NeuroTracker. Through the use of neuropsychological tests, and quantitative electroencephalography (qEEG) cognitive function was assessed among 20 university aged participants (divided into a training and non-training group). It was found that “10 sessions of 3D-MOT training can enhance attention, visual information processing speed, and working memory, and also leads to quantifiable changes in resting-state neuroelectric brain function” (Parsons, B., et al., 2014).

The cognitive function involved and cognitive enhancement possible through the use of the NeuroTracker (the 3D-MOT training device) are well demonstrated in the following tables pulled from Parsons, B, et al., 2014 article:

Table 1. The Cognitive Functions Involved in 3D-MOT

Cognitive Function	Definition
Attention	
-Sustained	The ability to maintain selective attention over time
-Selective	The ability to attend to/focus on/cognitively process a given thing
-Divided	The ability to selectively attend to multiple loci at once (multifocal)
-Inhibition	The ability to not attend/focus on/cognitively process a given thing
Short-term memory	The ability to retain information over a short time span (20-30 seconds)
Working memory	The ability to retain and transform information over a short time span
Information processing speed	The time needed to consciously integrate perceptual stimuli

Table 2. 3D-MOT as a Gold-Standard Cognitive Enhancer

Standard	Status	Details
1. Robust effects with transfer	Yes	Attention, working memory, visual information processing speed; corresponding changes in brain function
2. Side effects/ toxicity	Insignificant	Occasional mild fatigue immediately following training, dissipating within 20-30 minutes
3. Investment 5 hours	5 hours	Optimal training frequency and duration is unknown; 1 hour per week is sufficient
4. Lasting effects	Unknown	
5. Ethical issues	None	
6. Mutually exclusive	Unknown	Further research to examine training in combination; no contraindications were observed
7. Potential Populations	Known Unknown	Healthy, healthy aging, athletes Clinical domains

It has been demonstrated that perceptual-cognitive training may have other sports related benefits that include: injury reduction, concussion return-to-play management, and reduction of fatigue-related decision errors (Beauchamp, P., & Faubert, J., 2011). The “NeuroTracker system gives reliable and objective information on an athlete’s current perceptual state, with any drops from normative levels indicating some level of perceptual-cognitive impairment, including possible residual concussion effects. This data can be combined with traditional balance and neuropsychological tests to expand any medical examiner’s RTP assessments by incorporating return to healthy perceptual-cognitive functioning as an additional indicator” (Faubert, 2012).

1.3 Summary of Literature

Our brains are organized around vision. Vision is the interpretation of light stimuli. When light waves enter the eye and reach the photoreceptors, they are transduced from light energy into electrical energy, which is conveyed to the visual centers in the brain via the optic nerves. Signals continues on from the primary visual cortex to other

visual areas in the occipital lobe (extrastriate area), the parietal lobe (purveying information concerning motion), and the temporal lobe (involved in object recognition). Normal vision depends on the integration of information in all of these cortical areas.

Visual perception is the brain's ability to interpret what the eyes see. The processes underlying visual perception are not well understood and remain one of the central challenges of modern neuroscience (Purves, D., et al., 2012). At this point, the functional organization of the striate and extrastriate visual areas are believed to be highly specialized, and the concept of a hierarchy of cortical processing streams has been developed to explain how visual information moves from the occipital lobe to the parietal and temporal lobes. The parietal pathway, or the dorsal stream, has a role in visual guidance of movement (Milner, D., & Goodale, M., 2006), the inferior temporal pathway or ventral stream, is concerned with object perception, including color (Ungerleider, L., & Haxby, J., 1994), and the superior temporal sulcus or STS stream, is important in visuospatial functions and in the perception of certain types of movements (biological motion) (Kolb, B., & Whishaw, I. Q., 2009).

The brain is able to build the 2D input into a three-dimensional (3-D) picture. The perception of a 3-D environment occurs via binocular vision (Fahle, M., 1987), with binocular disparities in vision providing information that the brain can use to calculate depth (Blake, R., & Sekuler, R., 2006), otherwise referred to as stereopsis. How the brain combines the different cues – including stereo, motion, vergence angle and monocular cues – for sensing motion in depth and 3D object position is an area of active research in vision science and neighboring disciplines (Barry, S. R., 2012).

Aging itself is associated with declines in performance on a multitude of cognitive functions (Bherer L. et al., 2013), including: attention, memory, decision-making processes, executive processes, reaction time, and speed, which culminate in obstacles with processing complex visual information (J. Faubert, 2002; A. Bertone, Guy J., J. Faubert 2011; K. & R. Ball Sekuler, 1986).

Like aging, concussions or mTBI are also associated with cognitive deficits. Diagnosis and treatment of concussion must consider how visual deficits are linked to mTBI and how the processing of higher-order information (complex stimuli such as radical optic flow) over relatively long periods post injury (at least 12 weeks) are still affected (Brosseau-Lachaine, O., et al., 2008). Current treatments or training relevant to a concussed individual who is experiencing vestibular/ocular deficits, are: vision therapy, optokinetic exercises, and visual perceptual training. The possibility of a new form of perceptual cognitive testing/training, that can optimally analyze and engage, while still avoiding over load is paramount to a concussed population.

Perceptual cognitive training with the Neurotracker has been shown to improve sport performance and has potential impact on injury reduction, and concussion management (Faubert, J., & Sidebottom, L., 2012). The NeuroTracker can enhance cognitive functions such as: attention, visual information processing speed, and working memory (Parsons, B., et al., 2014). The NeuroTracker system gives reliable and objective information on an athlete's current perceptual state, with any drops from normative levels indicating some level of perceptual-cognitive impairment, including possible residual concussion effects (Faubert, 2012).

1.4 Rationale, Research Questions and Hypotheses

The NeuroTracker could be a new means to assess concussion and aid in return-to-play (RTP) processes. With enhanced cognitive ability and improvements in analytical behaviors such as problem solving, comprehension speed and learning ability (Parsons, B., et al., 2016) the NeuroTracker shows direct benefit to an aging population with decline in executive and cognitive function as well. Should two-dimensional cues for the 3D-MOT environment prove proficient in maintaining perceptual-cognitive enhancement, this computerized technology would be accessible to all.

So I ask, can the NeuroTracker (NT) yield the same positive performance results in different populations in different environments? More specifically, in a concussed population, will the NT differentiate between the perceptual-cognitive abilities of a prolonged concussed, a recently concussed, or a non-concussed individual? If so, will the NT aid in the learning adaptation of these symptomatic individuals, proving the NT to be a concussion rehabilitation device? Similarly, in an aging population, will the NT differentiate between the perceptual-cognitive abilities of an older adult (age 60+ years), an adult (age 35-59 years), a young adult (age 19-34 years), or a youth (age 8-18 years)? If so, will the NT aid in the learning adaptation of the older adult population associated with cognitive decline? Finally, in a two-dimensional (2D) representation of a three-dimensional (3D) environment, will the NT yield the same positive performance results it has in previous literature using a 3D representation of that same environment? If so, could this make the NT more accessible to the general public, or at risk populations, who may require perceptual-cognitive training, but are unable to access the 3D technology required (and currently used in laboratory and clinical settings only).

Based on previous literature, I hypothesizes that the NT will yield the same positive performance results in different populations, but not to the same degree in different environments. That is to say, I hypothesizes that the NT will be able to assess an individuals concussion status, with individuals suffering from more symptoms, for longer durations of time, presenting with lower perceptual-cognitive threshold speeds upon intake, but similar to accelerated learning adaption as training continues. I also hypothesizes that the NT will be able to differentiate between aging individuals upon initial assessment, and when comparing learning adaption. Though all populations should have a positive performance result from training, older adults perceptual-cognitive adaptability should be less than that of a young adult or youth. Finally, I hypothesizes that the NT, when used in different visual perceptual representations (2D or 3D) of a 3D environment, will yeild the same learning adaptation in both 2D and 3D representations of the 3D MOT training, but lower initial threshold speeds in the 2D representation. Based on the limited amount of research into this field, my hypothesis is based strictly on the assumption that stereoscopic depth cues built from 2D representations are cognitively processed differently than 3D disparities in binocular vision.

Chapter 2: Methodology

2.1 Participants

Ethical approval was sought and obtained from the Human Research Ethics Board at the University of Victoria in accordance with the Canadian Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (Approval Certificate 17-167). All participants in this study were properly informed on the purpose of the study and gave written consent prior to engaging in any testing/training. Testing/training was strictly voluntary and continuous written consent was obtained throughout all ten appointments.

Approximately 200 participants were recruited from Victoria, British Columbia, Canada. However, after screening only 93 participants eligible for comparison, completed testing/training. Testing/Training occurred from May 2015 until December 2017. Recruited was done in the following manners: in person, by paper posters in local communities and newsletters, online media (web posters on social media such as: IALH's Facebook and Twitter and Uvic's brainlab website), referrals from individuals already participating in the study, and referrals from local health professionals aware of the study. Participants were recruited into the study and divided into populations of interest after initial participation, making recruitment inclusion fairly open.

For study purposes (not testing/training, all individuals were allowed to participate for their own possible benefit), the following exclusion criteria was set for all groups to ensure accurate results: the presence of major neurocognitive disorders (e.g.

Alzheimer’s disease, Frontotemporal lobe dementia, Lewy Body dementia, and vascular dementia), and sensory deficits (e.g. color blindness, monocular/binocular blindness, and macular degeneration). Individuals above the age of 8, that have identified as either: having a current concussion, a prior concussion, complaining of cognitive difficulties, or never having had a concussion, were all included in the study. This high level of inclusion allowed for separate population comparisons, and further verification of the NeuroTracker as a perceptual cognitive testing/training tool.

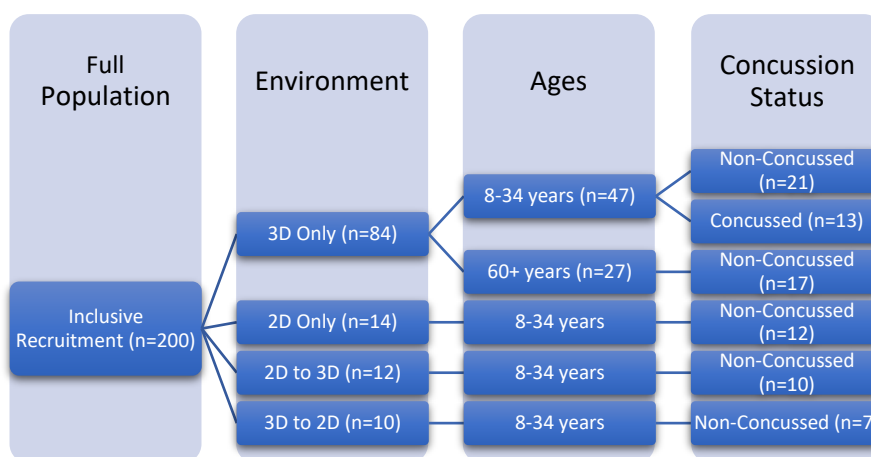


Figure 4: Flow Chart of Separation of Participants into Testing Populations

From left to right; a flow chart of how the population of recruited participants were divided into set populations. First, all participants who came forward were invited to participate. Once they passed screening test, and depending on age or concussion symptom they were included in specific study groups. If they were non-concussed and between the ages of 8-34 years, they could take part in all environmental representations of 3D-MOT training. If they were over the age of 60 years, they were invited to take part in the 3D representation only. Finally, if they were concussed and between the ages of 8-34 years, they were invited to take part in the 3D representation only.

For population comparison, when individuals came into the lab depending on their demographics they were offered to participate in one of three studies: an environment comparison (2D versus 3D), an age comparison, or a concussed population comparison. An environment comparison was open to individuals ages 8 to 59 years old,

and non-concussed. An age comparison added the inclusion of individuals over the age of 60 (still non-concussed). The concussed population comparison added the inclusion of concussed and prolong concussed individuals.

2.1.1 A Comparison of 2D and 3D MOT training Population

For the 2D and 3D MOT training, the data analyses was based on participants in the age range similar to the previous studies (Perico, et al., 2014; Parsons, et al., 2014; and Faubert, 2013). The sample included 60 healthy individuals, both male and female, ages 8 to 34 years old. These 60 individuals were randomly divided into 4 groups: 2D only, 2D switching to 3D, 3D switching to 2D, and 3D only. Individuals who reported current concussions, or were suffering from other psychiatric, or physiological disorders, such as anxiety, depression, panic, and/or posttraumatic stress disorder (PTSD), were excluded from this study. A Randomizer was used to assign each participant to their respective groups. As noted in Table 3, distribution of participants was not equivalent in all groups. This was due to high dropout rates, and the supplementation of non-concussed individuals from the concussion comparison study to the 3D MOT environment group.

Table 3. A Comparison of 2D and 3D MOT training population

Group	N (number of participants)	Average age (years)	Percentage of Females	Percentage of Males
1:2D only	12	19.17 +/-13.34	58.33%	41.67%
2:2D to 3D	10	17.90 +/-14.36	50.00%	50.00%
3:3D to 2D	7	23.29 +/-8.40	57.14%	42.86%
4:3D only	34	18.91 +/-11.20	35.29%	64.70%

2.1.2 A Comparison of 3D MOT training among Concussed Populations

For the concussion comparison strict inclusion and exclusion criteria were used to control as many variables as possible. Consistent with previous studies the age range for both environmental and concussion comparison was kept to a youth/ young adult population. Forty individuals, between the ages of 8 and 34, both male and female were recruited. There were 10 prolonged concussed individuals (symptomatic for up to 6 months), 10 recently concussed individuals, and 20 non-concussed individuals who were invited to participate in 10 appointments (60 trials per appointment) of MOT training on the NeuroTracker over a two to three-month period. The prolong concussed population had to be diagnosed with a brain injury by a doctor, have neuro-cognitive deficits and neuro-physical issues (vestibular issues) that require the intervention of a neuropsychologist and neuro-occupational therapist. The prolong concussed and concussed populations differed in that, concussed individuals had to be within 10 days of the initial mTBI/concussion, whereas the prolong concussed population could have been up to 6 months out of initial injury. Also, individuals were placed in the prolonged concussed population and excluded from the concussed population should their symptoms be maintained over the training/testing period. Similarly, if they were still reporting symptoms such as behavioral factors including: worries, sadness, and panic attacks, (because post-concussion psychological factors can magnify or cause cognitive and vestibular/ocular deficits) they were moved to the prolong concussed group. The movement of these individuals from one group to the other was to maintain clear

boundaries between what has been defined as a concussed individual or a prolonged concussed individual (based on previous literature). Subjects who identified with psychiatric disorders (Anxiety, Depression, Post-Traumatic Stress Disorder) were excluded from analysis all together. The non-concussed group had similar exclusion criteria to the concussed group, with the added criteria of not being concussed, receiving a mTBI within the last 6 months, or reporting any symptoms associated with concussion or cognitive deficit.

Due to harsh exclusion and inclusion criteria, time constraints, and high drop-out rates, the study finished with 3 individuals that were maintained in the concussed population group, 10 in the prolonged concussed group, and 21 in the healthy group.

Table 4. A Comparison of 3D-MOT training among Concussed populations

Group	N (number of participants)	Average age (years)	Percentage of Females	Percentage of Males
Symptomatic	13	24.62 +/-13.49	31.77%	68.23%
Prolonged Concussion	10	24.50 +/-14.84	40.00%	60.00%
Currently Concussed	3	25.00 +/-10.00	0%	100%
Non-Concussed	21	15.38 +/-7.98	38.10%	61.90%

2.1.3 A Comparison of 3D MOT training among Aging Populations

In the comparison of 3D MOT training among aging populations, a more inclusive age range (8-91 years of age) was used. In addition to the non-concussed individuals, ages 8-34 years old, who participated in the 3D MOT groups in the other two studies (2D versus 3D MOT, and concussion comparison), a group of 31 individuals between the ages of 49 and 89 were recruited completed 10 sessions of 3D-MOT training

on the NeuroTracker over 2-3months of testing. Due to screening, and dropout rates, only 17 of the participants (age 60 and above) were considered for this comparison. They were compared to the 21 non-concussed individuals who participated in similar testing when assessing 3D-MOT. Rather than using the standard age grouping of child (12 years of age and under), youth (13-18 years of age), young adult (19-25 years of age), adult (26-59 years of age), and older adult (60 years of age and over), seen in neuropsychological studies, the age comparison study grouped populations based on their current engagement in education and its level, with a consideration on maintaining within group variance of sex, and activity level, along with a desire to maintain continuity with the other two studies age ranges.

Table 5. A Comparison of 3D-MOT training among Aging populations

Group	N (number of participants)	Average age (years)	Percentage of Females	Percentage of Males
Youth (8-18)	15	11.00 +/-2.98	20.00%	80.00%
Young Adult (19-34)	6	26.33 +/-5.32	83.33%	16.67%
Elderly (60+)	17	74.82 +/-9.60	70.59%	29.41%

2.2 Experimental Design

This research focuses on learning more about perceptual cognitive training in subjects from different backgrounds in different environments. The use of a convenience sample of individuals with: no prior history of concussion, individuals who have recently been diagnosed with concussion, or individuals with a history of a diagnosed or suspected concussion, as well as older adults, was intended to be an inclusive intake. However, different factors (age, sex, prior history of concussion, etc.) can impact learning

performance and had to be taken into consideration. As such, three separate studies (environmental comparison, age comparison, and concussion comparison) were designed to assess these populations independent of each other. A number of screening tools to ensure correct categorization and assessment of these subjects were used.

The experiment used a between-group design, assessing differences in perceptual cognitive performance, via NeuroTracker (NT) scores, based on differences in environment, age, and concussion status. The dependent variables were: NT initial score, NT fifth score, NT final score, differences between these scores, and the learning curve produced when all NT scores (first to last) were fit to a logarithmic curve. All dependent variables were continuous variables (values that can range). The independent variables were: 2D or 3D environment (control for age and sex), age group (control for sex), concussion status (control for age and sex). All independent variables were categorical. The covariables were: age (a continuous variable), and sex (a categorical variable). Thus, each individual study (environment, age, and concussion status) was controlled for age and sex. Unfortunately, due to high drop out rates, the experimental design and results procured, do not perfectly align (control for age and sex were not perfectly applied).

The NeuroTracker: a computerized testing/training tool was used to examine the efficacy of perceptual cognitive training in prolonged concussed, concussed, and non-concussed populations. Questions such as ‘does a prolonged concussed population associate with lower threshold speeds (or performance) on the NeuroTracker than a recently concussed, or non-concussed population?’ and ‘can the NeuroTracker be an effective tool for perceptual cognitive training in all populations?’ were to be addressed.

Similarly, the recruitment of all ages was meant to measure the efficacy of the NeuroTracker at training perceptual cognitive ability in youth, young adults, and older adults, to answer questions such as, ‘do older adult populations associate with lower threshold speeds or learning adaptations on the NeuroTracker?’ and ‘can the NeuroTracker aid in perceptual-cognitive function for all ages?’.

The use of two-dimensional and three-dimensional environments to represent the three-dimensional multiple object tracking training device that is the NeuroTracker was for a few reasons. First, to see how different perceptual cues might affect cognitive function and the acquisition of higher threshold speeds in working memory, attention, and processing speeds. Next, to see if learning adaption occurred at the same rate despite differences in perceptual cues. Finally, to see if one could smoothly alternate between different environments and maintain similar learning adaptations as those who maintained training within the same environment. Should threshold speeds and learning adaption in both environments, despite changes in training regimes, be maintained this perceptual cognitive training tool could become more accessible to the general public (via the use of easily accessible two-dimensional technology).

2.3 Procedure

Once individuals (or parents of minors) show interest in the study, they were given more information about the study. Eligible and interested individuals of all ages provided consent through the consent or assent form (Appendix A, and B). Participants 18+ years of age were expected to read and sign the consent form on their own, whereas participants ages 13 to 17 years of age were expected to read and sign the consent form,

along with their parents. Children under the age of 13 provided verbal assent after a lab technician read the assent form, while the consent form was signed by their parents. Continuous consent was given (via their initial) by the participant every time they came into the lab and participated in testing (Appendix D).

All participants were given ID numbers and tested in private cubicles with sound barriers and headphones to ensure privacy and lack of distraction. Upon the initial appointment, participants completed a basic intake form (Appendix C) to give demographic information and medical history, to clarify if the subject meets inclusion/exclusion criteria. Participants also completed the following: a standardized activity questionnaire, either the Godin Leisure Time- Exercise Questionnaire (Appendix E) or the Leisure Activity Questionnaire by Daniel Eriksson Sorman et al., 2013 (Appendix F), either the Third edition of the standardized Sport Concussion Assessment Test (SCAT-3) (Appendix M) or the Child version of the SCAT-3 (ages 5-13) (Appendix N); with the addition of the weighted ruler drop (Appendix O) a reaction time test, then the King-Devick Test (KDT) (Appendix P) a visual-spatial skills test, and a Vestibular/Ocular Motor screen (VOMS) (Appendix Q), upon their first appointment. These tests aid in identification of individuals with concussion or ocular deficits, and in validation of the NeuroTracker as a perceptual cognitive training/testing tool.

Depending on their age some participants (60+ years of age) completed the following: The Mini Mental State Examination (MMSE) (Appendix H), a 30 point questionnaire used in clinical research settings to measure cognitive impairment, the Memory Complaint Questionnaire (Appendix I), and the Geriatric Depression Scale

(Appendix J). These tests were used for screening purposes to determine the participants eligibility to participate in the study.

Depending on their symptom report (concussion status) participants also completed a MOT and Related Post-concussion form (Appendix K), and a Brain Injury questionnaire (Appendix L). These were to document symptoms and recovery, to aid in screening participants as currently concussed, progressing to prolong-concussed, or at a new baseline (considered recovered and non-concussed).

After the participant had finished all the above listed testing/screening, they initiated their first of 10 appointments using CogniSens Athletics Inc.'s 3-D Perceptual-Cognitive computer program, the NeuroTracker. The 10 appointments of training on the NeuroTracker (at least once a week) consisted of three sessions of 20 trials per appointment, causing the individual to take part in 600 trials of testing.

Participants were reminded that participation is voluntary and they were capable of withdrawing at any time without consequence, by completing a withdraw form (Appendix R). At entrance and exit of testing /training (or upon concussion, should it occur during testing) all participants were offered information on return to play (RTP) procedures following concussion (Appendix S) should they be symptomatic or not.

2.4 Materials (Equipment)

Other than the NeuroTracker, a large portion of testing was used strictly for screening purposes. Similarly, not all of the above listed procedures were applicable to all participants, so they were not requested to partake in them. However, all participants did

complete the initial intake as well as the NeuroTracker testing/training, so those tools will be further described below.

2.4.1 Initial Intake and Screening Tools

Initial Intake and Screening tools consist of the following:

A Consent and Assent Form (Appendix A, and B): to ensure all participants are properly educated on the study, they are expected to read (Consent) or listen (Assent) and sign the form confirming they wish to participate in the study.

An Intake/Medical History Form (Appendix C): participants are expected to correctly fill out this form upon initial visit, informing examiners of contact information, age, concussion history and more. This tool will be specifically used to aid in inclusion/exclusion of participants from specific study groups.

A standardize activity questionnaire, either the Godin Leisure Time- Exercise Questionnaire (Appendix E) or the Leisure Activity Questionnaire by Daniel Eriksson Sorman et al., 2013 (Appendix F), will be used to assess activity level and ensure all population comparisons will have the same within group variance of leisure activity, intensity, etc. The questionnaire would request the participant rate their daily activities in the past week as mild, moderate, or vigorous activity level, and indicate the frequency and duration at which they participated in it.

Either the Third edition of the standardized Sport Concussion Assessment Test (SCAT-3) (Appendix M) or the Child version of the SCAT-3 (ages 5-13) (Appendix N); with the addition of the weighted ruler drop (Appendix O) a reaction time test, would be administered. This will aid in concussion diagnosis, and assess concussion symptoms, and

severity. This test consists of a background questionnaire, a self assessment of concussion symptoms and severity, a cognitive assessment (testing orientation, immediate memory, and concentration), balance examination, reaction time assessment, coordination examination, and the standardized assessment of concussion delayed recall. All parts of the test have standardized tracking and scoring to aid in the diagnosis of concussions.

The King-Devick Test (KDT) (Appendix P), an objective clinical test of eye movements that has been used to screen for concussions and visual-spatial issues, will be administered as well. The participant will be asked to read the three test cards, increasing in difficulty, while being timed. Should they make error, it will be recorded and they will be asked to start again.

A Vestibular/Ocular Motor screen (VOMS) (Appendix Q), to assess five different areas of the vestibular and ocular systems: smooth pursuits, saccades (or rapid eye movements), vestibular ocular reflex, visual motion sensitivity, and near-point-of-convergence distance, will be tested after the KDT. The participant will be asked to complete seven tasks, and asked how they felt on a ten point scale (ten being the worst). Differences in symptom (headache, dizziness, nausea, and fogginess) level will be tracked, along with comments about the test, and distance from the nose (on the convergence test only) during testing.

Finally, the Continuous Consent and Appointment history Form (Appendix D): to properly track testing, and confirm the participant wishes to continue with testing, this form was filled out by the examiner, tracking NT testing results, dates of testing and other tests performed, and initialed by the participant confirming they did arrive for testing and did wish to participate.

2.4.2 Three-Dimensional Multiple Object Tracking (3D-MOT)/The NeuroTracker

The NeuroTracker (NT) is a three-dimensional multiple object tracking computerized technology produced by CogniSens. It uses an intelligent staircase procedure to push perceptual-cognitive thresholds and achieve maximal stimulation. It also provides a direct indicator of perceptual capabilities such as: complex motion integration, distributed attentional control, fluid-rapid processing and visual working memory. The NT was used for perceptual cognitive training over ten appointments (at least once a week) consisting of three sessions of twenty trials per appointment, causing the individual to take part in 600 trials of testing.

Prior to the beginning of training/testing participants were given explanations of how to use the NT and asked if they had any questions. If not, they proceeded at their own pace until they had completed as much of the three sessions as they felt capable. To date, there has been no subject that failed to complete all three sessions, however they were always reminded of the option to leave at any time.

Participants initiated their training on the NT by sitting down, approximately 1.6m away, from a 60inch high definition television screen. The computerized program began by presenting eight yellow balls in what appeared to be a 3-D box. Four of the balls turned red, indicating themselves as the target balls. After two seconds the balls returned to yellow and all eight balls began to move and bounce within the box on the screen. After eight seconds the balls stopped and a number appeared (ranging from 1-8) on each ball. The participant indicated which balls he or she thought to be the initial target balls. (Refer to Figure 1 for an illustration of this process.) Whether correct or not

the program then indicated which balls are the initial target balls. If correct, a star would appear on the right-hand side of the screen and the speed at which the balls moved around the screen would increase by $0.05\log$ of the previous speed. If incorrect, a dash would appear on the right-hand side of the screen and the speed at which the balls moved would decrease by $0.05\log$ of the previous speed. After 20 trials in this manner, the speed threshold was calculated for that session based off of the final four inversions. The participant repeated this process twice more producing 3 threshold scores for that appointment.

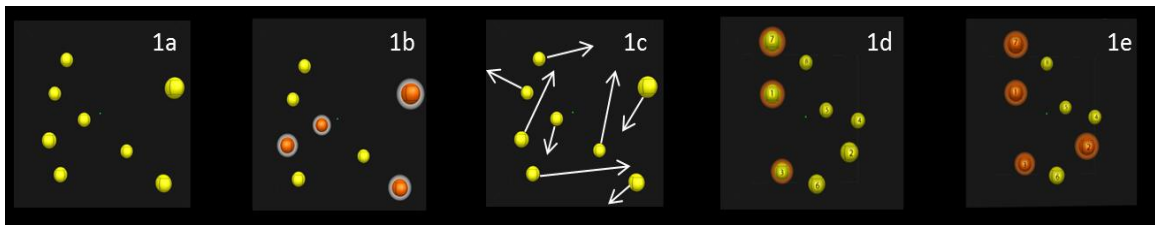


Figure 5: A Visual Representation of 3D-MOT Training/A Single Trial of NeuroTracker Training. 1A: Presentation, where eight stimuli are displayed on the viewing screen for the participant. **1B: Indexation**, where four of the stimuli are designated as targets for attention. **1C: Movement**, with all targets presented as a uniform color. **1D: Identification**, where targets are now stationary and assigned a numerical value between one and eight. **1E: Feedback**, where the original targets for the trial are now illuminated to provide feedback to the participant.

2.5 Analysis

Each individual's data was collected and tracked using excel. The dependant variable (each appointment's mean average of the three sessions NeuroTracker score) was calculated per individual. The difference between the 1st and 5th, as well as the 1st and 10th NeuroTracker (NT) mean average per appointment was also calculated per individual, producing two more dependent variables. The final dependant variable was the slope of the logarithmic curve that best represents each individual ($R^2 > 0.90$), which was also calculated and will thus forth be labeled as 'learning'.

To demonstrate perceptual cognitive adaptations, learning curves were produced per testing population (2D versus 3D, age groups, and concussion status). The mean average of each appointment per individual was grouped into their respective testing population. The mean average for all participants was calculated. This created 10 data points for that testing population. Standard Error of the Mean (SEM) was calculated for each data point of each testing population. The data points and their SEM were input into a 'NT score' versus 'appointment number' graph and a logarithmic trendline was fit to the data. The correlation of the data points in comparison to the trendline was then calculated. This confirmed that it was an accurate representation of the learning adaptation that occurred within that population.

R Studio was used to perform a descriptive analysis on the independent variables: 'environment group', 'symptom status', 'concussion status', 'age', 'age group', and 'gender', with the dependant variables: 10 mean average NT scores, the calculated difference scores, and the learning adaptation for each individual. Two tail T-tests were used to determine if there was significant difference between the mean of two groups (such as the group switching from 3D to 2D in comparison to the group switching from 3D to 2D, in the environmental comparison study). Pearson product-moment correlation coefficients were produced as a measure of the strength of the linear relationship between two variables. A linear regression was fit to the age comparison study to model the relationship between difference in first and final NT score, as well as learning adaptation, to age. Repeated measures ANOVAs were run assessing the difference between the first and final NT appointment and learning adaptations for all three studies to compare the mean scores of each group (such as the comparison between youth, young adult, and

older adult). Post-hoc analysis was also run on all three studies, to determine which population group comparison produced significant difference. The data pulled from the individuals who participated in the 3D concussion comparison portion of this study, also had two tailed t-test, correlations, repeated measures ANOVAs, and post-hoc analysis run comparing first appointment scores as well as final appointment scores on the NT.

Chapter 3: Results

A descriptive statistical analysis was conducted on the data collected, including: age, gender, concussion status, and 2-D or 3-D environment. The dependent variables were: NT initial score, NT fifth score, NT final Score, differences between these scores, and the learning curve produced when all NT scores (first to last) were fit to a logarithmic curve. All dependant variables were continuous variables. The independent variables were: 2D or 3D environment (control for age and sex), age group (control for sex), concussion status (control for age and sex). All independent variables were categorical. The covariables were: age (a continuous variable), and sex (a categorical variable). Thus, each individual study (environment, age, and concussion status) was controlled for age and sex.

Participants had an average age of 35.79 years old (SD=27.59). Out of 85 participants, 42 (49.41%) were male, and 43 (50.59%) were female. On average participants achieved 0.84 (SD = 0.42) on their initial appointment, 1.32 (SD = 0.55) on their final appointment, an average difference of 0.50 (SD = 0.42) between first and final appointments, and an average slope to their learning curve of 0.23 (SD = 0.21).

Table 6. Descriptive Statistics for all Dependent Variables used in Research:

	Mean	Standard Deviation
Age (years)	35.79	27.59
First NT appointment Score	0.84	0.42
Fifth NT appointment Score	1.19	0.49
Final NT appointment Score	1.32	0.55
Difference between First and Final NT Scores	0.50	0.42
Slope of the Learning Curve	0.23	0.21

The results of the Pearson correlation analysis of all participants (in all studies) revealed that there was a negative correlation between people's age and their difference between first and final NT appointment score ($r = -.39, p < .001$), such that the younger subjects did better. There was also a negative correlation between people's gender and their difference between first and final NT appointment score ($r = -.21, p = .05$), such that males did better than females. All studies controlled for these covariables separately (to avoid confounding results).

Table 7. Correlations between Covariables and Dependant Variables in Research:

	Age (years)	Sex (Male =1, Female =2)	Difference between first and final NT score
Age (years)	1.00	-	-
Sex (Male =1, Female =2)	-	1.00	-
Difference between first and final NT score	-0.39***	-0.21*	1.00
*p< .05; **p< .01; ***p< .001			

3.1 A Comparison of 2-Dimensional and 3-Dimensional MOT Training

In total, 58 participants took part in the environmental comparison. 12(21%) participants completed perceptual cognitive training in a two-dimensional (2D) representation of the three-dimensional multiple object tracking (3D-MOT) environment, 34(59%) participants completed training in a 3D representation, 10(17%) participants switched from a 2D to a 3D representation of the 3D-MOT while training, and 7(12%) participants switched from a 3D to a 2D representation of the 3D-MOT while training.

Table 8. Descriptive Statistics for all Dependant Variables used in the Comparison of 2D and 3D Representations of 3D-MOT Research, by Representation:

	Mean	Standard Deviation
Group 4: 3D only:		
First NT appointment Score	0.97	0.12
Fifth NT appointment Score	1.42	0.12
Final NT appointment Score	1.65	0.13
Difference between First and Final NT appointment Scores	0.68	0.06
Slope of the Learning Curve	0.29*	0.07
Group 1: 2D only:		
First NT appointment Score	0.89	0.62
Fifth NT appointment Score	1.32	0.69
Final NT appointment Score	1.38	0.69
Difference between First and Final NT appointment Scores	0.49	0.13
Slope of the Learning Curve	0.30*	0.44
Group 3: 3D switching to 2D:		
First NT appointment Score	1.14	0.28
Fifth NT appointment Score	1.45	0.25
Final NT appointment Score	1.26	0.28
Difference between First and Final NT appointment Scores	0.07	0.31
Slope of the Learning Curve	0.11*	0.21
Group 2: 2D switching to 3D:		
First NT appointment Score	0.86	0.22
Fifth NT appointment Score	1.24	0.22
Final NT appointment Score	1.49	0.30
Difference between First and Final NT appointment Scores	0.79	0.15
Slope of the Learning Curve	0.23*	0.16

A paired two tail t-test was performed to verify if there was an association between switching environmental representations or staying in the same environment and NT performance. No statistical significance was found between switching and maintaining the same training environment ($t(13.5) = .74$; $p = .47$ from t-test) when comparing the difference between first and final NT scores, or when comparing the learning adaptation based on the slope of the logarithmic best fit curve ($t(14.7) = .02$; $p = .98$ from t-test).

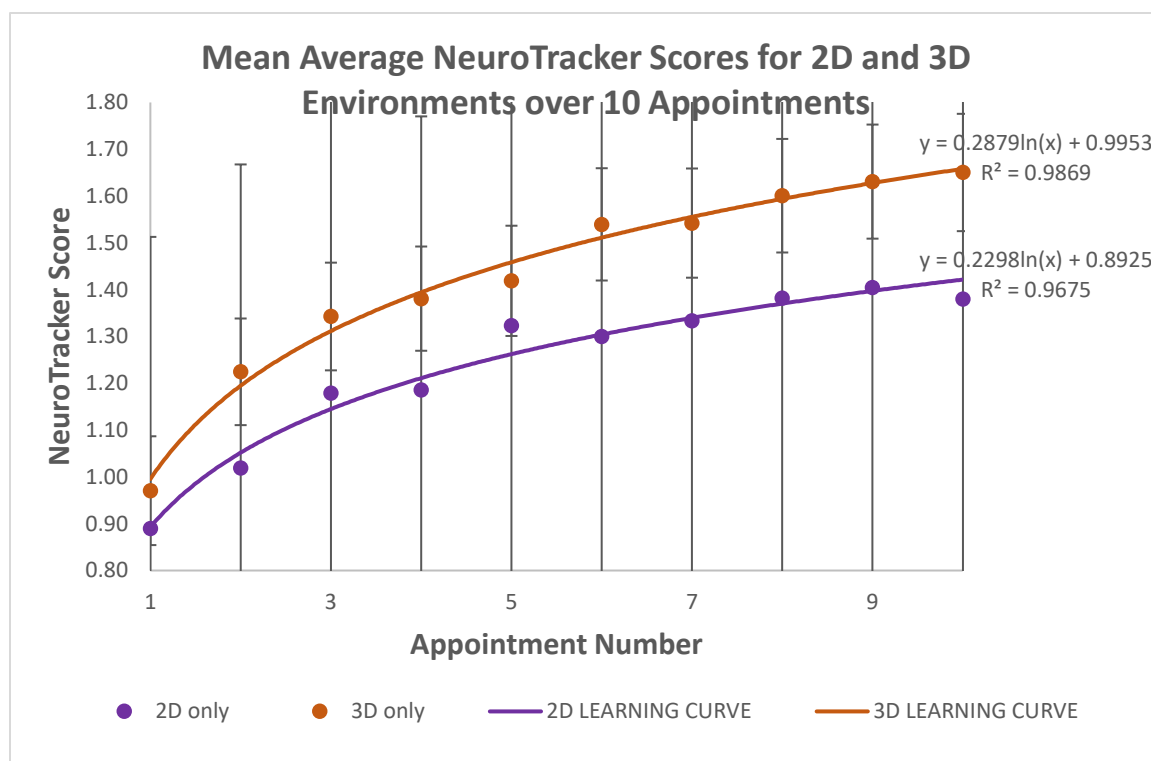


Figure 6: A Comparison of Learning Adaptations in 2D and 3D Environments. Data points represent the mean average speed threshold for each testing group per appointment (dark purple=2D only testing group, burnt orange=3D only testing group). This was calculated from the mean average of 3 sessions per person (2D only N=12, 3D only N=34) per appointment. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3 months. Learning curves equation and correlation are represented to the right of their respective curves.

No statistical significance was found between the testing groups that maintained their environment in either 2D or 3D ($t(16.7) = -1.29$; $p = .21$ from t-test) when comparing

the differences between first and final NT scores, or when comparing the learning adaptation based on the slope of the logarithmic best fit curve ($t(16.61) = -.94$; $p = .36$ from t-test) (Refer to Figure 6 & 7).

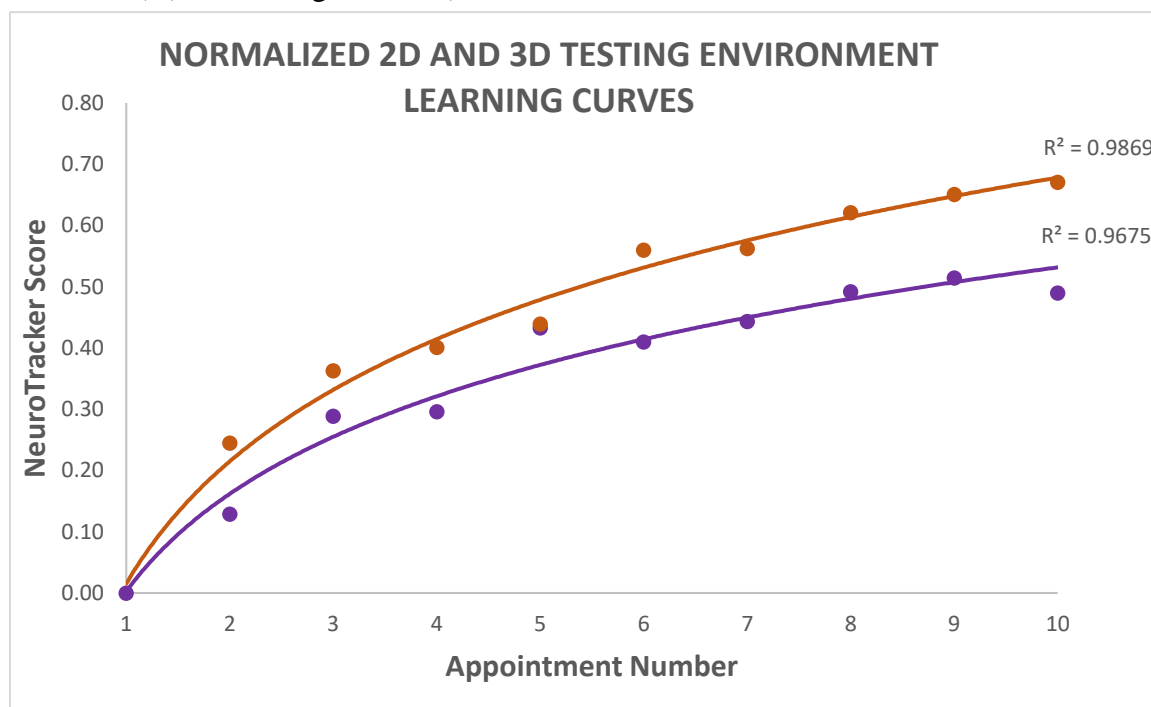


Figure 7: A Normalized Representation of Learning Adaptations in 2D and 3D Environments. Data points represent the normalized mean average speed threshold for each testing group per appointment (dark purple=2D only testing group, burnt orange=3D only testing group). This was calculated from the mean average of 3 sessions per person (2D only N=12, 3D only N=34) per appointment and by setting the initial appointment score to 0. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3 months. Learning curve correlations are represented to the right and above their respective curves.

A repeated measures ANOVA was performed to verify if there was an association between 2D or 3D representations of a 3D MOT training environment and NT performance. Statistical significance was found between 2D and 3D testing environments and NT performance when comparing the difference between first and final NT scores

($F(3,54)= 3.61$; $p= .01$ from ANOVA), and when comparing learning adaption based on the slope of the logarithmic best fit curve ($F(3,54)= 2.91$; $p= .04$ from ANOVA).

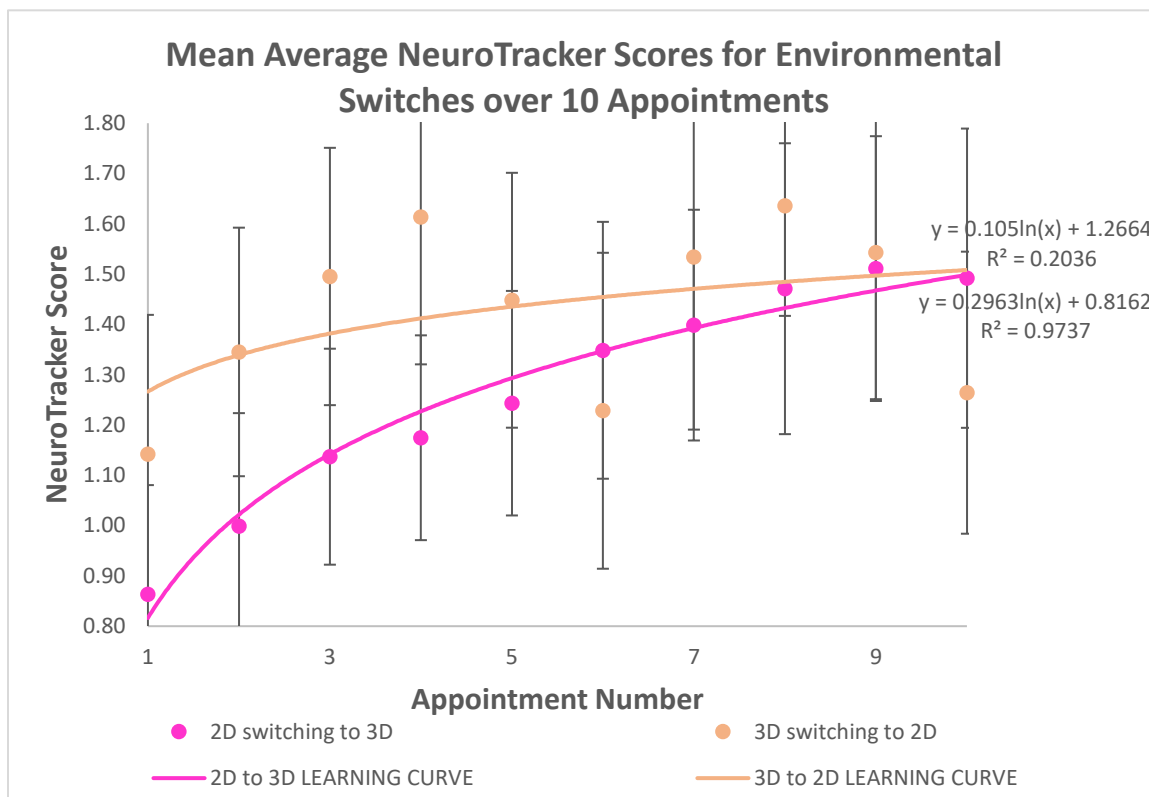


Figure 8: A Comparison of Learning Adaptations in Groups that Switched 2D and 3D Environments after 5th Appointment. Data points represent the mean average speed threshold for each testing group per appointment (light purple=2D switching to 3D testing group, light orange=3D switching to 2D testing group). This was calculated from the mean average of 3 sessions per person (2D to 3D N=10, 3D to 2D N=7) per appointment. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3 months. Learning curves equation and correlation are represented to the right and either slightly above in the case of 3D switching to 2D, or slightly below in the case of 2D switching to 3D.

Post-hoc comparisons (using the Bonferroni adjustment) revealed that significant differences occurred when comparing the difference between first and final NT scores, between participants who were in group 2 (switching from 2D to 3D) and group 3 (switching from 3D to 2D) ($p= .03$) and between participants who were in group 3 and 4 (maintained in 3D) ($p= .02$). There were no significant differences between participants who were in group 1 (maintained in 2D) and group 2 ($p= .91$), in group 1 and group 3 ($p=$

.44), in group 1 and group 4 ($p= 1.00$), or in group 2 and group 4 ($p= 1.00$), when comparing the difference between first and final NT scores.

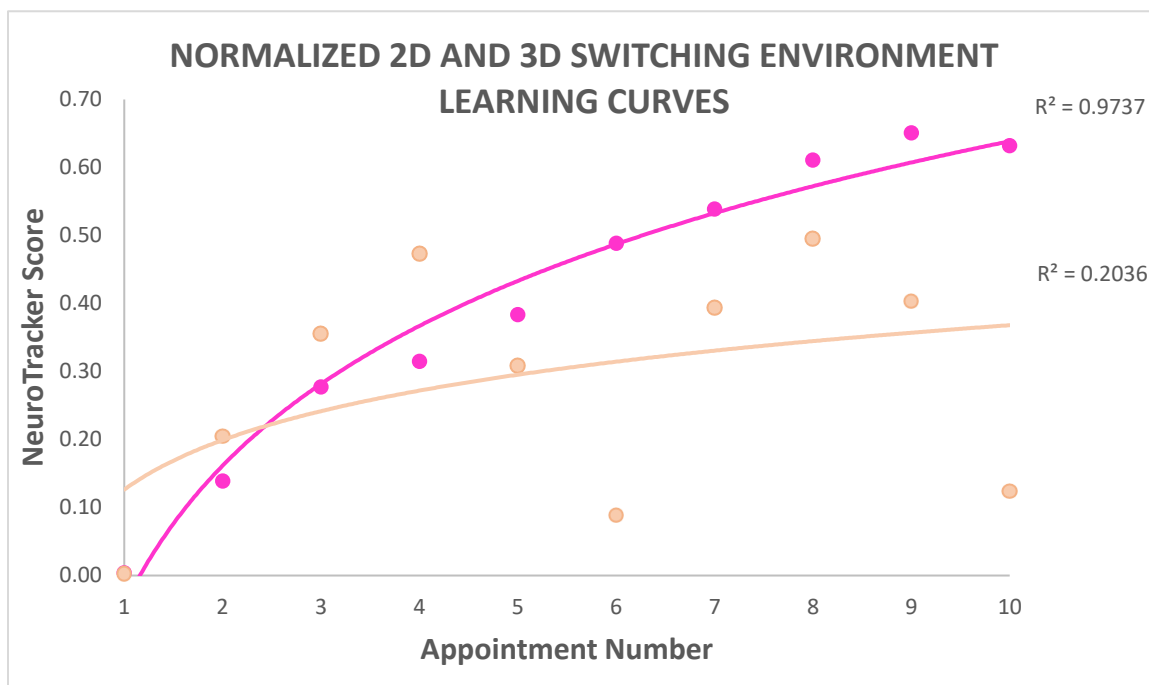


Figure 9: A Normalized Representation of Learning Adaptation in Groups that Switched 2D and 3D Environments. Data points represent the normalized mean average speed threshold for each testing group per appointment (light purple=2D switching to 3D testing group, light orange=3D switching to 2D testing group). This was calculated from the mean average of 3 sessions per person (2D to 3D $N=10$, 3D to 2D $N=7$) per appointment and by setting the initial score to 0. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3months. Learning curve correlations are represented to the right of their respective learning curves.

Similarly, when comparing learning adaptation based on the slope of the logarithmic best fit curve, post-hoc comparisons revealed that significant differences occurred when comparing participants who were in group 2 and group 3 ($p= .04$). However, there were no other significant differences between participants when comparing any other groups (1 vs. 2 $p= .34$, 3 vs. 4 $p= .19$, the rest $p= 1.0$).

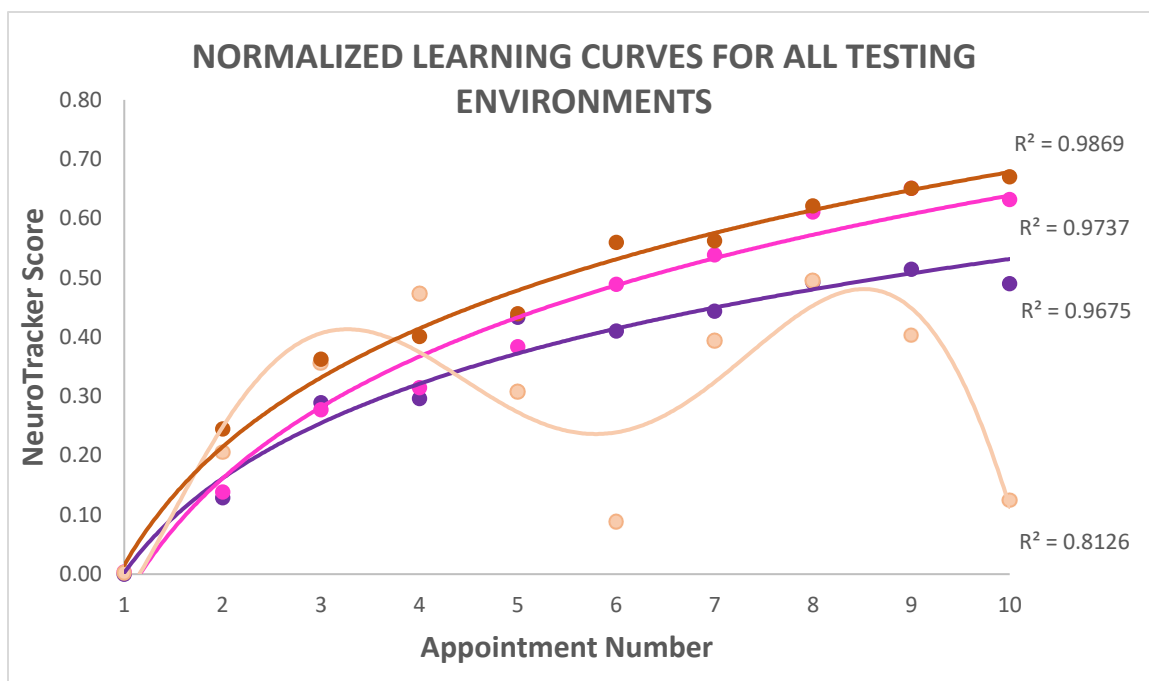


Figure 10: A Normalized Representation of Learning Adaptions in all Testing Environments. Data points represent the normalized mean average speed threshold for each testing group per appointment (burnt orange=3D only testing group, light purple=2D switching to 3D testing group, dark purple=2D only testing group, light orange=3D switching to 2D testing group). This was calculated from the mean average of 3 sessions per person (3D only N=34, 2D to 3D N=10, 2D only N=12, 3D to 2D N=7) per appointment, and by setting the initial appointment score to 0. Learning curves represent the best fit trendline (logarithmic for all testing groups but 3D to 2D, which was a 6th order polynomial) to these data points over 10 appointments that took place for 2-3months. Learning curves correlation are represented to the right of their respective curves.

To demonstrate perceptual cognitive adaptations, learning curves were produced per testing population (2D only, 2D switching to 3D, 3D switching to 2D, and 3D only). The mean average for each testing population for each appointment and their SEM were input into a 'NT score' versus 'appointment number' graph and a logarithmic trendline was fit to the data. The 2D only group produced a learning curve of 0.2298 ($R^2=0.9675$). The 3D only group produced a learning curve of 0.2879 ($R^2=0.9829$) (Refer to Figure 7 & 8). The 2D switching to 3D group produced a learning curve of 0.2963 ($R^2=0.9737$).

The 3D switching to 2D group produced a learning curve of 0.105 ($R^2=0.2036$) (Refer to Figure 9 & 10).

Due to the drastic change in performance on the 5th appointment (the switch of environmental representation), and the poor representation of adaptation via a logarithmic best fit line, the 3D switching to 2D group had a second-best fit line calculated to represent learning adaptation based on a 6th polynomial ($R^2= 0.8126$) (Figure 10).

3.2 The Affect Age has on 3-Dimensional MOT Training

In total, 38 participants took part in the age comparison. 15(39%) participants were considered youth (ages 8-18), 6(16%) participants were considered young adults (ages 19-35), 0 participants were considered adult (ages 36-60), and 17(45%) participants were categorized as older adults (ages 61+).

Table 9. Descriptive Statistics for all Dependant Variables used in 3D-MOT training among Aging populations Research, by Age Group:

	Mean	Standard Deviation
Youth (ages 8-18):		
First NT appointment Score	1.08	0.17
Final NT appointment Score	1.72	0.20
Difference between First and Final NT Scores	0.65*	0.11
Slope of the Learning Curve	0.27***	0.11
Young Adults (ages 19-35):		
First NT appointment Score	0.99	0.23
Final NT appointment Score	1.66	0.25
Difference between First and Final NT Scores	0.67*	0.13
Slope of the Learning Curve	0.27***	0.14
Older Adults (ages 61+):		
First NT appointment Score	0.61	0.13
Final NT appointment Score	0.84	0.13
Difference between First and Final NT Scores	0.24*	0.05
Slope of the Learning Curve	0.08***	0.07

The results of the Pearson correlation analysis revealed that there was a negative correlation between all participant's age and their difference between first and final NT score ($r = -.54$, $p < .001$).

Table 10. Correlations between Age and Dependant Variables in 3D-MOT training among Aging population Research:

	Age (years)	Difference between first and final NT Scores
Age (years)	1.00	-
Difference between first and final NT Scores	-0.54***	1.00
*p< .05; **p< .01; ***p< .001		

Since none of the VIF values were below 0.1 and none of the Tolerance values were above 10, the assumption of no multicollinearity has been met. Durbin-Watson statistics fell within an expected range, thus indicating that the assumption of no autocorrelation of residuals has been met as well. Finally, the scatterplot of standardised residuals on standardised predicted value did not funnel out or curve, and thus the assumptions of linearity and homoscedasticity have been met as well.

A repeated measures ANOVA was performed to verify the association between age (now in groups) and NT performance. Statistical significance was found between age groups and NT performance when comparing the difference between first and final NT scores ($F(2,35) = 8.148$, $p = .01$ from ANOVA), and when comparing learning adaption based on the slope of the logarithmic best fit curve ($F(2,35) = 9.997$, $p < .001$ from ANOVA). Post-hoc comparisons of differences between first and final NT scores revealed that significant differences occurred between youth and older adult participants ($p = .002$) and between participants who were in the young adult and older adult groups ($p = .01$). There were no significant differences between participants who were in the youth and young adult groups ($p = 1.0$). When comparing learning adaptation based on the slope of the logarithmic best fit curve, post-hoc comparisons revealed the same thing.

Significant differences occurred between youth and older adult participants ($p < .001$) and between participants who were in the young adult and older adult groups ($p = .009$).

Again, there was no significant differences between participants who were in the youth and young adult groups ($p = 1.0$).

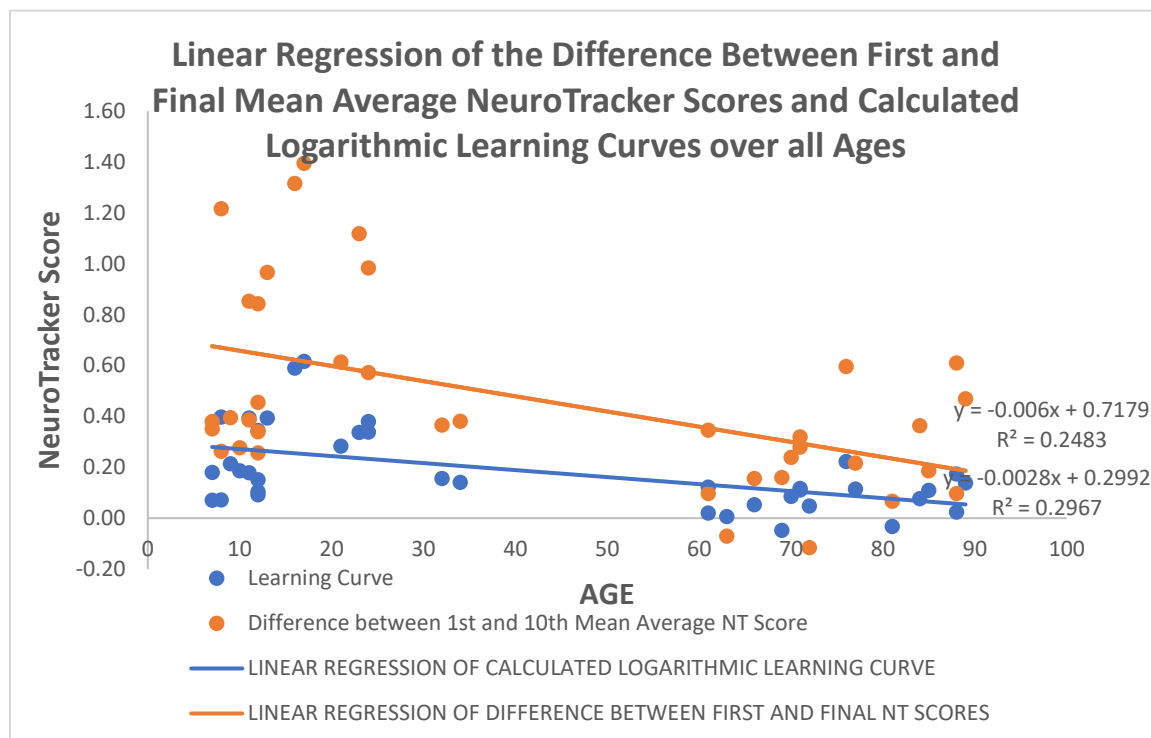


Figure 11: A Linear Regression of Learning Adaptations among all Ages. Data points represent the difference between 1st and 10th mean average speed threshold for participant (orange), and the calculated learning curve (logarithmic best fit trendline to all data points over 10 appointments) for each participant (blue). Linear regression lines represent the linear best fit trendline to these data points over the age of each participant (ages 8-89 years old). Linear equation and correlation are represented to the right and slightly above each linear regression line.

A linear regression model reached significance, meaning it successfully predicted NT performance scores when comparing the difference between first and final NT scores ($F(1,38) = 11.89, p = .001$) as well as their learning curve slope ($F(1,38) = 15.19, p < .001$). The model explained 24.8% of variance in difference between first and final NT scores, and 29.7% of variance in learning adaptation. Participants 3D-MOT performance was

predicted by their age ($B = -.006$, $t = -3.448$, $p = .001$) when comparing the difference between first and final NT scores, and 3D-MOT performance was predicted by their age ($B = -.002$, $t = -3.897$, $p < .001$) when comparing learning adaptation too. For every increase in age by 1 years, 3D-MOT performance decreased by .006, when comparing differences between first and final NT scores. Similarly, for every increase in age by 1 years, 3D-MOT performance decreased by .002, when comparing the learning adaption curve (Figure 11).

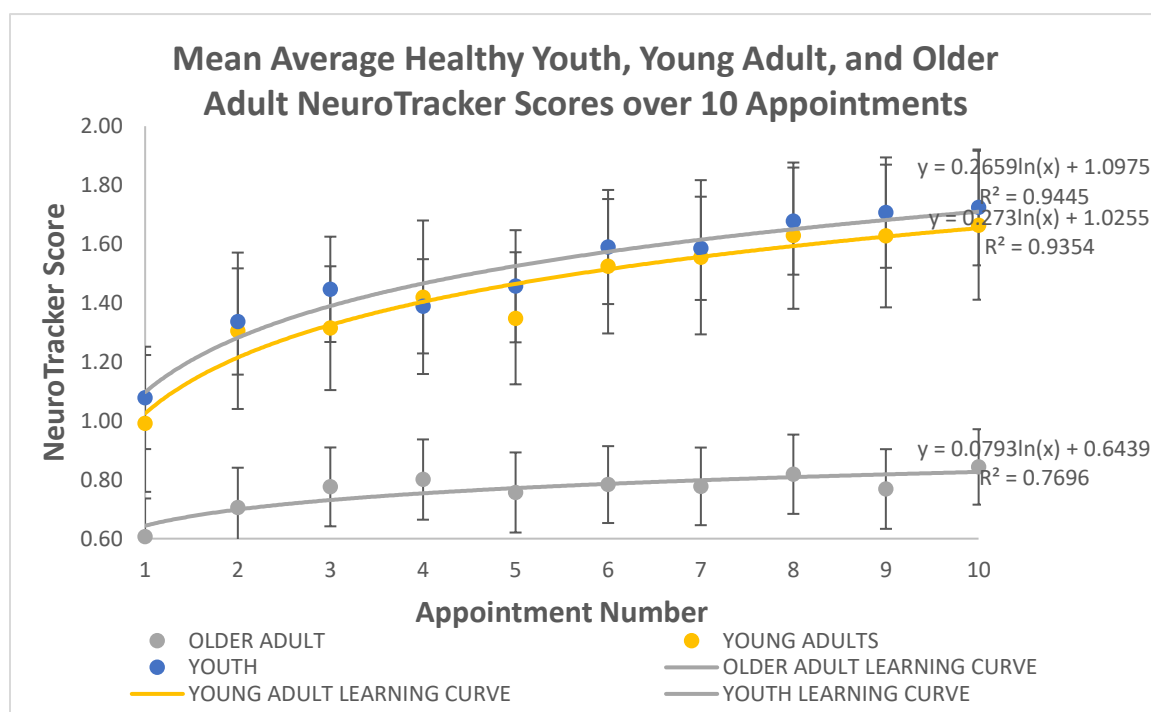


Figure 12: A Comparison of Learning Adaptions in Healthy Youth, Young Adults, and Older Adult Populations. Testing groups were divided into Older Adult (60+ yrs), Young Adult (19-35 yrs), and Youth (8-18 yrs). Data points represent the mean average speed threshold for each testing group per appointment (blue= youths, yellow= young adults, grey= older adult). This was calculated from the mean average of 3 sessions per person (Youth N=15, Young Adult N=6, Older Adult N=17) per appointment. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3months. Learning curves equation

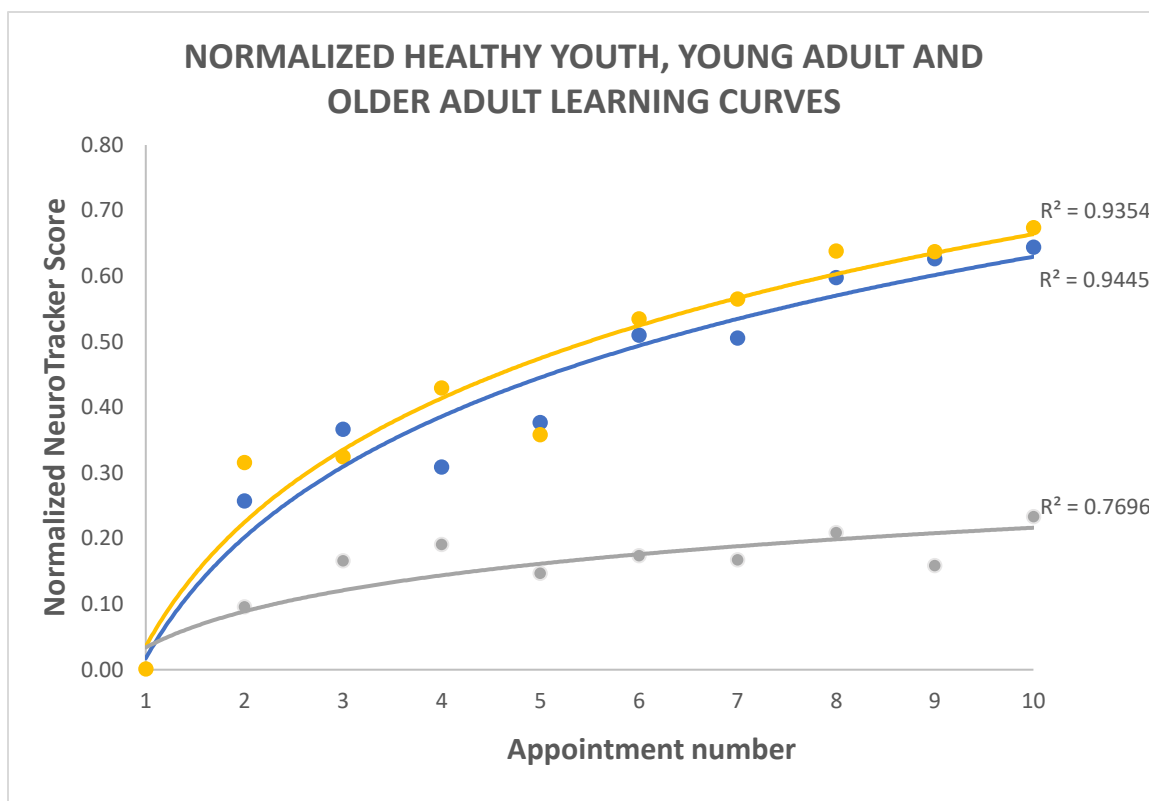


Figure 13: A Normalized Representation of Learning Adaptation in Healthy Youth, Young Adults, and Older Adults. Testing groups were divided into Older Adult (60+ yrs), Young Adult (19-35 yrs), and Youth (8-18 yrs). Data points represent the normalized mean average speed threshold for each testing group per appointment (blue= youths, yellow= young adults, grey= older adult). This was calculated from the mean average of 3 sessions per person (Youth N=15, Young Adult N=6, Older Adult N=17) per appointment, and by setting the initial appointment score to 0. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3months. Learning curves correlation are represented to the right of their respective curves.

To demonstrate perceptual cognitive adaptations, learning curves were produced per testing population (youth, young adult, and older adults). The mean average for each testing population for each appointment and their SEM were input into a ‘NT score’ versus ‘appointment number’ graph and a logarithmic trendline was fit to the data. The Youth group produced a learning curve of 0.2659 ($R^2=0.9445$). The Young Adult group produced a learning curve of 0.2730 ($R^2=0.9354$). The Older Adult group produced a learning curve of 0.0793 ($R^2=0.7696$) (Refer to Figure 12 & 13).

3.3 A Comparison of Concussed Populations using 3-Dimensional MOT Training

In total, 34 participants took part in the concussion comparison. 13(38.24%) participants were considered symptomatic (3 recently concussed, and 10 prolong concussed), 21(61.74%) participants were considered healthy (non-concussed).

Table 11. Descriptive Statistics for all Dependant Variables used in 3D-MOT training among Concussed populations Research, by Concussion Status:

	Mean	Standard Deviation
Healthy (non-concussed):		
First NT appointment Score	1.05	0.14
Final NT appointment Score	1.71	0.16
Difference between NT Scores	0.65	0.14
Slope of the Learning Curve	0.268	0.09
Symptomatic (concussed):		
First NT appointment Score	0.84	0.21
Final NT appointment Score	1.56	0.22
Difference between NT Scores	0.72	0.18
Slope of the Learning Curve	0.32	0.12
Recently Concussed (1-10 days):		
First NT appointment Score	1.09	0.46
Final NT appointment Score	1.71	0.51
Difference between NT Scores	0.61	0.24
Slope of the Learning Curve	0.3154	0.15
Prolong Concussed (1-6 months):		
First NT appointment Score	0.76	0.25
Final NT appointment Score	1.51	0.26
Difference between NT Scores	0.75	0.22
Slope of the Learning Curve	0.3354	0.14

A paired t-test was performed to verify if there was an association between symptomatic or non-concussed individuals and NT performance. No statistical significance was found between symptomatic and non-concussed individuals when comparing the difference between first and final NT scores ($t=-0.489$; $p=0.629$ from t-test), or when comparing learning adaptation based on the slope of the logarithmic best fit curve ($t=-0.928$; $p= 0.362$ from t-test) (Refer to Figure 14 & 15).

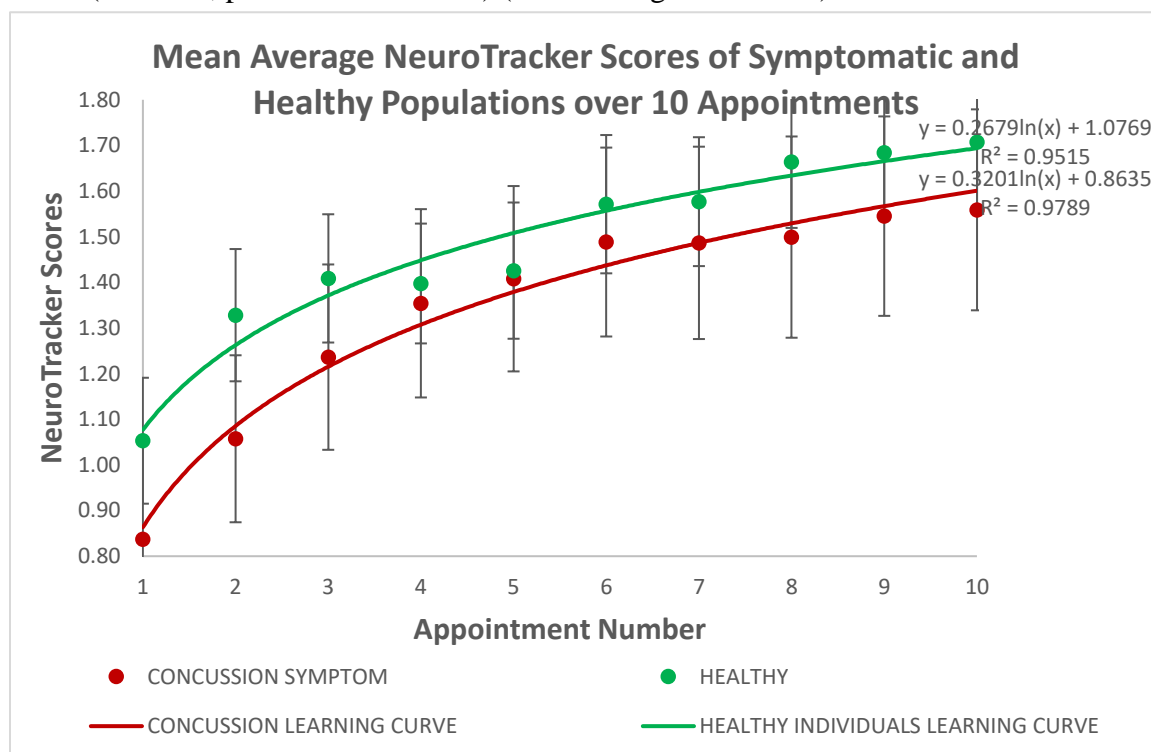


Figure 14: A Comparison of Learning Adaptation in Symptomatic and Healthy Populations. Populations are between the ages of 8 and 35 yrs. Data points represent the mean average speed threshold for each testing group per appointment (green=healthy non-concussed group, dark red= group with concussion symptoms). This was calculated from the mean average of 3 sessions per person (Symptomatic N=13, Healthy N=21) per appointment. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3months. Learning curves equation and correlation are represented to the right and slightly above and below their respective curves.

A repeated measures ANOVA was performed to verify if there was an association between recently concussed, prolong concussed and non-concussed individuals, and NT performance. No statistical significance was found between recently concussed, prolong

concussed and non-concussed individuals, and NT performance when comparing the difference between first and final NT scores ($F= 0.268$; $p= 0.767$ from ANOVA), or when comparing learning adaption based on the slope of the logarithmic best fit curve ($F= 0.421$; $p= 0.66$ from ANOVA).

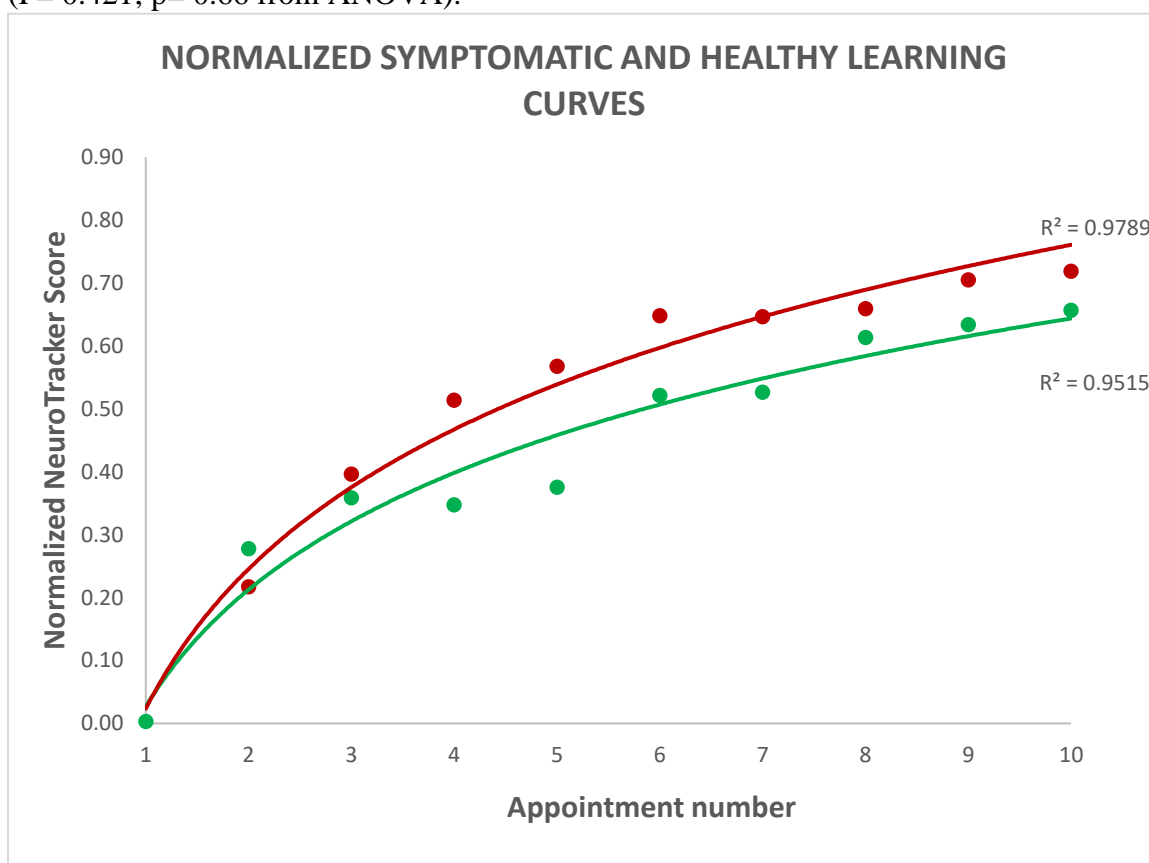


Figure 15: A Normalized Representation of Learning Adaptation in Concussed and Non-Concussed Populations. Populations are between the ages of 8 and 35 yrs. Data points represent the mean average speed threshold for each testing group per appointment (green=healthy non-concussed group, dark red= group with concussion symptoms). This was calculated from the mean average of 3 sessions per person (Symptomatic $N=13$, Healthy $N=21$) per appointment, and by setting the initial appointment score to 0. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3months. Learning curve correlations are represented to the right of their respective curves.

To demonstrate perceptual cognitive adaptations, learning curves were produced per testing population (healthy, symptomatic, recently concussed, and prolonged concussed). The mean average for each testing population for each appointment and their SEM were input into a 'NT score' versus 'appointment number' graph and a logarithmic

trendline was fit to the data. The ‘Healthy’ population produced a learning curve of 0.2679 ($R^2=0.9515$). The Symptomatic group produced a learning curve of 0.3201 ($R^2=0.9789$) (Refer to Figure 14 & 15). When the Symptomatic group is broken down into recently concussed and prolong concussed populations, a learning curve of 0.3154 ($R^2=0.94$) and 0.3354 ($R^2=0.8977$) are respectively produced (Refer to Figure 16 & 17).

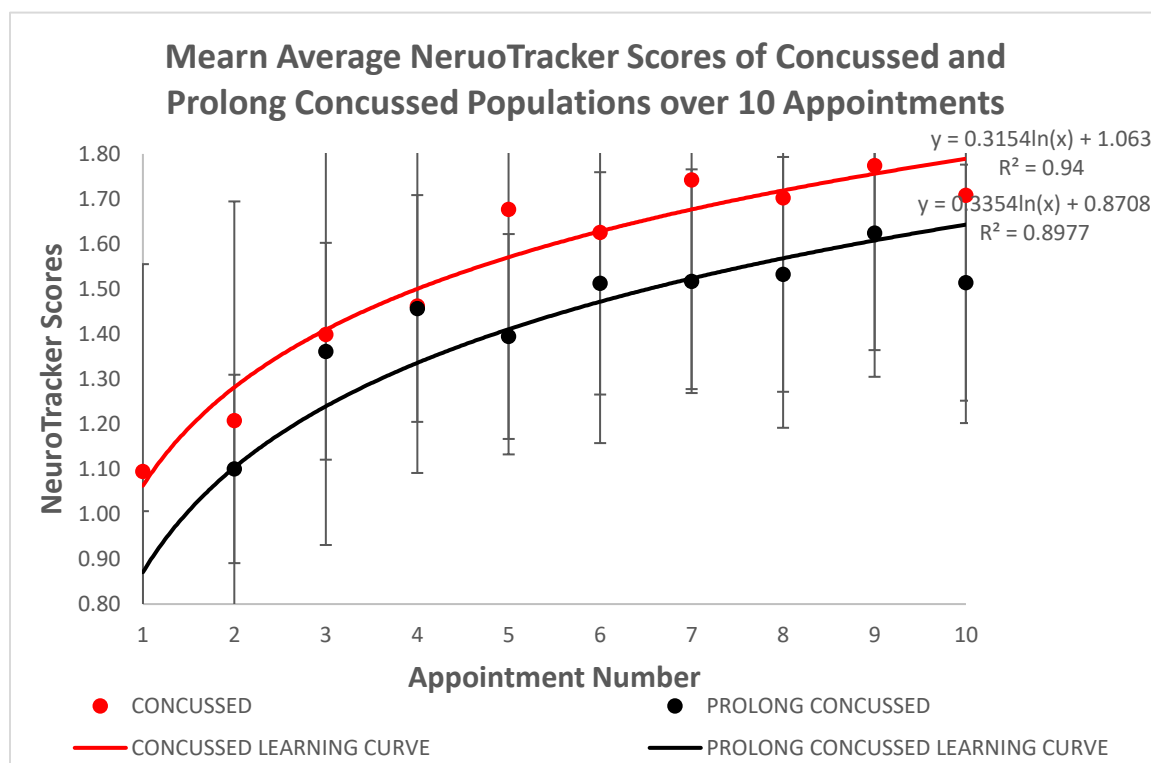


Figure 16: A Comparison of Learning Adaptations in Concussed and Prolong Concussed Populations. Symptomatic population was divided into a group of recently concussed (with in 10 days) and a group of prolong concussed (over 6 months). Data points represent the mean average speed threshold for each testing group per appointment (red =recently concussed group, black= prolong concussed). This was calculated from the mean average of 3 sessions per person (Concussed N=3, Prolong Concussed N=10) per appointment. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3months. Learning curves equation and correlation are represented to the right and slightly above their respective curves

Due to visual differences on the mean average learning curve graph (Refer to Figure 14 & 16) a repeated measures ANOVA were also performed to verify if there was an association between recently concussed, prolong concussed and non-concussed individuals and initial NT scores, as well as final NT scores. No statistical significance was found between recently concussed, prolong concussed and non-concussed individuals and NT performance when comparing the initial NT scores ($F= 1.649$; $p= 0.209$ from ANOVA), or when comparing the final NT scores ($F= 0.474$; $p= 0.627$ from ANOVA).

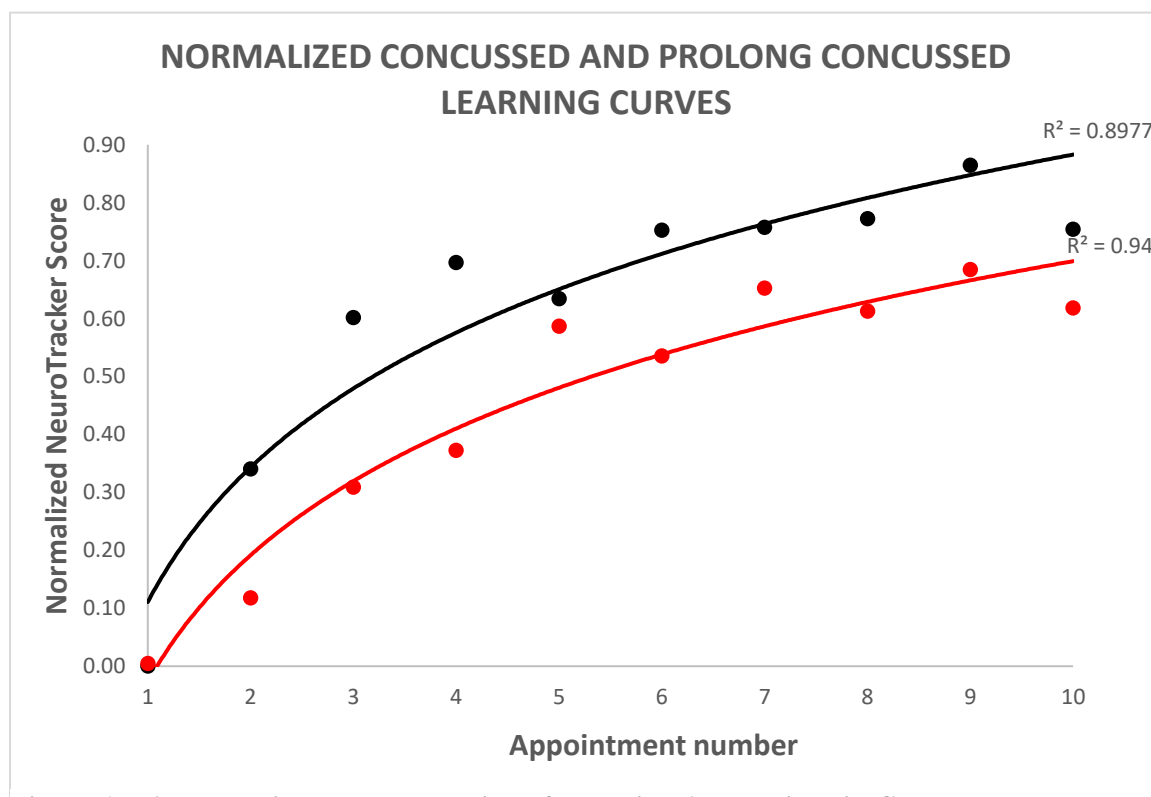


Figure 17: A Normalized Representation of Learning Adaptations in Concussed and Prolong Concussed Populations. Symptomatic population was divided into a group of recently concussed (with in 10 days) and a group of prolong concussed (over 6 months). Data points represent the mean average speed threshold for each testing group per appointment (red =recently concussed group, black= prolong concussed). This was calculated from the mean average of 3 sessions per person (Concussed N=3, Prolong Concussed N=10) per appointment, and by setting the initial appointment score to 0. Learning curves represent the logarithmic best fit trendline to these data points over 10 appointments that took place for 2-3months. Learning curve correlations are represented to the right and slightly above their respective curves

Chapter 4: Discussion and Conclusion

4.1 Discussion

This research both supports and negates the hypothesis, “the NeuroTracker will yield the same positive performance results in different populations, but not to the same degree in different environments”. Once further broken down into individual studies and hypotheses, this statement becomes more clear.

When considering a concussed population, this research supports the hypothesis, “that the NT will be able to assess an individual's concussion status, with individuals suffering from more symptoms, for longer durations of time, presenting with lower perceptual-cognitive threshold speeds upon intake, but similar to accelerated learning adaptation as training continues”. However this hypothesis is only supported in visual differences, and not significant findings.

When considering an aging population, this research significantly supports the hypothesis, “that the NT will be able to differentiate between aging individuals upon initial assessment, and when comparing learning adaptation”.

Finally, when considering the visual perceptual environment and its affect on perceptual cognitive performance, this research both supports and negates the hypothesis, “that the NT, when used in different visual perceptual representations (2D or 3D) of a 3D environment, will yield the same learning adaptation in both 2D and 3D representations of the 3D MOT training, but lower initial threshold speeds in the 2D representation”. There were no significant differences in initial threshold speeds or learning adaptation

between the groups that maintained a 2D or 3D representation, both supporting the first part of the hypothesis and negating the second.

This studies results also show a weak correlation between gender and performance in NT scores (Table 7). This could be because of limited testing populations, but it could also be an inherent demonstration of differences in the male and female brain. As this was not a focus of this research, further studies must be done to consider the differences in perceptual cognitive ability, or adaptability in different sexes.

4.1.1 A Comparison of 2-Dimensional and 3-Dimensional MOT Training

This research aimed to address questions such as “ how might different perceptual cues (2D or 3D) affect cognitive function and the acquisition of higher threshold speeds in working memory, attention, and processing speeds?” or “will learning adaption occur at the same rate despite differences in perceptual cues?”, and “can one smoothly alternate between different environments and maintain similar learning adaptations to others who maintained training within the same environment?”

In the first study, an examination of perceptual cognitive training in youth and young adults, there was a focus on determining if performance training in 3D had any advantages over 2D representations of 3D-MOT training. It was hypothesised that the brain would interpret the 3D representation more easily, because performing the task in the 2D representation would increase cognitive load, due to the need to interpret monocular cues. An inherent assumption in this study was that 2D and 3D representations of a 3D environment were interpreted differently.

A comparison of a 2-dimensional (2D) and 3-dimensional (3D) representation of 3D-Multiple Object Tracking (MOT) yielded significant differences between different environments. The 3D-MOT training or Neurotracker (NT) training scores of the 2D only group were lower than the 3D only scores for the entire duration of training (Refer to Figure 6), with a slightly lesser slope when comparing the two learning curves (Refer to Figure 7) to each other. Similarly, when switching between 2D and 3D representations of 3D-MOT, scores were lower on a per appointment basis for the 2D representation than for the 3D representation, causing a great increase in scores among the group who switched from 2D to 3D (Refer to Figure 8 & 9), and a great drop in performance (upon switch) among the group who switched from 3D to 2D (Refer to Figure 10 for best demonstration of this disruption). There was also a much higher level of variability among the individual test scores of participants who performed in the 2D representation of the 3D-MOT training. These results suggest that the representation of the environment matter. Based on the NT performance, it would seem that the brain does not process monocular cues (2D representations) for a 3D environment, either at the same rate, or at the same skill level, as it can binocular cues (3D representations) for a 3D environment. With research comparing 2D and 3D representations of a 3D environment being so limited, and a lack of full understanding into how the brain combines the different cues – including stereo, motion, vergence angle and monocular cues – for sensing motion in depth and 3D object position, not much more can be surmised.

4.1.2 The Affect Age has on 3-Dimensional MOT Training

This research aimed to address questions such as “do older adult populations associate with lower threshold speeds or learning adaptations on the NT?”.

In the second study, the relationship between perceptual cognitive performance on the NT and age were determined. It was hypothesised that NT performance would decline with increasing age, and cognitive decline. In this study, it is assumed that cognitive decline was associated with age, and would produce changes in perceptual-cognitive performance on the NT

Past literature illustrates an expectation of decline in cognitive flexibility as one ages. Based on the strong correlation of age and its ability to predict differences in NT scores, this study falls in line with past results. For example, when comparing age in the form of groupings (youth, young adults, and older adults) and its association with NT performance differences between first and final NT scores (Refer to Table 9), and learning adaption (Refer to Figure 12 & 13), significant differences were found. Similarly, when a linear regression was applied to age and NT performance differences between first and final NT scores, and learning adaptations, a significantly strong inverse correlation was found (Refer to Figure 11).

Though statistical significance was demonstrated, the population of adults (age 35-60) were not included in any of the calculations. This was due to a lack of completion of training or ineligibility due to changes in health status (becoming concussed). Further studies will need to be conducted to verify these findings.

High levels of similarity in youth and young adult NeuroTracker scores (staying within a 3% difference of each other) are not congruent with previous literature, however, they do open the door for future research across individuals ages 8 to 35 (Refer to Table 9 & Figure 12 & 13) and aid in the inclusion of this age range in our comparison of concussed populations.

4.1.3 A Comparison of Concussed Populations using 3-Dimensional MOT Training

This research aimed to address questions such as “does a prolonged concussed population associate with lower threshold speeds (or performance) on the NT than a recently concussed, or non-concussed population?” and “can the NT be an effective tool for perceptual cognitive training in all populations?”.

In the final study, a concussed population was examined to determine if the NT could be an effective tool for diagnosing perceptual cognitive deficits and potentially even serve as a means for decreasing these deficits over a ten-session training regime. This final study was greatly dependant on the honesty of the participants. As all studies were completely anonymous and were strictly for research purposes (not medical diagnostics), participants were expected to be honest about their symptoms or lack thereof (without fear of it affecting their lives).

Based on previous literature (specifically by Faubert), it can be expected that a prolonged concussed, recently concussed, and non-concussed individual will perform at slightly increasing levels of perceptual cognitive ability. It follows that NT scores should be lower among a symptomatic population in comparison to a non-symptomatic population. Since there were no significant differences between initial and final scores or

learning adaptations, when comparing symptom status or duration of concussion symptoms, within the concussion comparison populations, this research would be considered incongruent with previous literature. However, the population was limited and more testing needs to be done.

Though statistically not significant, concussed and prolong concussed individuals did associate with lower initial and final scores, demonstrating a visual difference between symptomatic and non-symptomatic individuals (Refer to Figure 14), which is in line with previous literature. Further testing will have to be done to explain how there can be visual differences in NeuroTracker scores across this testing population, and how there is no technical significance between the populations, though an N value is most likely to blame.

The high level of similarity in learning adaptation curves among non-concussed, concussed, and prolong concussed populations (Refer to Figure 14-17) is extremely encouraging and can be considered an important contribution to the current body of work on the NeuroTracker as a rehabilitation tool. In fact, this study suggests accelerated rates of learning adaptation in prolong concussed, over concussed, and lastly non-concussed populations, suggesting the initial (visually lower) NeuroTracker scores of a symptomatic individual, could approach that of a healthy individual over longer training periods (Refer to Figure 15 &17).

4.1.4 Implications of Research

This research supports previous literature by Faubert, Beachamp, Parsons, and many more, that state: perceptual cognitive training using 3D-MOT via the NeuroTracker

represents a unique type of training that could ultimately enhance athletic performance or quality of life in all populations.

The NeuroTracker could be a new means to assess concussion and aid in return-to-play (RTP) processes. The enhanced cognitive ability and improvements in analytical behaviors such as problem solving, comprehension speed and learning ability (Parsons, B., et al., 2016) demonstrated in past literature, suggest that the NeuroTracker has direct benefit to an aging population with decline in executive and cognitive function as well. Since two-dimensional cues for the 3D-MOT environment proved to be proficient in maintaining perceptual-cognitive enhancement, this computerized technology is accessible to all.

Through dissemination of information, the results of this research could influence training programs for athletes, older adults, and concussed individuals. It would do so by showing how training and improving visual perceptual skills can enhance cognitive abilities, athletic performance, and facilitate recovery from concussion.

Similarly, for the individuals who took part in the study, by training perceptual-cognitive ability, by stimulating: working memory, attention, and processing speeds of the individuals who participated in this study, their ability to react and function in their own everyday life situations should improve. Thus, increasing their quality of life, either through decrease in concussion symptom, risk of future incident, or cognitive decline due to age.

This research also aids in the validation of the NeuroTracker as a perceptual cognitive training tool, as all populations did increase in performance.

4.1.4 Limitations

A limitation present in this research, is the use of a convenient sample, allowing for only local comparison. Delimitations, are the use of three separate studies, to ensure there would be no confounding of variables, thus allowing concussion status, age, and environmental cues all to be compared independent of each other.

The most impeding limitation in this research, was the N value. Participants regularly dropped out of the study prior to completion of all 10 appointments. The use of an at home training device may be of use to lessen the degree to which drop out rates occurred, or the shortening of required appointments for analysis (possibly to five rather than 10). Participants also were moved from one population group to another (in the case of the concussion comparison) due to changes in concussion symptom and status, also greatly changing the N value of certain populations in certain studies. The most notable underpowered population, was the recently concussed population in the concussion comparison. N values were also decreased in each individual study, and the research comparison as a whole, due to screening and exclusion of individuals representative of multiple variables, for example, an older adult with a history of concussion, would be excluded from the age comparison, or a young adult who becomes concussed while training in the 2D perception, would be excluded from all comparisons.

4.2 Conclusion/Summary

Whether in different environments, of different ages or concussion status, training on the NeuroTracker progressed the cognitive load required to perform the task at hand.

The NeuroTracker did this by adapting the stimuli to constantly be pushing the perceptual cognitive threshold speed through a logarithmic scale that reacts to a participant's success or failure. Each trials success or failure produced a new threshold speed, constantly both testing and training the participant's perceptual cognitive ability, indicating the NeuroTracker as an excellent perceptual cognitive training and testing tool.

Significantly different levels of learning adaptations did occur depending on environmental representation (2D or 3D) and age. This suggests the use of 3D-MOT training in either the 2D or 3D perceptual environment, but not alternating between the two, should perceptual-cognitive comparison and adaptation be the goal. These differences in learning adaptation among aging populations, are also congruent with literature suggesting aging is associated with cognitive decline. Interestingly, concussion status did not seem to have any effect on the individual's ability to move forward, suggesting that this form of perceptual cognitive training can be very beneficial to symptomatic individuals, as their rate of learning adaptation is no less than a healthy individual. This study even suggests prolonged concussed individuals would greatly benefit from the use of perceptual-cognitive training as a means to advance their rehabilitation.

Further investigation is required to verify these results. The addition of a population between the ages of 35-60 could strengthen the significance at which age correlates with NT performance. The addition of more recently concussed individuals, who maintain training, and do not progress to a prolonged concussed status may also add significance to the concussed status population comparison. Finally, the addition of other tools, such as an EEG, to monitor brain activity, or the testing of biomarkers to aid in

segregation of individuals into different symptomatic populations would also be of great use in solidifying findings in all population comparisons.

References

- Barry, S. R. (2012). Beyond the critical period. Acquiring stereopsis in adulthood. In Plasticity in Sensory Systems. *Cambridge University Press*, 187-188.
- Beauchamp, P., & Faubert, J. (2011). Visual Perception Training: Cutting Edge Psychophysics and 3D Technology Applied to Sport Science. *High Performance CIRCUIT e-Journal*.
- Blake, R., & Sekuler, R. (2006). Perception fifth edition. *McGraw-Hill*, New York, NY.
- Bolouri, H., et al. (2012). Animal model for sport-related concussion; ICP and cognitive function. *Acta Neurologica Scandinavica*, 124, 241-247.
- Born, R. T., & Bradley, D. C. (2005). Structure and function of visual area MT. *Annual Review of Neuroscience*, 28: 157-189.
- Broshek, D. K., De Marco, A. P., & Freeman, J. R. (2015). A review of post-concussion syndrome and psychological factors associated with concussion. *Brain Injury*, 29(2), 228-237.
- Brosseau-Lachaine, O., et al. (2008). Mild Traumatic Brain Injury Induces Prolonged Visual Processing Deficits in Children. *Brain Injury*, 22(9), 657-668.
- Chen, J., et al. (2008). Neural substrates of symptoms of depression following concussion in male athletes with persisting post-concussion symptoms. *Archives of General Psychiatry*, 65, 81-89.
- Ciuffreda, K. J., et al. (2008). Vision therapy for oculomotor dysfunction in acquired brain injury: A retrospective analysis. *Optometry*, 79, 18-22.

- Clarke, L.A., Genat, R. C., & Anderson, J. F. I. (2012). Long-term cognitive complaint and post-concussive symptoms following mild traumatic brain injury: the role of cognitive and affective factors. *Brain Injury*, 26, 298-307.
- Covassin, T., Elbin, R., & Stiller-Ostrowski, J. L. (2009). Current Sport-Related Concussion Teaching and Clinical Practices of Sports Medicine Professionals. *J Athl Train*, 44(4), 400–404.
- Desimone, R., & Duncan, J. (1995). Neural Mechanisms of Selective visual attention. *Annual Review of Neuroscience*, 18: 193-222.
- Didehbani, N., et al. (2013). Depressive symptoms and concussion in aging retired NFL players. *Archives of Clinical Neuropsychology*, 28, 418-424.
- Domini, F., et al. (2006). Stereo and motion information are not independently processed by the visual system. *Vision Research*, 46(11): 1707-1723.
- Etkin, A., (2010). Functional neuroanatomy of anxiety: a neural circuit perspective. *Current Topics in Behavioral Neuroscience*, 2, 251-277.
- Etkin, A. (2012). Neurobiology of anxiety: from neural circuits to novel solutions? *Depression & Anxiety*, 29, 355-358.
- Fahle, M. (1987). Wozu zwei Augen? [Why two eyes?]. *Naturwissenschaften*, 74: 383-385.
- Faubert, J. (2012). Neurotracker as Supportive indicator for RTP decision making. *CogniSens Athletics*.
- Faubert, J., & Sidebottom, L. (2012). Perceptual-Cognitive Training of Athletes. *Journal of Clinical Sport Psychology*, 6, 85-102.

- Faubert, J. (2013). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. *Scientific Reports*, 3, 1154.
- Fine, I., & Jacobs, R. A. (1995). Modeling the Combination of Motion, Stereo, and Vergence Angle Cues to Visual Depth. *Neural Computation*, 11(6): 1297-1330.
- Fehr, L. A., et al. (1983). Coordination of perspectives: the importance of stimulus dimensionality. *J. Gen. Psychol*, Jan; 108(1st half): 73-78.
- Fifel, T. D., & Kalra, D. (?). Persistent vertigo and dizziness after mild traumatic brain injury. *Annals of the New York Academy of Sciences (Issue: Dizziness and Balance Disorders)*.
- Fragala, M., et al. (2014). Resistance Exercise May Improve Spatial Awareness and Visual Reaction in Older Adults. *Journal of Strength and Conditioning Research*, 28(8), 2079-2087.
- Gilchrist, J., et al. (2009). Nonfatal Traumatic Brain Injuries Related to Sports and Recreation Activities Among Persons Aged <19 years—United States, 2001-2009. *Div of Injury Response, National Center for Injury Prevention and Control, CDC*.
- Greffou, S., et al. (2008). Development of visually driven postural reactivity: A fully immersive virtual reality study. *Journal of Vision*, 8(11), 15, 1-10.
- Griesbach, G. S. (2011). Exercise after traumatic brain injury: is it a double-edged sword? *Physical Medicine & Rehabilitation*, 3, S64-S72.
- Griesbach, G. S., et al. (2004). Voluntary exercise following traumatic brain injury: brain-derived neurotrophic factor upregulation and recovery of function. *Neuroscience*, 125, 129-139.

- Griesbach, G. S., Gomez-Panilla, F., & Hovda, D. A. (2007). Time window for voluntary exercise-induced increases in hippocampal neuroplasticity molecules after traumatic brain injury is severity dependent. *Journal of Neurotrauma*, 24, 1161-1171.
- Guskiewicz, K. M., et al. (2007). Recurrent concussion and risk of depression in retired professional football players. *Medicine & Science in Sports & Exercise*, 39, 903-909.
- Harmon, K. G., et al. (2013). American Medical Society for Sports Medicine position statement: concussion in sport. *Br J Sports Med*, 47, 15-26.
- Hart, J. K. M., et al. (2013). Neuroimaging of cognitive dysfunction and depression in aging retired NFL players: a cross-sectional study. *JAMA Neurology*, 70, 326-335.
- Heitger, M. H., et al. (2009). Impaired eye movements in post-concussion syndrome indicate suboptimal brain function beyond the influence of depression, malingering or intellectual ability. *Brain*, 132, 2850-2870.
- Hiroshi, B., et al. (2012). The integration of motion and disparity cues to depth in dorsal visual cortex. *Nature Neuroscience*, 15(4): 636-643.
- Howard, I. P., & Rogers, B. J. (1995). Binocular vision and stereopsis. *New York: Oxford University Press*.
- Howard, I. P., & Rogers, B. J. (2012). Perceiving in Depth. *New York: Oxford University Press*, Vol.3.
- Igarashi, et al. (2014). Effects of stimulation by three-dimensional natural images on prefrontal cortex and autonomic nerve activity: a comparison with stimulation using two-dimensional images. *Cogn. Process*, Nov; 15(4): 551-556.
- Iverson, G. L., & Lange, R. T. (2011). Mild traumatic brain injury. In: Schoenberg MG, Scott JG, editors. *The little black book of neuropsychology*, 697-720.

Kastner, S., & Ungerleider, L. G. (2000). Mechanisms of Visual Attention in the Human Cortex. *Annual Review of Neuroscience*, 23: 315-341.

Kay, T., et al. (1992). Toward a neuropsychological model of functional disability after mild traumatic brain injury. *Neuropsychology*, 6, 371-384.

Kennedy, J. E., et al. (2007). Posttraumatic stress disorder and posttraumatic stress disorder-like symptoms and mild traumatic brain injury. *Journal of Rehabilitation Research & Development*, 44, 895-920.

Kerr, Z. Y., et al. (2012). Nine-year risk of depression diagnosis increases with increasing self-reported concussions in retired professional football players. *American Journal of Sports Medicine*, 40, 2206-2212.

Kolb, B., & Whishaw, I. Q. (2009). *Fundamentals of Human Neuropsychology* sixth edition.

Landy, M. S., et al. (1995). Measurement and modeling of depth cue combination: in defense of weak fusion. *Vision Research*, 35(3): 389-412.

Legault, I., et al. (2012). Healthy older observers show equivalent perceptual-cognitive training benefits to young adults for multiple object tracking. *Frontiers in Psychology*.

Legault, I., & Faubert, J. (2012). Perceptual-cognitive training improves biological motion perception: evidence for transferability of training in healthy aging. *NeuroReport*, 23, 469-473.

Mangine, G. T., et al. (2014). Visual tracking speed is related to basketball-specific measures of performance in NBA players. *J Strength Cond Res*, 28(9), 2406-2414.

- McCrory, P., et al. (2013). Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *British Journal of Sports Medicine*, 47, 250-258.
- Montgomery, G. K. (1995). A multi-factor account of disability after brain injury: implication for neuropsychological counselling. *Brain Injury*, 9, 453-469.
- Mucha, A., et al. (2014). A Brief Vestibular/Ocular Motor Screening (VOMS) Assessment to Evaluate Concussions. *Am J Sports Med*, 42(10), 2479-2486.
- Neubauer. Aljoscha, C., et al. (2010). Two- vs. Three-dimensional presentation of mental rotation tasks: Sex differences and effects of training on performance and brain activation. *Intelligence*, 38(5), 529-539.
- Parsons, B., et al. (2014). Enhancing Cognitive Function Using Perceptual-Cognitive Training. *Clinical EEG and Neuroscience*, 17: 1-11.
- Patankar, & Padasalagi. (2017). Three-dimensional versus two-dimensional laparoscopy in urology: A randomized study. *Indian J. Urol.* Jul-Sep; 33(3): 226-229.
- Patterson, R. (2009). Unresolved issues in stereopsis: dynamic disparity processing. *Spatial Vision*, 22(1): 83-90.
- Pavlou, M., et al. (2013). Randomized Trial of Supervised Versus Unsupervised Optokinetic Exercise in Persons with Peripheral Vestibular Disorders. *Neurorehabilitation Neural Repair*, 27, 208.
- Perico, C., et al. (2014). The effect of feedback on 3D multiple object tracking performance and its transferability to other attentional tasks. *Journal of Vision*, 14, 357.
- Ponsford, J., et al. (2012). Predictors of post-concussive symptoms 3 months after mild traumatic brain injury. *Neuropsychology*, 26, 304-313.

- Purves, D., et al. (2012). Neuroscience fifth edition.
- Put, Koen, et al. (2014). The use of 2D and 3D information in perceptual-cognitive judgement task. *Journal of Sport Sciences*, 32(18).
- Ryokai, K., et al. (2013). Assessing multiple object tracking in young children using a game. *Education Tech Research Dev*, 61, 153-170.
- Romeas, T., Guldner, A., & Faubert, J. (2016). 3D-Multiple Object Tracking training task improves passing decision-making accuracy in soccer players. *Psychology of Sports and Exercise*, 22, 1-9.
- Silverberg, N. D., & Iverson, G. L. (2011). Etiology of the post-concussion syndrome: physiogenesis and psychogenesis revisited. *NeuroRehabilitation*, 29, 317-329.
- Stanfield, C. I. (2011). Principles of human physiology fourth edition.
- Thiebaut de Schotten, M., et al. (2012). Subdivision of the occipital lobes: An anatomical and functional MRI connectivity study. *Cortex*, Special issue: Research report, 1-17.
- Trick, L., Perl, T., & Sethi, N. (2005). Age-Related Differences in Multiple-object tracking. *Journal of Gerontology: Psychological Sciences*, 60B (2), 102-105.
- Tyler, Jodie. (2015). The Science of Vision: How do our eyes see?
<https://www.independent.co.uk/life-style/health-and-families/features/the-science-of-vision-how-do-our-eyes-see-10513902.html>
- Van Essen, D. C. (1979). Visual Areas of the Mammalian Cerebral Cortex. *Annual Review of Neuroscience*, 2: 227-263.
- Yammine, & Violato. (2015). A meta-analysis of the educational effectiveness of three-dimensional visualization technologies in teaching anatomy. *Anat. Sci. Educ.*, Nov-Dec; 8(6): 525-538.

Appendix

Appendix A – Participant Consent Form

An Examination of Visual Perceptual Training

Participants Selection

You have been invited to participate in a study that is being conducted by Dr. Brian Christie and graduated students at the University of Victoria. You are being invited to participate in this study because you are

- A) between the ages of 11 and 59 years of age and nonconcussed
- B) between the ages of 11 and 59 years of age and suffering from concussion symptoms, either prolonged or current.

Your participation is voluntary and you are under no obligation to participate in this study, and that should you experience a concussion, training can continue, however the tests used in our research laboratory are not intended to take the place of a proper evaluation by your doctor.

Dr. Christie, Ph.D. is a faculty member in the Division of Medical Sciences at the University of Victoria and you may contact him by phone (250)472-4244 or email brain64@uvic.ca should you have further questions.

This research is being funded by the Canadian Institute for Health Research and the Canada Foundation for Innovation. This research is not not being funded by CogniSens Inc. though Dr. Christie has purchased software used by numerous professional sports teams from them and is sharing de-identified data with them.

Purpose and Objectives

Research has demonstrated that visual perceptual training using the NeuroTracker can improve sport performance in elite athletes as well as aid in recovery speeds post-concussion. For

example, higher scores on the NeuroTracker are related to better performance in professional athletes. NHL, NFL, and pro soccer players have been found to have better visual perceptual skills when compared to adult amateur athletes and non-athletes. However, whether visual perceptual training is beneficial to young athletes or general populations has not yet been examined. The extent to which visual perceptual training aids the recovery process requires more research as well. For this reason, we are interested in learning more about how visual perceptual training may improve sporting performance in young athletes as well as the recovery process. We will also examine how performance in youth athletes compares to local young adults. Because visual perceptual training may differ across age span, we will be considering elder populations and how visual perceptual training effects attention and memory.

This work will also examine how effective using visual perceptual tools can be in helping parents, teachers, trainers/coaches, and health professionals train athletes as well as determine when an individual has recovered from concussion and can return to their usual activities (e.g., physical activity, school/work). This is a research study and individuals who experience a concussion should see a medical doctor for advice/clearance regarding return to sport and other activities.

Importance of this Research

Concussions are a form of mild traumatic brain injury. Any blow to the head, face, neck, or to the body that causes a sudden shaking or jarring of the brain inside the skull may cause a concussion. Concussions can affect how an individual thinks and may cause a variety of cognitive and physical symptoms (e.g.,). Although there are many tools available for managing concussion, most concussion management programs are not evidence-based and have little to no research to help support their use. If Multiple Object Tracking (MOT) can aid in the management of concussion, it is likely that MOT prior to concussion should decrease injury percentages as well. In this case visual perceptual training using the NeuroTracker MOT program may represent a unique type of training that could be used as a

performance training for young people, adults and elderly. It can be also used as a rehabilitation plan for individuals having cognitive impairments, because there is evidence to suggest that a history of concussion can increase a person's risk of developing Alzheimer's disease.

What is involved?

If you choose to participate in any of the following cohorts, you will be asked to complete:

Cohort A & B (MOT Training): baseline and/or post-injury testing, as well as 10 or more consolidating training sessions. If you have not completed baseline testing, you will still be invited to do post-injury testing.

1. Initial Baseline 3D NeuroTracker Training (1 session – 30minutes):

At this testing session, you will complete a short questionnaire about your background (health and demographics)- You will complete 1 session (3 rounds) of multiple object tracking (MOT) training on the NeuroTracker program. For this session, you will be required to sit in a chair in front of a large computer. On a large screen you will see 8 yellow-colored balls, 4 of which will turn red and then will turn back to yellow. You will be instructed to track the 4 balls that changed color. Once the balls have stopped moving, you will be asked to identify the balls that had previously changed to red. The balls will be numbered and you will be required to identify which balls they tracked using the numbers below the balls. You will also complete related visual spatial testing, a simple test of reaction time. You will be asked to fill out questionnaires about symptoms you are experiencing and how you respond to these symptoms. This session will take about 45 mins. All training is non-invasive.

2. Consolidation (9 - 40 sessions – 30 minutes each):

Participants will come in for 9 or more sessions (3 rounds each session) of training during the consolidation phase. These training

sessions will follow the same protocol explained above, without the initial paperwork. Appointments should take 25-30 minutes. Participants will be encouraged to continue to schedule training on the NeuroTracker 2-3 times per week, if possible. There are no risks to training every day so participants may book as frequently as their schedules allow.

Cohort A and B(Other Training):

1. Initial Baseline and Final Session Testing (1 session – 30 minutes):

Participants included into the populations of concussed and non-concussed individuals age 11-60 years old will also complete testing at baseline and exit to help validate the training they have done on the NeuroTracker. This testing may or may not include: the Godin Leisure Time – Exercise Questionnaire to assess activity level, the MOT and Related Concussion Assessment Form and a Brain Injury Questionnaire to assess and track concussion symptoms, the third edition of the Sport Concussion Assessment Test, a Reaction Time test, the King Devick test, and a Visual Ocular Motor Screen to validate the NeuroTracker as an effective tool to assess/train/rehabilitate individuals in sport or who have a concussion.

1. Sport-Specific Training (10 - 30 sessions – 30 minutes each)

After the initial 10 sessions, we will add sports specific activities to the NeuroTracker training. You will complete sports specific activity while completing the NeuroTracker sessions. First, you will perform the NeuroTracker while standing/balancing (10 - 20 sessions) and then you will perform the NeuroTracker + sport specific task (e.g. puck handling, basketball dribbling, etc.) (10 sessions). During the sports specific training phase, participants will complete 1 round of NeuroTracker training only (without the sports specific training) every 5 rounds. This will be done to establish current NeuroTracker performance.

2. Return to play and other activities will be decided on by your family physician.

Any test results collected as a part of this research study can be made available to your physician upon request.

Inconvenience

Participation in this study should cause little inconvenience. We are asking you to schedule regular weekday appointments, which may cause a slight inconvenience to you. We will work together to develop a flexible schedule of training that will be acceptable for both parties. We suggest coming in regularly (i.e. 2 to 3 times per week) but you may come in more or less frequently depending on your schedules.

Risks

There are no known or anticipated risks to you by participating. Though, participants in Cohort B may experience physical effects of eyestrain as a result of completing computerized training sessions with the Neurotracker. This can include symptoms such as redness and itchiness of eyes, and, in rare cases, headaches, backaches, and fatigue. To reduce these risks, you will be given a 5-minute break at the end of each run during the Neurotracker session. We will also ask for you to report any symptoms should they occur.

Benefits

The study will use a perceptual training task to assess and help individuals improve their focus and scanning abilities. By improving an individual's visual skills and providing a qualitative measure of their perceptual abilities, we hope to not only help athletes improve their visual perceptual performance, but also prevent situations that may lead to injury.

Concussions are common and as such are a major public health concern. Decreasing percentages of concussion in sport and establishing best practice guidelines developed through research to help direct the timing, intensity and duration of post-injury care is important. This research program focuses on validating MOT and visual spatial tools that may help provide definitive guidelines on management and recovery of concussions. It may also help

determine the amount of time it takes for a concussed individual to return to their baseline. This work will potentially generate improvements in sport and a decrease in concussion incidents.

As the commercial rights holder of the of the 2D or 3D perceptual-cognitive NeuroTracker, Cognisens Athletics Inc. is interested in validating the NeuroTracker as a performance training tool that could be used by coaches, parents and/or training staff. Cognisens Athletics Inc. is not funding this research.

Voluntary Participation

Your participation in this research must be completely voluntary. If you participate, you may withdraw at any time without any consequences or any explanation. If you withdraw from the study data will be used only if you give permission.

On-going Consent

To make sure that you continue to consent to participate in this research, we will schedule all appointments well in advance and provide you with a summary of dates and times. You will initial and date and on-going consent form at the beginning of each session.

Cohort A and B: Subsequent to any head injury, it will be up to you to contact us to determine the best time for you to start post-injury sessions. We will work together to develop a schedule of testing that will be acceptable for both parties. Our preferred minimum follow-up testing schedule for anyone suffering a concussion is 1, 3, 5, 7, 14, and 28 days post-concussion. This strict timeline is not mandatory, but will greatly assist our research on post-concussion recovery.

Anonymity

In terms of protecting your anonymity, a number will be assigned to you so that names will not be used. Loss of anonymity may occur due to the nature of this research in that only those with head injuries will be re-tested on the NeuroTracker. All attempts will be made to ensure your data remain anonymous. No links or codes will be

provided to Cognisens Athletics Inc. to allow participants to be re-identified.

Confidentiality

Your confidentiality and the confidentiality of the data will be protected by storing all data in a password-protected computer program (i.e., NeuroTracker system) and excel file. All paperwork will be stored in a locked filing cabinet. De-identified NeuroTracker data will also be shared with and stored by Cognisens Inc. Cognisens Inc. may use this de-identified data for future analyses. You will also be provided with a randomly generated number so that your data are not stored with your personal information electronically. Both UVic and CogniSens Athletics Inc. acknowledge that CogniSens Athletics Inc. shall be entitled to disclose the existence and nature of this collaboration for internal and commercial purposes and retain and use any and all information, data or results emanating from the collaboration provided that CogniSens Athletics Inc. shall not in any way, directly identify or associate such results with the participants in the study.

Dissemination of Results

It is anticipated that the results of this study will be shared with others in the following ways:

- 1) Directly to participants and/or the parents of the participants via Summary Reports;
- 2) Published articles;
- 3) Presentations at scholarly meetings;
- 4) Company promotions (Cognisens Inc., CBI).

Disposal of Data

Data from this study will be stored in locked filing cabinets and password protected computer files for 10 years after which, all hard copies of the data collected relating to the study will be shredded. De-identified electronic data will be stored indefinitely in a password protected database by Cognisens Athletics Inc. (but will remain de-identified) and the principal investigator will delete all electronic files after 10 years.

Future Use of Data *PLEASE SELECT 1 OF THE STATEMENTS BELOW:*

I consent to the use of my data in future UVic research:
_____ (Participant to provide initials)

I **do not** consent to the use of my data in future UVic research:
_____ (Participant to provide initials)

I consent to be contacted in the event my data is requested for future UVic research: _____ (Participant to provide initials)

Contacts

Individuals that may be contacted regarding this study include:

Erika Shaw,

Phone: (250) 889-4108

Email: erikas073@live.com

Dr. Brian Christie,
(250)634-4471

Phone: (250) 472-4244 or

Email: brainlab@uvic.ca

In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

Your signature below indicates that you understand the above conditions of participation in this study, that you have had the opportunity to have your questions answered by the researchers, and that you give your consent for your child to participate in this research project.

*Name of
Participant*

*Signature of Participant
Date*

Name of Parent/Guardian

Signature of Parent/Guardian

Date

Appendix B – Participant Assent Form

Division of Medical Sciences
University of Victoria

Participant Assent Form

ASSENT TO BE IN A RESEARCH STUDY ABOUT CONCUSSIONS

The following script is to be read to all children 11-12 years old.

Why are we meeting with you?

We want to tell you about something we are doing called a research study. A research study is when doctors collect a lot of information to learn more about something. We are doing a study to learn more about children with head injuries. After we tell you about it, we will ask if you'd like to be in this study or not.

Why are we doing this study?

We want to find out how well our computer game helps us learn about what happens when children hurt their heads playing sports, so we are getting information from lots of boys and girls like you. In the whole study, there will be over 1000 children and adults.

What will happen to you if you are in this study?

1. You will be asked to play our computer game for about 20-30 minutes. This is the same computer game that players in the National Hockey League use to help them train.
2. If you ever hurt your head you'll be able to come back and play the game again.
3. If you have already hurt your head, you can still come in and play the game.

You will also complete a couple quick tests of your thinking and balance and reaction time,

The purpose of playing this game and testing is we think it can help us figure out when it will be safe for you to play sports and other activities again. You'll be able to play the game as many times as it takes to help you do as well on it as before you got hurt, and when you feel ready, you can go see your doctor again and see if he also thinks you're ready return to sports and other activities. We want you to have a great time play sports and doing your usual activities.

Do you have any questions?

You can ask questions any time. You can ask now. You can ask later. You can talk to me or you can talk to someone else and have them talk to me.

Do you have to be in this study?

No, you don't. No one will be mad at you if you don't want to do this. If you don't want to be in this study, just tell us. Or if you do want to be in the study, tell us that. And, remember, you can say yes now and change your mind later. It's all up to you.

SIGNATURE OF PERSON CONDUCTING ASSENT DISCUSSION

I have explained the study to _____ (*print name of child here*) in language he/she can understand, and the child has agreed to be in the study.

Appendix C – Intake Form/ Medical History

Group		Participant Number	
DOB (yyyy/mm/dd)		Gender	
Date (yyyy/mm/dd)		Baseline or Post-Injury	

MOT AND RELATED TESTING – INTAKE FORM

CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			

EMERGENCY CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			
Relationship to You			

GENERAL INFORMATION			
Height (ft)		Weight (lbs)	
Age		DOB (yyyy/mm/dd)	

Gender		Highest Education Level	
<u>Marital Status</u>			
What hand do you write with?			
<u>How many languages do you speak fluently?</u>			
<u>Is English your first language?</u>			

MEDICAL INFORMATION	
<u>Do you have any incidence of heart attack/cardiovascular problems?</u>	
<u>Have you ever had a stroke?</u>	
<u>Are you currently diagnosed with high blood pressure?</u>	
<u>Are you currently diagnosed with Diabetes?</u>	
Have you ever been diagnosed with a Major Neurocognitive Disorder (e.g. Alzheimer's Disease, Lewy Body Dementia, Vascular Dementia, Frontotemporal Dementia)?	
Have you ever been diagnosed with visual blindness or color blindness?	
Have you ever been diagnosed with a visual or auditory disorder that cannot be corrected?	

EXTRA CURRICULARS			
List any instruments you play		For how many years?	
Do you play video games?		For how many hrs/wk?	

CURRENT SPORT PARTICIPATION			
SPORT	POSITION	LEVEL	YEARS

CONCUSSION HISTORY	
Have you ever had a concussion?	
Date of most recent concussion (yyyy/mm/dd)	
How many concussions have you had in total?	

SPECIFIC CONCUSSION HISTORY				
Date of Concussion (yyyy/mm/dd)	Did you lose consciousness?	Were you playing sport?	Did you see a Doctor?	How long did it take to Return to Play?

--	--	--	--	--

NOTES

Division of Medical Sciences University of Victoria

Appendix E – Godin Leisure Time – Exercise Questionnaire

Godin Leisure-Time Exercise Questionnaire

INSTRUCTIONS

In this excerpt from the Godin Leisure-Time Exercise Questionnaire, the individual is asked to complete a self-explanatory, brief four-item query of usual leisure-time exercise habits.

CALCULATIONS

For the first question, weekly frequencies of strenuous, moderate, and light activities are multiplied by nine, five, and three, respectively. Total weekly leisure activity is calculated in arbitrary units by summing the products of the separate components, as shown in the following formula:

$$\text{Weekly leisure activity score} = (9 \times \text{Strenuous}) + (5 \times \text{Moderate}) + (3 \times \text{Light})$$

The second question is used to calculate the frequency of weekly leisure-time activities pursued "long enough to work up a sweat" (see questionnaire).

EXAMPLE

Strenuous = 3 times/wk

Moderate = 6 times/wk

Light = 14 times/wk

$$\text{Total leisure activity score} = (9 \times 3) + (5 \times 6) + (3 \times 14) = 27 + 30 + 42 = 99$$

Godin Leisure-Time Exercise Questionnaire

1. During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

	Times Per Week
a) STRENUOUS EXERCISE (HEART BEATS RAPIDLY) (e.g., running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)	_____

**b) MODERATE EXERCISE
(NOT EXHAUSTING)**

(e.g., fast walking, baseball, tennis, easy bicycling,
volleyball, badminton, easy swimming, alpine skiing,
popular and folk dancing)

**c) MILD EXERCISE
(MINIMAL EFFORT)**

(e.g., yoga, archery, fishing from river bank, bowling,
horseshoes, golf, snow-mobiling, easy walking)

2. During a typical **7-Day period** (a week), in your leisure time, how often do you engage in any regular activity **long enough to work up a sweat** (heart beats rapidly)?

OFTEN

SOMETIMES

NEVER/RARELY

1.

2.

3.

Appendix F- Leisure Activity Questionnaire

LEISURE ACTIVITY QUESTIONNAIRE

Daniel Eriksson Sorman et al. (2013)

Participant Number

INSTRUCTION

For each activity, please indicate your frequency of participation in the last three months, using the following codes:

0 = NEVER

1 = OCCASIONALLY

2 = A FEW TIMES A MONTH

3 = A FEW TIMES PER WEEK

4 = EVERY DAY

1.	Travel/Trips	0	1	2	3	4
2.	Restaurants visits	0	1	2	3	4
3.	Spending time with family, relatives and friends	0	1	2	3	4
4.	Attending Courses/Workshops	0	1	2	3	4
5.	Religious assemblies	0	1	2	3	4
6.	Association work	0	1	2	3	4
7.	Sports/Exercise/Walking in the forest or parks	0	1	2	3	4
8.	Hunting/ Fishing	0	1	2	3	4
9.	Reading books	0	1	2	3	4
10	Reading magazines	0	1	2	3	4
11	Reading newspapers	0	1	2	3	4
12	Watching TV/ Listening to the radio	0	1	2	3	4
13	Movies/Concerts/Theatre	0	1	2	3	4
14	Playing a musical instrument	0	1	2	3	4
15	Needlework	0	1	2	3	4
16	Other hobbies/Activities	0	1	2	3	4

Appendix G – International Physical Activity Questionnaire for the Elderly

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH MIDDLE-AGED ADULTS AND ELDERLY

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health-related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an *International Physical Activity Prevalence Study* is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L.

(2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

_____ **days per week**

No vigorous physical activities



Skip to question 3

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

_____ **hours per day** _____ **minutes per day**

Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

No moderate physical activities



Skip to question 5

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day** _____ **minutes per day**

Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

No walking



Skip to question 7

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day** _____ **minutes per day**

Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

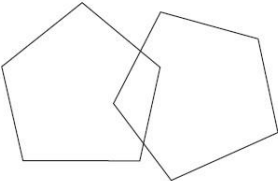
_____ **hours per day** _____ **minutes per day**

Don't know/Not sure

Appendix H – Mini Mental Examination Scale

STANDARDIZED MINI-MENTAL STATE EXAMINATION
(MMSE)

	QUESTION	TIME ALLOWED	SCORE
1	a. <i>What year is this?</i>	10 seconds	/1
	b. <i>Which season is this?</i>	10 seconds	/1
	c. <i>What month is this?</i>	10 seconds	/1
	d. <i>What is today's date?</i>	10 seconds	/1
	e. <i>What day of the week is this?</i>	10 seconds	/1
2	a. <i>What country are we in?</i>	10 seconds	/1
	b. <i>What province are we in?</i>	10 seconds	/1
	c. <i>What city/town are we in?</i>	10 seconds	/1
	d. <i>IN HOME – What is the street address of this house?</i> <i>IN FACILITY – What is the name of this building?</i>	10 seconds	/1
	e. <i>IN HOME – What room are we in? IN FACILITY – What floor are we on?</i>	10 seconds	/1
3	SAY: I am going to name three objects. When I am finished, I want you to repeat them. Remember what they are because I am going to ask you to name them again in a few minutes. Say the following words slowly at 1-second intervals - ball/ car/ man	20 seconds	/3
4	Spell the word WORLD. Now spell it backwards.	30 seconds	/5
5	Now what were the three objects I asked you to remember?	10 seconds	/3
6	SHOW wristwatch. ASK: What is this called?	10 seconds	/1
7	SHOW pencil. ASK: What is this called?	10 seconds	/1
8	SAY: I would like you to repeat this phrase after me: No ifs, ands or buts.	10 seconds	/1
9	SAY: Read the words on the page and then do what it says. Then hand the person the sheet with CLOSE YOUR EYES on it. If	10 seconds	/1

	the subject reads and does not close their eyes, repeat up to three times. Score only if subject closes eyes		
1 0	HAND the person a pencil and paper. SAY: Write any complete sentence on that piece of paper. (Note: The sentence must make sense. Ignore spelling errors)	30 seconds	/1
1 1	PLACE design, eraser and pencil in front of the person. SAY: Copy this design please.  Allow multiple tries. Wait until person is finished and hands it back. Score only for correctly copied diagram with a 4-sided figure between two 5-sided figures.	1 minute	/1
1 2	ASK the person if he is right or left-handed. Take a piece of paper and hold it up in front of the person. SAY: Take this paper in your right/left hand (whichever is nondominant), fold the paper in half once with both hands and put the paper down on the floor . Score 1 point for each instruction executed correctly. Takes paper correctly in hand Folds it in half Puts it on the floor	30 seconds	/1 /1 /1
TOTAL TEST SCORE			/30

Note: This tool is provided for use in British Columbia with permission by Dr. William Molloy. This questionnaire should not be further modified or reproduced without the written consent of Dr. D. William Molloy.

Provided by the Alzheimer's Drug Therapy Initiative for physician use.
GLOBAL DETERIORATION SCALE (GDS)

Stage	Deficits in cognition and function	Usual care setting
1	Subjectively and objectively normal	Independent
2	<ul style="list-style-type: none"> • Subjective complaints of mild memory loss. • Objectively normal on testing. 	Independent

	<ul style="list-style-type: none"> No functional deficit 	
3	Mild Cognitive Impairment (MCI) <ul style="list-style-type: none"> Earliest clear-cut deficits. Functionally normal but co-workers may be aware of declining work performance. Objective deficits on testing. Denial may appear. 	Independent
4	Early dementia <ul style="list-style-type: none"> Clear-cut deficits on careful clinical interview. Difficulty performing complex tasks, e.g. handling finances, travelling. Denial is common. Withdrawal from challenging situations. 	Might live independently – perhaps with assistance from family or caregivers.
5	Moderate dementia <ul style="list-style-type: none"> Can no longer survive without some assistance. Unable to recall major relevant aspects of their current lives, e.g. an address or telephone number of many years, names of grandchildren, etc. Some disorientation to date, day of week, season, or to place. They require no assistance with toileting, eating, or dressing but may need help choosing appropriate clothing. 	At home with live-in family member. In seniors' residence with home support. Possibly in facility care, especially if behavioural problems or comorbid physical disabilities.
6	Moderately severe dementia <ul style="list-style-type: none"> May occasionally forget name of spouse. Largely unaware of recent experiences and events in their lives. Will require assistance with basic ADLs. May be incontinent of urine. 	Most often in Complex Care facility.

	<ul style="list-style-type: none"> • Behavioural and psychological symptoms of dementia (BPSD) are common, e.g., delusions, repetitive behaviours, agitation. 	
7	<p>Severe dementia</p> <ul style="list-style-type: none"> • Verbal abilities will be lost over the course of this stage. • Incontinent. Needs assistance with feeding. • Loses ability to walk. 	Complex Care

Adapted by Dr. Doug Drummond from Reisberg B, Ferris SH, Leon MJ, et al. The global deterioration scale for assessment of primary degenerative dementia. American Journal of Psychiatry 1982;139:1136-1139.

Provided by the Alzheimer's Drug Therapy Initiative for physician use.

Appendix I – Memory Complaint Questionnaire

176

T. H. Crook, III, E. P. Feher, and G. J. Larrabee

APPENDIX

Memory Complaint Questionnaire (MAC-Q)

As compared to when you were in high school or college, how would you describe your ability to perform the following tasks involving your memory?

	Much better now (1)	Somewhat better now (2)	About the same (3)	Somewhat poorer now (4)	Much poorer now (5)
1. Remembering the name of a person just introduced to you					
2. Recalling telephone numbers or zip codes that you use on a daily or weekly basis					
3. Recalling where you have put objects (such as keys) in your home or office					
4. Remembering specific facts from a newspaper or magazine article you have just finished reading					
5. Remembering the item(s) you intended to buy when you arrive at the grocery store or pharmacy					
6. In general, how would you describe your memory as compared to when you were in high school?	(2)	(4)	(6)	(8)	(10)

Total Score _____

Appendix J – Geriatric Depression Scale

The Geriatric Depression Scale (GDS)

By: Sherry A. Greenberg, PhD(c), MSN, GNP-BC,
Hartford Institute for Geriatric Nursing, NYU College of Nursing

WHY: Depression is common in late life, affecting nearly 5 million of the 31 million Americans aged 65 and older with clinically significant depressive symptoms reaching 13% in older adults aged 80 and older (Blazer, 2009). Major depression is reported in 8-16% of community dwelling older adults, 5-10% of older medical outpatients seeing a primary care provider, 10-12% of medical-surgical hospitalized older adults with 23% more experiencing significant depressive symptoms (Blazer, 2009). Recognition in long-term care facilities is poor and not consistent amongst studies (Blazer, 2009).

Depression is not a natural part of aging. Depression is often reversible with prompt recognition and appropriate treatment. However, if left untreated, depression may result in the onset of physical, cognitive, functional, and social impairment, as well as decreased quality of life, delayed recovery from medical illness and surgery, increased health care utilization, and suicide.

BEST TOOL: While there are many instruments available to measure depression, the Geriatric Depression Scale (GDS), first created by Yesavage, et al., has been tested and used extensively with the older population. The GDS Long Form is a brief, 30-item questionnaire in which participants are asked to respond by answering yes or no in reference to how they felt over the past week. A Short Form GDS consisting of 15 questions was developed in 1986. Questions from the Long Form GDS which had the highest correlation with depressive symptoms in validation studies were selected for the short version. Of the 15 items, 10 indicated the presence of depression when answered positively, while the rest (question numbers 1, 5, 7, 11, 13) indicated depression when answered negatively. Scores of 0-4 are considered normal, depending on age, education, and complaints; 5-8 indicate mild depression; 9-11 indicate moderate depression; and 12-15 indicate severe depression.

The Short Form is more easily used by physically ill and mildly to moderately demented patients who have short attention spans and/or feel easily fatigued. It takes about 5 to 7 minutes to complete.

TARGET POPULATION: The GDS may be used with healthy, medically ill and mild to moderately cognitively impaired older adults. It has been extensively used in community, acute and long-term care settings.

VALIDITY AND RELIABILITY: The GDS was found to have a 92% sensitivity and a 89% specificity when evaluated against diagnostic criteria. The validity and reliability of the tool have been supported through both clinical practice and research. In a validation study comparing the Long and Short Forms of the GDS

for self-rating of symptoms of depression, both were successful in differentiating depressed from non-depressed adults with a high correlation ($r = .84, p < .001$) (Sheikh & Yesavage, 1986).

STRENGTHS AND LIMITATIONS: The GDS is not a substitute for a diagnostic interview by mental health professionals. It is a useful screening tool in the clinical setting to facilitate assessment of depression in older adults especially when baseline measurements are compared to subsequent scores. It does not assess for suicidality.

FOLLOW-UP: The presence of depression warrants prompt intervention and treatment. The GDS may be used to monitor depression over time in all clinical settings. Any positive score above 5 on the GDS Short Form should prompt an in-depth psychological assessment and evaluation for suicidality.

Geriatric Depression Scale: Short Form

Choose the best answer for how you have felt over the past week:

1. Are you basically satisfied with your life? YES / **NO**
2. Have you dropped many of your activities and interests? **YES** / NO
3. Do you feel that your life is empty? **YES** / NO
4. Do you often get bored? **YES** / NO
5. Are you in good spirits most of the time? YES / **NO**
6. Are you afraid that something bad is going to happen to you? **YES** / NO
7. Do you feel happy most of the time? YES / **NO**
8. Do you often feel helpless? **YES** / NO
9. Do you prefer to stay at home, rather than going out and doing new things?
YES / NO
10. Do you feel you have more problems with memory than most? **YES** / NO
11. Do you think it is wonderful to be alive now? YES / **NO**
12. Do you feel pretty worthless the way you are now? **YES** / NO
13. Do you feel full of energy? YES / **NO**
14. Do you feel that your situation is hopeless? **YES** / NO
15. Do you think that most people are better off than you are? **YES** / NO

Answers in **bold** indicate depression. Score 1 point for each bolded answer.

A score > 5 points is suggestive of depression.

A score \geq 10 points is almost always indicative of depression.

A score > 5 points should warrant a follow-up comprehensive assessment.

The Hartford Institute for Geriatric Nursing would like to acknowledge the original author of this Try This, Lenore Kurlowicz, PhD, RN, CS, FAAN, who made significant contributions to the field of geropsychiatric nursing and passed away in 2007.

Appendix K – MOT and Related Concussion Assessment Form

Group		Participant Number	
DOB (yyyy/mm/dd)		Gender	

MOT AND RELATED POST-CONCUSSION INFORMATION

DID YOU/YOUR CHILD EXPERIENCE A HEAD INJURY (A DIRECT OR INDIRECT BLOW TO THE HEAD) RESULTING IN CONCUSSION-LIKE SYMPTOMS (EG. HEADACHE, NAUSEA, BALANCE PROBLEMS, TIREDNESS, VISUAL PROBLEMS, COGNITIVE ISSUES)?

YES	NO
-----	----

Current Date (yyyy/mm/dd)	
Date of Injury (yyyy/mm/dd)	
Time of Injury (hh:mm)	
Did you lose consciousness?	
Duration of loss of consciousness (min)	
Mechanism of Injury	
Location of Injury	

LIST OF SYMPTOMS

NOTES

Appendix L – Brian Injury Questionnaire

Appendix G: Quality of Life After Brain Injury

In the first part of this questionnaire we would like to know how satisfied you are with different aspects of your life since your brain injury. For each question please choose the answer which is closest to how you feel now (including the past week) and mark the box with an "X." If you have problems filling out the questionnaire, please ask for help.

PART 1

A. These questions are about your thinking abilities now (including the past week).

1. How satisfied are you with your ability to concentrate, for example when reading or keeping track of a conversation?

Not at all Slightly Moderately Quite Very

2. How satisfied are you with your ability to express yourself and understand others in a conversation?

Not at all Slightly Moderately Quite Very

3. How satisfied are you with your ability to remember everyday things, for example where you have put things?

Not at all Slightly Moderately Quite Very

4. How satisfied are you with your ability to plan and work out solutions to everyday practical problems, for example what to do when you lose your keys?

Not at all Slightly Moderately Quite Very

5. How satisfied are you with your ability to make decisions?

Not at all Slightly Moderately Quite Very

6. How satisfied are you with your ability to find your way around?

Not at all Slightly Moderately Quite Very

7. How satisfied are you with your speed of thinking?

Not at all Slightly Moderately Quite Very

B. These questions are about your emotions and view of yourself now (including the past week).

1. How satisfied are you with your level of energy?

Not at all Slightly Moderately Quite Very

2. How satisfied are you with your level of motivation to do things?

Not at all Slightly Moderately Quite Very

3. How satisfied are you with your self-esteem, how valuable you feel?

Not at all Slightly Moderately Quite Very

4. How satisfied are you with the way you look?

Not at all Slightly Moderately Quite Very

5. How satisfied are you with what you have achieved since your brain injury?

Not at all Slightly Moderately Quite Very

6. How satisfied are you with the way you perceive yourself?
 Not at all Slightly Moderately Quite Very
7. How satisfied are you with the way you see your future?
 Not at all Slightly Moderately Quite Very

C. These questions are about your independence and how you function in daily life now (including the past week).

1. How satisfied are you with the extent of your independence from others?
 Not at all Slightly Moderately Quite Very
2. How satisfied are you with your ability to get out and about?
 Not at all Slightly Moderately Quite Very
3. How satisfied are you with your ability to carry out domestic activities, for example cooking or repairing things?
 Not at all Slightly Moderately Quite Very
4. How satisfied are you with your ability to run your personal finances?
 Not at all Slightly Moderately Quite Very
5. How satisfied are you with your participation in work or education?
 Not at all Slightly Moderately Quite Very
6. How satisfied are you with your participation in social and leisure activities, for example sports, hobbies, parties?
 Not at all Slightly Moderately Quite Very
7. How satisfied are you with the extent to which you are in charge of your own life?
 Not at all Slightly Moderately Quite Very

D. These questions are about your social relationships now (including the past week).

1. How satisfied are you with your ability to feel affection towards others, for example your partner, family, friends?
 Not at all Slightly Moderately Quite Very
2. How satisfied are you with your relationships with members of your family?
 Not at all Slightly Moderately Quite Very
3. How satisfied are you with your relationships with your friends?
 Not at all Slightly Moderately Quite Very
4. How satisfied are you with your relationship with a partner or with not having a partner?
 Not at all Slightly Moderately Quite Very
5. How satisfied are you with the attitudes of other people towards you?
 Not at all Slightly Moderately Quite Very

PART 2

In the second part we would like to know how bothered you feel by different problems. For each question please choose the answer which is closest to how you feel now (including the past

week), and mark the box with an “X.” If you have problems filling out the questionnaire, please ask for help.

E. These questions are about how bothered you are by your feelings now (including the past week).

- | | | | | | |
|---|------------|----------|------------|-------|------|
| 1. How bothered are you by feeling lonely, even when you are with other people? | Not at all | Slightly | Moderately | Quite | Very |
| 2. How bothered are you by feeling bored? | Not at all | Slightly | Moderately | Quite | Very |
| 3. How bothered are you by feeling anxious? | Not at all | Slightly | Moderately | Quite | Very |
| 4. How bothered are you by feeling sad or depressed? | Not at all | Slightly | Moderately | Quite | Very |
| 5. How bothered are you by feeling angry or aggressive? | Not at all | Slightly | Moderately | Quite | Very |

F. These questions are about how bothered you are by physical problems now (including the past week).

- | | | | | | |
|---|------------|----------|------------|-------|------|
| 1. How bothered are you by slowness and/or clumsiness of movement? | Not at all | Slightly | Moderately | Quite | Very |
| 2. How bothered are you by effects of any other injuries you sustained at the same time as your brain injury? | Not at all | Slightly | Moderately | Quite | Very |
| 3. How bothered are you by pain, including headaches? | Not at all | Slightly | Moderately | Quite | Very |
| 4. How bothered are you by problems with seeing or hearing? | Not at all | Slightly | Moderately | Quite | Very |
| 5. Overall, how bothered are you by the effects of your brain injury? | Not at all | Slightly | Moderately | Quite | Very |

Adapted from: von Steinbüchel, N., Wilson, L., Gibbons, H., Hawthorne, G., Höfer, S., Schmidt, S., ... Truelle, J.-L. (2010). Quality of Life after Brain Injury (QOLIBRI): scale development and metric properties. *Journal of Neurotrauma*, 27(7), 1167–1185.

The Quality of Life after Brain Injury (QOLIBRI) questionnaire has internal consistency, test-retest reliability and is a new cross-culturally developed instrument for evaluating health-related quality of life (von Steinbüchel et al., 2009).

von Steinbüchel, N., Wilson, L., Gibbons, H., Hawthorne, G., Höfer, S., Schmidt, S., ... Truelle, J.-L. (2010). Quality of Life after Brain Injury (QOLIBRI): scale validity and correlates of quality of life. *Journal of Neurotrauma*, 27(7), 1157–1165.

Appendix M - Sport Concussion Assessment Tool – 3rd Edition



Name _____ Date/Time of Injury: _____ Examiner: _____
Date of Assessment: _____

What is the SCAT3?¹

The SCAT3 is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged from 13 years and older. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively¹. For younger persons, ages 12 and under, please use the Child SCAT3. The SCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool¹. Preseason baseline testing with the SCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the SCAT3 are provided on page 3. If you are not familiar with the SCAT3, please read through these instructions carefully. This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. Any revision or any reproduction in a digital form requires approval by the Concussion in Sport Group.

NOTE: The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The SCAT3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgement. An athlete may have a concussion even if their SCAT3 is "normal".

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific signs and/or symptoms (some examples listed below) and most often does not involve loss of consciousness. Concussion should be suspected in the presence of **any one or more** of the following:

- Symptoms (e.g., headache), or
- Physical signs (e.g., unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour (e.g., change in personality).

SIDELINE ASSESSMENT

Indications for Emergency Management

NOTE: A hit to the head can sometimes be associated with a more serious brain injury. Any of the following warrants consideration of activating emergency procedures and urgent transportation to the nearest hospital.

- Glasgow Coma score less than 15
- Deteriorating mental status
- Potential spinal injury
- Progressive, worsening symptoms or new neurologic signs

Potential signs of concussion?

If any of the following signs are observed after a direct or indirect blow to the head, the athlete should stop participation, be evaluated by a medical professional and **should not be permitted to return to sport the same day** if a concussion is suspected.

- Any loss of consciousness? Y N
"If so, how long?" _____
- Balance or motor incoordination (tumbles, slow/laboured movements, etc.)? Y N
- Disorientation or confusion (inability to respond appropriately to questions)? Y N
- Loss of memory: _____
"If so, how long?" _____
- "Before or after the injury?" _____
- Blank or vacant look: Y N
- Visible facial injury in combination with any of the above: Y N

1 Glasgow coma scale (GCS)

Best eye response (E)	
No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4
Best verbal response (V)	
No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5
Best motor response (M)	
No motor response	1
Extension to pain	2
Abnormal flexion to pain	3
Flexion/Withdrawal to pain	4
Localizes to pain	5
Obeys commands	6
Glasgow Coma score (E + V + M)	of 15

GCS should be recorded for all athletes in case of subsequent deterioration.

2 Maddocks Score³

"I am going to ask you a few questions, please listen carefully and give your best effort."
Modified Maddocks questions (1 point for each correct answer)

What venue are we at today?	0	1
Which half is it now?	0	1
Who scored last in this match?	0	1
What team did you play last week/game?	0	1
Did your team win the last game?	0	1
Maddocks score	of 5	

Maddocks score is validated for sideline diagnosis of concussion only and is not used for serial testing.

Notes: Mechanism of Injury ("tell me what happened?"):

Any athlete with a suspected concussion should be REMOVED FROM PLAY, medically assessed, monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle until cleared to do so by a medical professional. No athlete diagnosed with concussion should be returned to sports participation on the day of injury.

BACKGROUND

Name: _____ Date: _____
 Examiner: _____
 Sport/team/school: _____ Date/time of injury: _____
 Age: _____ Gender: M F
 Years of education completed: _____
 Dominant hand: right left neither
 How many concussions do you think you have had in the past? _____
 When was the most recent concussion? _____
 How long was your recovery from the most recent concussion? _____
 Have you ever been hospitalized or had medical imaging done for a head injury? Y N
 Have you ever been diagnosed with headaches or migraines? Y N
 Do you have a learning disability, dyslexia, ADD/ADHD? Y N
 Have you ever been diagnosed with depression, anxiety or other psychiatric disorder? Y N
 Has anyone in your family ever been diagnosed with any of these problems? Y N
 Are you on any medications? If yes, please list: Y N

SCAT3 to be done in resting state. Best done 10 or more minutes post exercise.

SYMPTOM EVALUATION

3 How do you feel?

"You should score yourself on the following symptoms, based on how you feel now".

	none	mid	moderate	severe			
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

Total number of symptoms (Maximum possible 22) _____
Symptom severity score (Maximum possible 132) _____
 Do the symptoms get worse with physical activity? Y N
 Do the symptoms get worse with mental activity? Y N
 self rated self rated and clinician monitored
 clinician interview self rated with parent input

Overall rating: If you know the athlete well prior to the injury, how different is the athlete acting compared to his/her usual self?
 Please circle one response:
 no different very different unsure N/A

Scoring on the SCAT3 should not be used as a stand-alone method to diagnose concussion, measure recovery or make decisions about an athlete's readiness to return to competition after concussion. Since signs and symptoms may evolve over time, it is important to consider repeat evaluation in the acute assessment of concussion.

COGNITIVE & PHYSICAL EVALUATION

4 Cognitive assessment

Standardized Assessment of Concussion (SAC)⁴

Orientation (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1

Orientation score _____ of 5

Immediate memory

List	Trial 1	Trial 2	Trial 3	Alternative word list					
elbow	0	1	0	1	0	1	candle	baby	finger
apple	0	1	0	1	0	1	paper	monkey	penny
carpet	0	1	0	1	0	1	sugar	perfume	blanket
saddle	0	1	0	1	0	1	sandwich	sunset	lemon
bubble	0	1	0	1	0	1	wagon	iron	insect

Total _____

Immediate memory score total _____ of 15

Concentration: Digits Backward

List	Trial 1	Alternative digit list			
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6

Total of 4 _____

Concentration: Month in Reverse Order (1 pt. for entire sequence correct)

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0	1
--	---	---

Concentration score _____ of 5

5 Neck Examination:

Range of motion _____ Tenderness _____ Upper and lower limb sensation & strength _____
Findings: _____

6 Balance examination

Do one or both of the following tests:
 Footwear (shoes, barefoot, braces, tape, etc.) _____
Modified Balance Error Scoring System (BESS) testing⁵
 Which foot was tested (i.e. which is the non-dominant foot) Left Right
 Testing surface (hard floor, field, etc.) _____
Condition
 Double leg stance: _____ Errors
 Single leg stance (non-dominant foot): _____ Errors
 Tandem stance (non-dominant foot at back): _____ Errors
And/Or
Tandem gait^{6,7}
 Time (best of 4 trials): _____ seconds

7 Coordination examination

Upper limb coordination
 Which arm was tested: Left Right
Coordination score _____ of 1

8 SAC Delayed Recall⁴

Delayed recall score _____ of 5

Appendix N – Child - Sport Concussion Assessment Tool – 3rd Edition

Downloaded from bjsm.bmj.com on August 4, 2014 - Published by group.bmj.com

Child-SCAT3™



Sport Concussion Assessment Tool for children ages 5 to 12 years

For use by medical professionals only

What is childSCAT3?

The ChildSCAT3 is a standardized tool for evaluating injured children for concussion and can be used in children aged from 5 to 12 years. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively. For older persons, ages 13 years and over, please use the SCAT3. The ChildSCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool. Preseason baseline testing with the ChildSCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the ChildSCAT3 are provided on page 3. If you are not familiar with the ChildSCAT3, please read through these instructions carefully. This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. Any revision and any reproduction in a digital form require approval by the Concussion in Sport Group.

NOTE: The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The ChildSCAT3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgement. An athlete may have a concussion even if their ChildSCAT3 is "normal".

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific signs and/or symptoms (like those listed below) and most often does not involve loss of consciousness. Concussion should be suspected in the presence of any one or more of the following:

- Symptoms (e.g., headache), or
- Physical signs (e.g., unsteadiness), or
- Impaired brain function (e.g., confusion) or
- Abnormal behaviour (e.g., change in personality).

SIDELINE ASSESSMENT

Indications for Emergency Management

NOTE: A hit to the head can sometimes be associated with a more severe brain injury. If the concussed child displays any of the following, then do not proceed with the ChildSCAT3; instead activate emergency procedures and urgent transportation to the nearest hospital:

- Glasgow Coma score less than 15
- Deteriorating mental status
- Potential spinal injury
- Progressive, worsening symptoms or new neurologic signs
- Persistent vomiting
- Evidence of skull fracture
- Post traumatic seizures
- Coagulopathy
- History of Neurosurgery (eg Shunt)
- Multiple injuries

1 Glasgow coma scale (GCS)

Best eye response (E)	
No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4
Best verbal response (V)	
No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5
Best motor response (M)	
No motor response	1
Extension to pain	2
Abnormal flexion to pain	3
Flexion/ Withdrawal to pain	4
Localizes to pain	5
Obeys commands	6
Glasgow Coma score (E + V + M)	of 15

GCS should be recorded for all athletes in case of subsequent deterioration.

Potential signs of concussion?

If any of the following signs are observed after a direct or indirect blow to the head, the child should stop participation, be evaluated by a medical professional and **should not be permitted to return to sport the same day** if a concussion is suspected.

- Any loss of consciousness? Y N
- "If so, how long?" _____
- Balance or motor incoordination (stumbles, slow/laboured movements, etc)? Y N
- Disorientation or confusion (inability to respond appropriately to questions)? Y N
- Loss of memory: Y N
- "If so, how long?" _____
- "Before or after the injury?" _____
- Blank or vacant look: Y N
- Visible facial injury in combination with any of the above: Y N

2 Sideline Assessment – child-Maddocks Score³

"I am going to ask you a few questions, please listen carefully and give your best effort."

Modified Maddocks questions (1 point for each correct answer)

Where are we at now?	0	1
Is it before or after lunch?	0	1
What did you have last lesson/ class?	0	1
What is your teacher's name?	0	1
child-Maddocks score	of 4	

Child-Maddocks score is for sideline diagnosis of concussion only and is not used for serial testing.

Any child with a suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration (i.e., should not be left alone). No child diagnosed with concussion should be returned to sports participation on the day of injury.

BACKGROUND

Name: _____ Date/Time of Injury: _____
 Examiner: _____ Date of Assessment: _____
 Sport/team/school: _____
 Age: _____ Gender: M F
 Current school year/grade: _____
 Dominant hand: right left neither
 Mechanism of injury ("tell me what happened?"): _____

For Parent/ carer to complete:

How many concussions has the child had in the past? _____
 When was the most recent concussion? _____
 How long was the recovery from the most recent concussion? _____
 Has the child ever been hospitalized or had medical imaging done (CT or MRI) for a head injury? Y N
 Has the child ever been diagnosed with headaches or migraines? Y N
 Does the child have a learning disability, dyslexia, ADD/ADHD, seizure disorder? Y N
 Has the child ever been diagnosed with depression, anxiety or other psychiatric disorder? Y N
 Has anyone in the family ever been diagnosed with any of these problems? Y N
 Is the child on any medications? If yes, please list: Y N

SYMPTOM EVALUATION

3 Child report

Name: _____

	never	rarely	sometimes	often
I have trouble paying attention	0	1	2	3
I get distracted easily	0	1	2	3
I have a hard time concentrating	0	1	2	3
I have problems remembering what people tell me	0	1	2	3
I have problems following directions	0	1	2	3
I daydream too much	0	1	2	3
I get confused	0	1	2	3
I forget things	0	1	2	3
I have problems finishing things	0	1	2	3
I have trouble figuring things out	0	1	2	3
It's hard for me to learn new things	0	1	2	3
I have headaches	0	1	2	3
I feel dizzy	0	1	2	3
I feel like the room is spinning	0	1	2	3
I feel like I'm going to faint	0	1	2	3
Things are blurry when I look at them	0	1	2	3
I see double	0	1	2	3
I feel sick to my stomach	0	1	2	3
I get tired a lot	0	1	2	3
I get tired easily	0	1	2	3

Total number of symptoms (Maximum possible 20) _____

Symptom severity score (Maximum possible 20x3=60) _____

self rated clinician interview self rated and clinician monitored

4 Parent report

The child

	never	rarely	sometimes	often
has trouble sustaining attention	0	1	2	3
is easily distracted	0	1	2	3
has difficulty concentrating	0	1	2	3
has problems remembering what he/ she is told	0	1	2	3
has difficulty following directions	0	1	2	3
tends to daydream	0	1	2	3
gets confused	0	1	2	3
is forgetful	0	1	2	3
has difficulty completing tasks	0	1	2	3
has poor problem solving skills	0	1	2	3
has problems learning	0	1	2	3
has headaches	0	1	2	3
feels dizzy	0	1	2	3
has a feeling that the room is spinning	0	1	2	3
feels faint	0	1	2	3
has blurred vision	0	1	2	3
has double vision	0	1	2	3
experiences nausea	0	1	2	3
gets tired a lot	0	1	2	3
gets tired easily	0	1	2	3

Total number of symptoms (Maximum possible 20) _____

Symptom severity score (Maximum possible 20x3=60) _____

Do the symptoms get worse with physical activity? Y N

Do the symptoms get worse with mental activity? Y N

parent self rated clinician interview parent self rated and clinician monitored

Overall rating for parent/teacher/coach/carer to answer.
How different is the child acting compared to his/her usual self?
Please circle one response:

no different very different unsure N/A

Name of person completing Parent-report: _____

Relationship to child of person completing Parent-report: _____

Scoring on the ChildSCAT3 should not be used as a stand-alone method to diagnose concussion, measure recovery or make decisions about an athlete's readiness to return to competition after concussion.

COGNITIVE & PHYSICAL EVALUATION

5 Cognitive assessment

Standardized Assessment of Concussion – Child Version (SAC-C)*

Orientation (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1

Orientation score _____ of 4

Immediate memory

List	Trial 1	Trial 2	Trial 3	Alternative word list					
elbow	0	1	0	1	0	1	candle	baby	finger
apple	0	1	0	1	0	1	paper	monkey	penny
carpet	0	1	0	1	0	1	sugar	perfume	blanket
saddle	0	1	0	1	0	1	sandwich	sunset	lemon
bubble	0	1	0	1	0	1	wagon	iron	insect

Total _____

Immediate memory score total _____ of 15

Concentration: Digits Backward

List	Trial 1	Alternative digit list			
6-2	0	1	5-2	4-1	4-9
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6

Total of 5 _____

Concentration: Days in Reverse Order (1 pt. for entire sequence correct)

Sunday-Saturday-Friday-Thursday-Wednesday-Tuesday-Monday	0	1
--	---	---

Concentration score _____ of 6

6 Neck Examination:

Range of motion Tenderness Upper and lower limb sensation & strength

Findings: _____

7 Balance examination

Do one or both of the following tests.

Footwear (shoes, bare foot, braces, tape, etc.) _____

Modified Balance Error Scoring System (BESS) testing⁷

Which foot was tested (i.e. which is the non-dominant foot) Left Right

Testing surface (hard floor, field, etc.) _____

Condition

Double leg stance: _____ Errors

Tandem stance (non-dominant foot at back): _____ Errors

Tandem gait^{8,7}

Time taken to complete (best of 4 trials): _____ seconds

If child attempted, but unable to complete tandem gait, mark here

8 Coordination examination

Upper limb coordination

Which arm was tested: Left Right

Coordination score _____ of 1

9 SAC Delayed Recall*

Delayed recall score _____ of 5

Since signs and symptoms may evolve over time, it is important to consider repeat evaluation in the acute assessment of concussion.

Appendix O – Reaction Time Test (Ruler Drop)

Reaction Time: The Ruler Drop Test

The time it takes from when your eye first notices the ball to when your arm reaches up to catch it is an example of **reaction time**. Even though **stimuli**—or changes in your environment that you react to—travel very quickly along your nervous system as messages, your body doesn't react instantly. Many athletes spend hours practicing to improve their reaction time. In this activity, you will conduct a simple, measurable experiment (the ruler drop test) to study reaction time and determine how it can be improved with practice.

Problem

How can reaction time be measured and improved?

Materials

Metric ruler
One or more volunteers
Table
Chair

Procedure

Ask your first volunteer to sit in the chair with good upright posture and eyes looking across the room.

Have the volunteer place her forearm (the part of the arm from elbow to hand) so it extends over the edge of the table.

Ask the volunteer to place her thumb and index (pointer) finger on either side of the bottom of the vertically placed ruler. The number “1” should be on the bottom, the “30” near the top.

Let your volunteer practice holding the ruler with those two fingers.

Now, ask your volunteer to remove her fingers from the ruler while you continue hold it so that the bottom of the ruler is at a height of 2cm above her fingers.

Tell your volunteer that you will release the ruler without telling her. Her job will be to catch it with her thumb and forefinger as soon as she senses it dropping.

Drop the ruler. When your volunteer catches it, record the number on the ruler displayed just over her thumb. The lower the number, the faster her reaction time.

Conduct several trials with the same volunteer, dropping the ruler from 2cm above her fingers each time.

Make sure to record the results for each trial in a table similar to the following:

Appendix P – King-Devick Test

KING-DEVICK TEST SCORE SHEET

Subject Name: _____ Date: _____

COMMENTS: _____

ANSWER KEY CARD I	ANSWER KEY CARD II	ANSWER KEY CARD III
2-5-8-0-7	3-7-5-9-0	5-4-1-8-0
3-7-9-4-6	2-5-7-4-6	4-6-3-5-9
5-3-1-6-4	1-4-7-6-3	7-5-4-2-7
7-9-7-3-5	7-9-3-9-0	3-2-6-9-4
1-5-4-9-2	4-5-2-1-7	1-4-5-1-3
6-5-5-7-3	5-3-7-4-8	9-3-4-8-5
3-1-8-6-4	7-4-6-5-2	5-1-6-3-1
5-3-7-5-2	9-0-2-3-6	4-3-5-2-7
ERRORS: _____	ERRORS: _____	ERRORS: _____
TIME: _____	TIME: _____	TIME: _____

TOTAL ERRORS: _____

*TOTAL TIME: _____

**Do not include time between completing individual test cards – Total testing times for all three tests combined.*

RESULTS

Age	Maximum Time	Maximum Errors
Adult (Age 14 and Older)	57 Seconds	1
13	60 Seconds	1
12	68 Seconds	2
11	71 Seconds	2
10	95 Seconds	3
9	100 Seconds	4
8	107 Seconds	5
7	127 Seconds	13
6	160 Seconds	17

For more information: info@kingdevicktest.com

<p style="text-align: center;">DEMONSTRATION CARD</p>	<p style="text-align: center;">TEST I</p>																																																																																
<table style="width: 100%; border-collapse: collapse;"> <tr><td style="width: 10%;">3</td><td style="width: 10%;">7</td><td style="width: 10%;">5</td><td style="width: 10%;">9</td><td style="width: 10%;">0</td></tr> <tr><td>2</td><td>5</td><td>7</td><td>4</td><td>6</td></tr> <tr><td>1</td><td>4</td><td>7</td><td>6</td><td>3</td></tr> <tr><td>7</td><td>9</td><td>3</td><td>9</td><td>0</td></tr> <tr><td>4</td><td>5</td><td>2</td><td>1</td><td>7</td></tr> <tr><td>5</td><td>3</td><td>7</td><td>4</td><td>8</td></tr> <tr><td>7</td><td>4</td><td>6</td><td>5</td><td>2</td></tr> <tr><td>9</td><td>0</td><td>2</td><td>3</td><td>6</td></tr> </table> <p style="text-align: center;">TEST II</p>	3	7	5	9	0	2	5	7	4	6	1	4	7	6	3	7	9	3	9	0	4	5	2	1	7	5	3	7	4	8	7	4	6	5	2	9	0	2	3	6	<table style="width: 100%; border-collapse: collapse;"> <tr><td style="width: 10%;">5</td><td style="width: 10%;">4</td><td style="width: 10%;">1</td><td style="width: 10%;">8</td><td style="width: 10%;">0</td></tr> <tr><td>4</td><td>6</td><td>3</td><td>5</td><td>9</td></tr> <tr><td>7</td><td>5</td><td>4</td><td>2</td><td>7</td></tr> <tr><td>3</td><td>2</td><td>6</td><td>9</td><td>4</td></tr> <tr><td>1</td><td>4</td><td>5</td><td>1</td><td>3</td></tr> <tr><td>9</td><td>3</td><td>4</td><td>8</td><td>5</td></tr> <tr><td>5</td><td>1</td><td>6</td><td>3</td><td>1</td></tr> <tr><td>4</td><td>3</td><td>5</td><td>2</td><td>7</td></tr> </table> <p style="text-align: center;">TEST III</p>	5	4	1	8	0	4	6	3	5	9	7	5	4	2	7	3	2	6	9	4	1	4	5	1	3	9	3	4	8	5	5	1	6	3	1	4	3	5	2	7
3	7	5	9	0																																																																													
2	5	7	4	6																																																																													
1	4	7	6	3																																																																													
7	9	3	9	0																																																																													
4	5	2	1	7																																																																													
5	3	7	4	8																																																																													
7	4	6	5	2																																																																													
9	0	2	3	6																																																																													
5	4	1	8	0																																																																													
4	6	3	5	9																																																																													
7	5	4	2	7																																																																													
3	2	6	9	4																																																																													
1	4	5	1	3																																																																													
9	3	4	8	5																																																																													
5	1	6	3	1																																																																													
4	3	5	2	7																																																																													

Appendix Q – Vestibular/ocular Motor Screen

UPMC Vestibular/Ocular-Motor Screening (VOMS) for Concussion

Vestibular/Ocular Motor Test:	Not Tested	Headache 0-20	Dizziness 0-10	Nausea 0-10	Fogginess 0-10	Comments
BASELINE SYMPTOMS:	N/A					
Smooth Pursuits						
Saccades – Horizontal						
Saccades – Vertical						
Convergence (Near Point)						(Near Point in cm) Measure 1: _____ Measure 2: _____ Measure 3: _____
VOR – Horizontal						
VOR – Vertical						
Visual Motion Sensitivity Test						

Instructions:

Interpretation: This test is designed for use with subjects ages 9-40. When used with patients outside this age range, interpretation may vary. Abnormal findings or provocation of symptoms with any test may indicate dysfunction – and should trigger a referral to the appropriate health care professional for more detailed assessment and management. **Equipment:** Tape measure (cm); Metronome; Target w/ 14 point font print. **Baseline Symptoms – Record:** Headache, Dizziness, Nausea & Fogginess on 0-10 scale prior to beginning screening

- **Smooth Pursuits** - Test the ability to follow a slowly moving target. The patient and the examiner are seated. The examiner holds a fingertip at a distance of 3 ft. from the patient. The patient is instructed to maintain focus on the target as the examiner moves the target smoothly in the horizontal direction 1.5 ft. to the right and 1.5 ft. to the left of midline. One repetition is complete when the target moves back and forth to the starting position, and 2 repetitions are performed. The target should be moved at a rate requiring approximately 2 seconds to go fully from left to right and 2 seconds to go fully from right to left. The test is repeated with the examiner moving the target smoothly and slowly in the vertical direction 1.5 ft. above and 1.5 ft. below midline for 2 complete repetitions up and down. Again, the target should be moved at a rate requiring approximately 2 seconds to move the eyes fully upward and 2 seconds to move fully downward. **Record:** Headache, Dizziness, Nausea & Fogginess ratings after the test. (Figure 1)

- **Saccades** – Test the ability of the eyes to move quickly between targets. The patient and the examiner are seated.
 - **Horizontal Saccades:** The examiner holds two single points (fingertips) horizontally at a distance of 3 ft. from the patient, and 1.5 ft. to the right and 1.5 ft. to the left of midline so that the patient must gaze 30 degrees to left and 30 degrees to the right. Instruct the patient to move their eyes as quickly as possible from point to point. One repetition is complete when the eyes move back and forth to the

starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea & Foggiess ratings after the test. (Figure 2)

- Vertical Saccades: Repeat the test with 2 points held vertically at a distance of 3 ft. from the patient, and 1.5 feet above and 1.5 feet below midline so that the patient must gaze 30 degrees upward and 30 degrees downward. Instruct the patient to move their eyes as quickly as possible from point to point. One repetition is complete when the eyes move up and down to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea & Foggiess ratings after the test. (Figure 3)

- Convergence – Measure the ability to view a near target without double vision. The patient is seated and wearing corrective lenses (if needed). The examiner is seated front of the patient and observes their eye movement during this test. The patient focuses on a small target (approximately 14 point font size) at arm's length and slowly brings it toward the tip of their nose. The patient is instructed to stop moving the target when they see two distinct images or when the examiner observes an outward deviation of one eye. Blurring of the image is ignored. The distance in cm. between target and the tip of nose is measured and recorded. This is repeated a total of 3 times with measures recorded each time. Record: Headache, Dizziness, Nausea & Foggiess ratings after the test. Abnormal: Near Point of convergence ≥ 6 cm from the tip of the nose. (Figure 4)

- Vestibular-Ocular Reflex (VOR) Test – Assess the ability to stabilize vision as the head moves. The patient and the examiner are seated. The examiner holds a target of approximately 14 point font size in front of the patient in midline at a distance of 3 ft. • Horizontal VOR Test: The patient is asked to rotate their head horizontally while maintaining focus on the target. The head is moved at an amplitude of 20 degrees to each side and a metronome is used to ensure the speed of rotation is maintained at 180 beats/minute (one beat in each direction). One repetition is complete when the head moves back and forth to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea and Foggiess ratings 10 sec after the test is completed. (Figure 5) • Vertical VOR Test: The test is repeated with the patient moving their head vertically. The head is moved in an amplitude of 20 degrees up and 20 degrees down and a metronome is used to ensure the speed of movement is maintained at 180 beats/minute (one beat in each direction). One repetition is complete when the head moves up and down to the starting position, and 10 repetitions are performed. Record: Headache, Dizziness, Nausea and Foggiess ratings after the test. (Figure 6)

- Visual Motion Sensitivity (VMS) Test – Test visual motion sensitivity and the ability to inhibit vestibular-induced eye movements using vision. The patient stands with feet shoulder width apart, facing a busy area of the clinic. The examiner stands next to and slightly behind the patient, so that the patient is guarded but the movement can be performed freely. The patient holds arm outstretched and focuses on their thumb. Maintaining focus on their thumb, the patient rotates, together as a unit, their head, eyes and trunk at an amplitude of 80 degrees to the right and 80 degrees to the left. A metronome is used to ensure the speed of rotation is maintained at 50 beats/min (one beat

in each direction). One repetition is complete when the trunk rotates back and forth to the starting position, and 5 repetitions are performed. Record: Headache, Dizziness, Nausea & Foggiess ratings after the test. (Figure 7

Appendix R – Withdraw form

DOB (yyyy/mm/dd)		Participant Number	
------------------	--	--------------------	--

I have decided to withdraw from this study. I acknowledge that I am withdrawing from this study at my own free will and will not face any consequence for withdrawing my participation

- I consent to the use of data collected prior to the withdrawal date noted below. Data collected prior to the withdrawal will be used for analysis and publication purposes.
- I do not consent to the use of data collected prior to the withdrawal date noted below. Data collected prior to the withdrawal will not be used for analysis and publication purposes.

Withdrawal Date:

Participant Name:

Participant Signature:

Appendix S – Instructions for Athletes in case of concussion

Instruction for Athletes following a Concussion

Following a concussion, please contact the concussion lab or a lab technician (Phone: (250)472-5997 or (250)634-4471 (lab cell), email: brainlab@uvic.ca , or erikas3@uvic.ca (Erika Shaw)) to book a follow-up assessment.

The assessment will include sessions on the Neurotracker, the Sports Concussion Assessment Tool- Third Edition, the King-Devick Test, the Ruler Reaction Time Test, and Visual Oculomotor Screening.

Athletes are asked to come in for testing 24-72 hours following a concussion – the sooner, the better. Athletes will continue sessions will continue with follow-up testing every few days until symptoms resolve. Sessions will take 30-45 minutes.

When athletes are symptom free for 24 hours, they can begin return to play procedures.

Our preferred follow-up testing schedule is 1, 3, 5, 7, 14 and 28 days post-concussion. This is not mandatory, but would greatly assist our research on post-concussion recovery.

Appendix T – Certificate of Ethical Approval

Certificate of Renewed Approval
Certification

This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria Research Regulations Involving Human Participants.

17-167

PROJECT TITLE: An Examination of Visual Perceptual Training

28-Jun-17

APPROVAL EXPIRY DATE: 27-Jun-19

Brian Christie

RENEWED ON: 11-Jun-18

PRINCIPAL INVESTIGATOR:

DMSCUVic DEPARTMENT:

DECLARED PROJECT FUNDING: 1. Canada Foundation for Innovation; 2. CogniSens Athletics

Certificate Issued On: 11-Jun-18

Lab Coordinator: Caroline Spaner, UVic; Research Assistants/Graduate Students (UVic): Erika Shaw, Stella Musteata

UVic STATUS: Faculty

RESEARCH TEAM MEMBER

Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a "Request for Renewal" form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.

17-167 Christie, Brian

Appendix U - Three-Dimensional Multiple Object Tracking/The NeuroTracker

