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DEVELOPMENTAL ASSESSMENT OF MOTOR & COGNITIVE SKILLS

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DEVELOPMENTAL ASSESSMENT OF MOTOR & COGNITIVE SKILLS

by

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Report

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Kinesiology

The University of Texas at Austin

December 2014

Dedication

I would like to dedicate my efforts in completion of this degree to my Father for his generosity & love, to my Mother for her support & love and to Lauren for her patience & love. I owe everything to God for being there for me when I was not there for myself.

Acknowledgements

I would like to acknowledge Dr. Jody Jensen for her guidance in my work, Dr. Lawrence Abraham for being my second reader on short notice and to Dr. Malcolm Conway for his inspiration & mentorship over the years.

Abstract

Developmental Assessment of Motor & Cognitive Skills

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The University of Texas at Austin, 2014

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ABSTRACT: The C3 Logix system (i-comet technologies, 2013) is a portable evaluation tool on the iPad Air tablet computer that is currently being used as for screening concussion severity in an athlete population. The application employs a neurocognitive exam that is comprised of a battery of tests to evaluate both cognition and motor skills: reaction time, memory, processing time, postural stability, vision, and the vestibulo-ocular reflex. With the exclusion of the concussion screening questionnaire, the C3 Logix program may be an effective, portable tool to study developmental changes in executive function.

The Developmental Motor and Cognition Laboratory at The University of Texas at Austin has begun a project to 1) create a functional test battery from the C3 Logix system that is portable, simple and reliable in measuring motor development in children.

The extant literature contains reports on individual measures of executive function as they change with age. However, the C3 Logix system provides a battery of data on the same individual that may allow for coupling of the executive function data with an assessment of motor skills into a full data collection of multiple measures. The assessment protocol developed in this report will also include functional performance measures to complement the executive function data of the C3 Logix system. The inclusion of functional assessments will yield a tool that is capable of screening for physical readiness to engage in activities that demand greater movement competence. For example, activities of competitive sport require both decision making (executive function) and physical ability for safe and satisfactory execution.

The objective of this report is to support this project in three ways: 1) Create an annotated bibliography for background understanding of the tests in the C3 Logix System. 2) Consult with the literature to devise procedures for administration of three function performance tests that challenge the individual's performance capability beyond basic fundamental motor competency, and 3) complement the description of the selected functional performance tests with video demonstrations.

Table of Contents

List of Tables

List of Figures

List of Illustrations

INTRODUCTION

C3 LOGIX ASSESSMENT BATTERY

The C3 Logix system (i-comet technologies, 2013) is a portable evaluation tool on the iPad Air tablet computer that is currently being used as for screening concussion severity in an athlete population. The application employs a neurocognitive exam that is comprised of a battery of tests to evaluate both cognition and motor skills: reaction time, memory, processing time, postural stability, vision, and the vestibulo-ocular reflex. With the exclusion of the concussion screening questionnaire, the C3 Logix program may be an effective, portable tool to study developmental changes in executive function.

The extant literature contains reports on individual measures of executive function as they change with age. However, the C3 Logix system provides a battery of data on the same individual that may allow for coupling of the executive function data with an assessment of motor skills into a full data collection of multiple measures. The assessment protocol developed in this report will also include functional performance measures to complement the executive function data of the C3 Logix system. The inclusion of functional assessments will yield a tool that is capable of screening for physical readiness to engage in activities that demand greater movement competence. For example, activities of competitive sport require both decision making (executive function) and physical ability for safe and satisfactory execution.

The Developmental Motor and Cognition Laboratory at The University of Texas at Austin has begun a project to 1) create a functional test battery from the C3 Logix system that is portable, simple and reliable in measuring motor development in children. 2) to create a normative database of the functional performance measures for children between the age group 7-14 years using the C3 Logix assessment battery and selected functional performance tests.

ESTABLISHING PHYSICAL READINESS TO PLAY

Functional performance skills demand greater movement competence than fundamental motor skills. Functional performance skills (FPS) are specific, complex movement skills that present an increased performance challenge over fundamental motor skills (FMS). Activities of FPS offer an intermediate context for challenging one's movement competence between FMS and competitive sport or recreational activities. FMS are the building blocks of recreational and sporting skills, but they are typically self-paced and performed under controlled conditions to scale the challenge.

As a child ages, they become involved in games and activities that promote skill development. In athletic activities, the FMS will provide the basis for throwing movements. These can then be developed into the sporting skill for throwing a ball from the outfield to home plate or throwing a javelin. The FMS of hopping becomes the athletic skill for cutting on a football field or for complex jumping like the triple jump. Functional performance skills are not sport specific, but are complex movements that challenge the basic motor abilities of the performer. A functional performance skill of simple hopping can be upgraded to a more challenging FPS of continuous hopping for a specified time period, or hopping along a prescribed course. A FMS of jumping can be progressed to the FPS of jumping for multiples (bounding) or in multiple directions. The activities of FPS reveal more about an individual's balance or strength under more challenging conditions than the simple tests of balance most often used in the developmental literature.

Developmentally, we know a great deal about the age-related expectations for competence in the fundamental movement skills. The leap from FMS to athletic performance, however, is great. The gap between individuals receiving a clinical diagnosis related to poor motor function and the "average" performer accounts for approximately 15% of the population (those between -1 and -2 standard deviations from the mean). Children on the lower ends of the performance scale are typically encouraged to participate in sport and recreational activities, but self-select out of those activities because of low motor competence.

Thus, the purpose of this research project is to establish a developmental trajectory for functional performance skills so that interventionists can identify when functional skill begins to diverge from fundamental motor skill and associate that divergence in motor skills with emerging differences in executive function. Motor competence is not solely dependent upon the structural attributes of the body or measures of muscle strength. The interpretation of sensory cues contributes to the processing of contextual information that aids in the success of response selection and execution. Our goal is to create a developmental database that merges these two aspects of the developmental literature.

OBJECTIVE

The objective of this report is to support this project in three ways: 1) Create an annotated bibliography for background understanding of the tests in the C3 Logix System. 2) Consult with the literature to devise procedures for administration of three function performance tests that challenge the individual's performance capability beyond basic fundamental motor competency, and 3) complement the description of the selected functional performance tests with video demonstrations.

SECTION ONE: C3 LOGIX

Chapter One: Balance

PROTOCOL AS SUBMITTED TO IRB

The protocol in the C3 Logix program is a hybrid between the Clinical Test of Sensory Organization and Balance (CTSIB) and the Balance Error Scoring System (BESS) tests of balance.

Instructions

Prior to beginning, a harness with an iPad holder will be affixed to the waist and the iPad will be clipped in. This test will be performed on the floor and on a foam pad with eyes closed. On both surfaces, the participant will be tested during three conditions- normal stance (both feet on the surface), single-leg stance and a tandem stance (heel-to-toe standing with both feet on the surface). The test administrator will count the errors and input into the iPad after each test and before proceeding to the next module.
The accelerometer and the gyroscope in the iPad will also measure the sway.

TEST BACKGROUND

Clinical Test of Sensory Organization and Balance (CTSIB)

Shumway-Cook, A., & Horak, F. B. (1986). Assessing the influence of sensory interaction on balance – suggestion from the field. Physical Therapy, 66(10), 1548-1550.

The following are the protocols laid for the CTSIB that have been refined through trial in the field. The CTSIB calls for the participant to complete 4 conditions with 3 trials of 10 sec each included in each condition. Upon completion of the 4 conditions, any remaining questions will be answered and copies of all documentation will be given to the participant and guardian

First condition: Subject will be asked to stand on the center of a force plate in a quiet stance with arms crossed against their chest.

Second condition: Subject will be asked to take the same position on the force plate as stated above, but will be blindfolded for the entire duration of each trial within this condition.

Third condition: Same guidelines as condition 1, but standing on 3in thick high-density foam pad placed on top of the force plate.

Fourth condition: Same guidelines as condition 2, but standing on 3in thick high-density foam pad placed on top of the force plate.

BALANCE ERROR SCORING SYSTEM (BESS)

Bell, D., Guskiewicz, K., Clark, M., Padua, D. (2011). Systematic Review of the Balance Error Scoring System. Sports Health, 3(3): 287–295.

The Balance Error Scoring System (BESS) consists of three stances and two surface conditions. Measurement is performed using the non-dominant leg.

Stance:

1) Double-leg stance (hands on the hips and feet together).
2) Single-leg stance (standing on the non-dominant leg with hands on hips).
3) Tandem stance (non-dominant foot behind the dominant foot) in a heel-to-toe fashion.

Conditions:

The 3 stances are performed on a firm surface and on a foam surface with the eyes closed.

Errors:

Errors are counted during each 20-second trial. An error is defined as opening eyes, lifting hands off hips, stepping, stumbling or falling out of position, lifting forefoot or heel, abducting the hip by more than 30°, or failing to return to the test position in more than 5 seconds.

TEST RELIABILITY AND VALIDITY

Murray, N., Salvatore, A., Powell, D., & Reed-Jones, R. (2014). Reliability and validity evidence of multiple balance assessments in athletes with a concussion. Journal of Athletic Training, 49(4): 540+.

The objective of this study was to examine the reliability and validity evidence for the CTSIB, SOT, BESS, Romberg test, and Wii Fit for detecting balance disturbance in athletes with a concussion.

Articles considered for this review included publications with reliability and validity data for the assessments of balance (CTSIB, SOT, BESS, Romberg test, and Wii Fit). Sixty-three relevant articles were identified with twenty-eight of them considered appropriate for inclusion.

It was concluded that there was "no current reliability or validity information supporting the use of the CTSIB, SOT, Romberg test, or Wii Fit for balance assessment in athletes with a concussion. The BESS demonstrated moderate to high reliability (interclass correlation coefficient = 0.87) and low to moderate validity (sensitivity = 34%, specificity = 87%). The Romberg test and Wii Fit have been shown to be reliable tools in the assessment of balance in Parkinson patients."

The BESS can evaluate balance problems after a concussion, but lacks the ability to detect balance problems after the third day of recovery.

Pandian, T., Ukamath, S., & Jetley, N. (2011). Clinical test of sensory interaction in balance (CTSIB): Concurrent validity study in healthy Indian children. Journal Of Pediatric Neurology, 9(3), 311-318.

This study looked at the concurrent validity of a field test administered by physical therapists to measure balance. The Clinical Test of Sensory Interaction for Balance (CTSIB) score on therapist's observation was compared using a force plate with force plate measures to find concurrent validity in healthy Indian children aged 7 to 12 yr. The r-value for concurrent validity was 0.681 and 0.799 with force plate measures, indicating a good correlation and that the CTSIB was a valid test for balance evaluation in Indian children.

Sheehan, D. P., Lafave, M. R., & Katz, L. (2011). Intra-Rater and Inter-Rater Reliability of the Balance Error Scoring System in Pre-Adolescent School Children. Measurement In Physical Education & Exercise Science, 15(3), 234-243.

This study was designed to test the intra- and inter-rater reliability of the Balance Error Scoring System in 9-10 year old children. Four adult raters scored the balance tests of 46 normally developing 4th grade students to yield Cronbach's alpha scores of reliability. It was concluded that the Balance Error Scoring System showed high reliability when used with fourth-grade elementary school children.

BALANCE & IPHONE TECHNOLOGY

Pattterson, J., Amick, R., Tarunkumar, T., Rogers, M. (2014). Validation of measures from the smartphone sway balance application: A pilot study. Int J Sports Phys Ther, 9(2): 135–139.

The purpose of this pilot study was to assess the value and validity of using software developed to access the iPod and iPhone accelerometers output and translate that to the measurement of human balance.

Thirty healthy college-aged individuals (13 male, 17 female; age = 26.1 ± 8.5 years) volunteered. Participants performed a static Athlete's Single Leg Test protocol for 10 sec, on a Biodex Balance System SD while concurrently utilizing a mobile device with balance software. Anterior/posterior stability was recorded using both devices, described as the displacement in degrees from level, and was termed the “balance score.”

There were no significant differences between the two reported balance scores on the balance platform compared to using the mobile device. Therefore, the results showed that a balance scores derived from the accelerometers of a smartphone were consistent with balance scores obtained from a previously validated balance system. The one limitation was that the mobile software assessed balance in the anterior/posterior direction only. The authors suggested that further would be needed on a healthy population, as well as those with impairment of the motor control system.

Chapter Two: Reaction

PROTOCOL AS SUBMITTED TO IRB

Instructions

The participant will perform two types of test- one each for simple reaction time and choice reaction time. For simple reaction time- the participant will place the index finger on a button at the bottom of eth screen. There will be a spotlight at the top of the screen which will be yellow in color. As soon the spotlight turns green, the participant is required to lift and tap the green spotlight with the same finger as soon as possible. The screen set up for the choice reaction time is similar except that there will be two spotlights and two buttons instead of one. Both index fingers will be placed on "press" buttons indicated at the bottom of the screen. During the test, two colored indicator lights will show either green or blue. The participant will have to lift the finger on the same side as the green light, tapping the indicator as fast as possible. This is to be executed while the opposite finger (on the side of the blue light) remains in contact with the "press" button. If the participant lifts the finger from the "hold" button on the blue side at any time, the trial is stopped by the program and given a redo.

BACKGROUND

Brebner, JT and Welford AT (1980). Introduction: an historical background sketch. In A. T. Welford (Ed.), Reaction Times. Academic Press, New York, pp. 1-23.

In a section of this history and review, the authors look at the history of the reaction time literature. Psychologists have named three basic kinds of reaction time experiments (Luce, 1986; Welford,1980):

1. In a simple reaction time experiment, there is only one stimulus and one response.
2. In a recognition reaction time experiments, there are some stimuli that should be

responded to (the “memory set”), and others that should get no response (distracter set). There is still only one correct response.

3. In a choice reaction time experiment, the user must give a response that corresponds to the stimulus, such as pressing a key corresponding to a letter if the letter appears on the screen.

“The pioneer reaction time study of Donders (1868) showed that a simple reaction time is shorter than a choice reaction time, and that the recognition reaction time is longest of all. This is in line with many studies concluding that a complex stimulus (e.g., several letters in symbol recognition vs. one letter) elicits a slower reaction time (Brebner and Welford, 1980; Luce, 1986; Teichner and Krebs, 1974)." "

Light vs. Sound:

The mean reaction time to sound is significantly faster than the mean reaction time to light. "For about 100 years, the accepted figures for mean simple reaction times for college-age individuals have been about 190 ms (0.19 sec) for light stimuli and about 160 ms for sound stimuli (Brebner and Welford, 1980; Fieandt et al., 1956; Galton, 1899; Welford, 1980)."

Laming, J. (1968). Information Theory of Choice-Reaction Times. Academic Press, London.

For a typical, healthy adult mean simple reaction time = 220ms, while mean recognition reaction time = 384ms.

Saville, W. N., S. Shihare, S. Iyengar, D. Daley, J. Intriligator, S. G. Boehm, B. Feige, C. Klein. (2012). Is Reaction Time Variability Consistent Across Sensory Modalities? Insights From Latent Variable Analysis of Single-Trial Pdb Latencies. Biological Psychology, 91 (2): 275-282.

This study used EEG to analyze stimulus and response across visual and auditory sensory modalities. The authors found that intra-subject variability represents a unitary construct across modalities. People who had variable reaction times to a visual stimulus also had variable reaction times to an auditory stimulus. The processes underlying this generality appear to cross different cognitive tasks amd different sensory modalities

RELATIONSHIP TO BRAIN INJURY

Bashore, T. R., Ridderinkhof, K. R. (2002). Older age, traumatic brain injury, and cognitive slowing: some convergent and divergent findings. Psychological Bulletin 128(1): 151.

This article presents a meta-analysis of the effect of traumatic brain injury on processing speed and reaction time

Brain injury significantly slows reaction time, but different types of responses are slowed to different degrees. There are some similarities in the effects of older age and TBI on processing speed.

Kontos, A. P., T. Covassin, R. J. Elbin, and T. Parker (2012). Depression and neurocognitive performance after concussion among male and female high school and collegiate athletes. Archives of Physcical Rehabilitation and Medicine 93(10): 1751-1756.

Seventy-five high school and collegiate athletes with a diagnosed concussion were measured in a pretest, multiple posttest, repeated-measures design. The results showed that concussed athletes exhibited significantly higher levels of depression, slower reaction times and decrements in scores of visual memory from baseline as much as 14 days post-concussion.

Collins, M. W., Field, M., Lovell, M. R., Iverson, G., Johnston, K.M., Maroon, J., Fu, F.H. (2003). Relationship between postconcussion headache and neuropsychological test performance in high school athletes. The American Journal of Sports Medicine (31(2): 168-174.

One week after injury, high school athletes reporting posttraumatic headache demonstrated significantly worse performance on reaction time and memory ImPACT neurocognitive composite scores than athletes with concussions but no headache.

Leuthcke, C. A., Bryan, C.J., Morrow, C.E., Isler, W.C. (2011). Comparison of concussive symptoms, cognitive performance, and pshychological symptoms between acute blast- vs. nonblast-induced mild traumatic brain injury. Journal of the International Neuropsychological Society 17(1): 36-45.

Soldiers and contractors in Iraq who suffered mild traumatic brain injury showed a marked impairment of reaction time when measured within 72 hours of the injury

Chapter Three: Vestibulo-Ocular Reflex

PROTOCOL AS SUBMITTED TO IRB

Instructions

The tester and the participant will be seated 5 feet apart. A metronome chimes as the participant move their head from 10-to-2 position while fixing their gaze on the iPad screen which is held by the tester. The participant will read the letters on the screen from left to right which get smaller as they complete a line.

BACKGROUND

Glasauer S. Current models of the ocular motor system (2007). Dev Ophthalmol. 40: 158-74.

Also known by the oculocephalic reflex, the VOR produces an eye movement that stabilizes images on the center of the retina during head movement. The reflex responds with an eye movement that is equal in magnitude but opposite in direction to the head movement.

Both rotational and translational head movements stimulate the vestibuloocular reflex. Rotational movements occur as the head moves relative to the body. Rotational movements include turning the head back and forth, nodding, and bringing the ear in contact with the shoulder. Translational movements occur when the entire body (including the head) is moved in tandem. An example of translational movement is when an individual stands on a moving sidewalk.

The rotational component of the vestibuloocular reflex (r-VOR) responds to angular motion of the head and results from stimulation of the semicircular canals. The translational component of the vestibuloocular reflex (t-VOR) responds to linear motion of the head and results from stimulation of the otolithic organs. Some head movements may involve a combination of both types of VOR reflex.

Schubert, MC, Minor LB (2204). Vestibulo-ocular Physiology Underlying Vestibular Hypofunction. Physical Therapy, 84(4): 373-385.

This article is a review of the anatomy and physiology of the vestibular system and to describe the neurophysiological mechanisms responsible for the vestibulo-ocular abnormalities in patients with vestibular hypofunction.

The vestibular system detects motion of the head and maintains stability of images on the fovea of the retina as well as postural control during head motion. Signals representing angular and translational motion of the head as well as the tilt of the head relative to gravity are transduced by the vestibular end organs in the inner ear. This sensory information is then used to control reflexes responsible for maintaining the stability of images on the fovea (the central area of the retina where visual acuity is best) during head movements. Information from the vestibular receptors also is important for posture and gait.

When vestibular function is normal, these reflexes operate with exquisite accuracy and, in the case of eye movements, at very short latencies. However, when compromised, there is a significant latency detectable in the reflex.

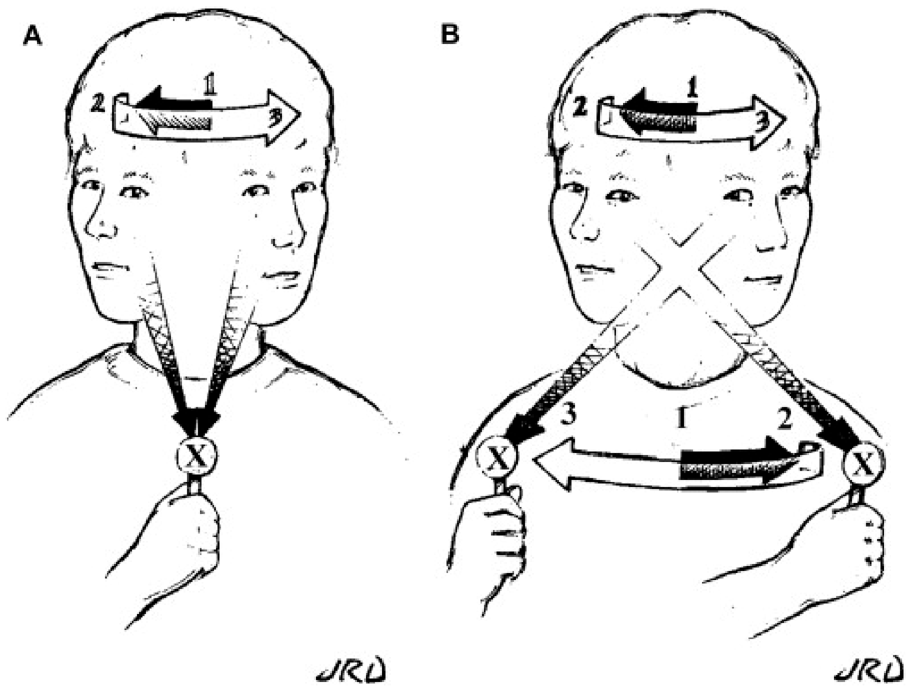
Hall CD, Cox LC (2009). The Role of Vestibular Rehabilitation in the Balance Disorder Patient. The Otolaryngologic Clinics of North America. 42(1); 161-169.

Studies have shown that the incidence of falls is greater in persons with vestibular hypofunction when compared with healthy individuals of the same age living in the community.

A critical signal to induce adaptation is retinal slip during head movements. Without the VOR, gaze stabilization during head movement is poor.

In regards to rehabilitation, "adaptation exercises involve head movement while maintaining focus on a target which may be stationary or moving (Illustration 1A). Typical progression of adaptation exercises involves increased velocity of head movement, movement of the target and head, target placement in a distracting visual pattern, and maintenance of a challenging posture (Illustration 1B)."

Illustration 1 (A) and (B)



Hall & Cox (2009) Adaptation Exercises for Head Movement

USE OF VOR AS DIAGNOSTIC TOOL

Arriaga, M.A., Chen, D.A., Hillman, T.A., Kunschner, L., Arriaga, R.Y. Visually Enhanced Vestibulo-Ocular Reflex: A Diagnostic Tool for Migraine Vestibulopathy. The Laryngoscope, 116 (9): 1577–1579, 2006.

The visually enhanced vestibular-ocular reflex (VVOR) rotational gain measures visual-vestibular interaction and its central connections. It may be useful as a tool to evaluate severity of vestibulopathy in migraine patients manifesting disequilibrium and motion sensitivity.

Of 20 normal controls, one had elevated VVOR gain; whereas 49 of 69 (71%) of migraine vestibulopathy patients had elevated VVOR gain. The VVOR gain was more frequently elevated in migraine vestibulopathy patients than in the normal controls, as well as a significant differential between the two groups.

NORMATIVE DATA

Casselbrant, M.L., Mandel, E.M., Sparto, P.J., Perera, S., Redfern, M.S., Fall, P.A., Furman, J.M. (2010). Longitudinal Posturography and Rotational Testing in Children Three to Nine Years of Age: Normative Data. Otolaryngology - Head and Neck Surgery, 142 (5): 708-714.

This study looked to obtain normative longitudinal vestibulo-ocular and balance test data in children with normal middle ear status starting at age 3 years old with yearly tests up to the age of 9 years of age. The results from the usable data on 127 children showed a linear increase in the vestibulo-ocular reflex gain as children aged but without a change in the phase of the response from head movement.

*See Appendices for Tables of Normative Data.

Chapter Four: Trail Making Test

PROTOCOL AS SUBMITTED TO IRB

Instructions

This test is similar to 'connect the dots'. In the first part, the participant will place their finger on the dot marked number "1" and then drag their finger to connect the numbers in numerical order as quickly as possible without lifting the finger. In the second part of the test, the participant will perform the same protocol, but connecting an alternating sequence of numbers and letters.

BACKGROUND

Rabina L.A., Barrb, W.B., Burtonc, L.A. (2005). Assessment Practices of Clinical Neuropsychologists in the United States and Canada: A Survey of INS, NAN, and APA Division 40 Members. Archives of Clinical Neuropsychology, 20 (1): 33–65.

The TMT is the third most often used neuropsychological tests in clinical practice and research settings to investigate complex cognitive processes.

Spreen, O., & Strauss, E. (1998). A compendium of neuropsychological tests: Administration, norms and commentary (2nd ed.). New York: Oxford University Press.

Guidelines for administration of Trails A and B:

"Participants were instructed to complete each part of the TMT as quickly and accurately as possible. When an error was made, the participant was instructed to return to the "circle" where the error originated and continue. Time to complete each part was recorded."

Soukup, V.M., Ingam, F. (1996). The Trail Making Test: A Review and Compilation of Normative Data. Archives of Clinical Neuropsychology, 11 (5): 453.

"The TMT assesses a number of neurocognitive abilities including psychomotor speed, complex attention, visual scanning and mental flexibility, and has been repeatedly demonstrated to be sensitive to brain injury in children and adults (Boll, 1974 and Jaffe et al., 1993; Reed, Reitan, & Klove, 1965; Reitan, 1955, Reitan, 1958 and Reitan, 1971)."

The adult version of the TMT is administered in two parts: TMT-A requires that the subject draw lines to sequentially connect a series of 25 numbered circles. TMT-B requires that the subject draw lines sequentially connecting a series of numbers and letters, alternating between numbers and letters (e.g., 1,A,2,B,3,C ...). Both sections are timed and the subject receives a score based on the amount of time (in seconds) taken to complete each part of the test.

Youth between the ages of 9 and 14 years complete a shortened version, referred to as the TMT for older children. Youth between the ages of 5 and 8 years complete the progressive figures test (PFT).

Salthouse, T.A. (2011). What Cognitive Abilities are Involved in Trail-Making Performance? Intelligence, 39 (4): 222-232.

Evaluation of Cognitive Abilities (Speed, Working Memory & Cognitive Fluidity)

It was found that the connections version of the TMT primarily reflects the cognitive abilities of speed and fluid intelligence. There were no relations of working memory with connections trail making performance beyond those shared with fluid ability.

Simple & Alternating

Performance in the simple (A) condition was found to be strongly related to spreed and also, to a lesser degree, related to Gf (fluidity of cognitive ability). Performance in the alternating (B) condition was found to be slightly weaker in relation to speed but strongly related to Gf.

The speed influence likely occurs because of the requirement for rapid responding in both conditions. The Gf relation may be due to the cognitive demands of maintaining the current sequence position while searching for next element in the sequence. The existence of a uniquely greater Gf relation in the alternating version suggests that there are additional requirements related to fluid abilities when there is a need to alternate between two sequences.

Difference (B-A)

The contextual analysis indicated that the simple difference (B − A) primarily reflects speed, and thus it may not be sensitive to other influences of interest in the test.

Ratio (B:A)

The ratio measure does not completely eliminate the influence on speed, but it does so to a greater extent than the simple difference. The authors suggested that, for that reason, it may be preferable to use the ratio as the derived index in trail making tasks when sample sizes are too small to permit meaningful regression analyses to derive residuals.

Notes on Working Memory

The analyses with WM and Gf as simultaneous predictors revealed no unique prediction of WM. Many of the prior studies in which relations of WM were investigated had not included other variables in the analyses. Therefore and of the variance that WM shared with other predictors was unduly attributed to WM.

"In this study, the availability of multiple predictors allows the relative contributions of Gf and WM to be assessed. "Similar findings were recently reported by Shamosh et al. (2008) as there was little unique contribution of WM in the prediction of delay discounting performance when it was examined simultaneously with a measure of general intelligence."

Function of Age on TMT Performance

Trail making tests such as the connections test are very sensitive to individual differences, and particularly to age-related differences. With the exception of the youngest age, performance was slightly faster with numbers than with letters, and was faster when the alternating sequence started with numbers than when it started with letters.

Periáñez, J.A., Ríos-Lago, M., Rodríguez-Sánchez, J.M., Adrover-Roig, D., Sánchez-Cubillo, I., Crespo-Facorro, B., Quemada, J.I., Barceló, F. (2007). Trail Making Test in Traumatic Brain Injury, Schizophrenia, and Normal Ageing: Sample Comparisons and Normative Data. Archives of Clinical Neuropsychology, 22 (4): 433-447.

The main purpose of this study was to compare the performance of schizophrenia and traumatic brain injury (TBI) patients in the TMT and to provide normative data from two large samples.The authors looked at the two direct scores of Trail-A & Trail-B and the three derived scores of B-A, B:A, (B-A)/A.

The scores of both the schizophrenia group and the TBI group were both significantly less than the healthy controls on all measures. In addition, the TBI patients performance was poorer in Trails A, Trails B, and B–A than the schizophrenia patients. No differences were found in the B:A and B–A/A ratio scores between TBI and schizophrenia samples.

"These results confirm and extend prior evidences about a specific executive control deficit in both TBI and schizophrenia patients, that should be dissociated from a deficit in speed of processing (Evans, Chua, McKenna, & Wilson, 1997;Krabbendam, de Vugt, Derix, & Jolles, 1999; Ríos et al., 2004 and Rodríguez-Sánchez et al., 2005)."

*See Appendices for Tables of Normative Data

Tombaugh, T.N. (2004). Trail Making Test A and B: Normative Data Stratified by Age and Education. Archives of Clinical Neuropsychology, 19 (2): 203-214.

Normative data base was developed from 911 total subjects, stratified into 11 age groups (18–89 years) and 2 education levels (0–12 and 12+ years). All participants were living independently community-living residences and ranged in age from 18 to 89 years (*M*=58.5, S.D.=21.7). The education level varied from 5 to 25 years (*M*=12.6, S.D.=2.6). The male to female ratio was 408 to 503. Trails A and B were administered according to the guidelines presented by Spreen and Strauss (1998).

Performance on the TMT decreased (scores on Trails A and B increased) with increasing age and lower levels of education. Gender was not significantly correlated with TMT scores. Age was more highly correlated with the scores than was education.

Chapter Five: Executive Processing Time

PROTOCOL AS SUBMITTED TO IRB

Instructions

Processing time- the participant will be presented with the 9 symbols matched with the 1-9 digits in a key, which will remain at the top of the iPad screen for the duration of the test, in the middle of the screen there will be a row of symbols with blank spaces beneath each one. The participant will fill out the blank spaces from left to right without skipping, by tapping each the number at the bottom of the screen corresponding to each symbol

BACKGROUND

Duff K, Schoenberg MR, Scott JG, Adams RL. (2005). The relationship between executive functioning and verbal and visual learning and memory. Arch Clin Neuropsychol, 20(1): 111-22.

Executive function is also known as cognitive control or the supervisory attentional system. It is an umbrella term for the management of cognitive processes - this includes working memory, reasoning, task flexibility, and problem solving - but has been difficult to concretely show a relationship to these abilities. In this study the authors examined the relationship between executive function and a wide array of standardized neuropsychological tests, including IQ. The results of the analysis showed a clear and robust relationship between executive functioning and memory.

ANALYZING RESULTS OF A CONTINUOUS PERFORMANCE TEST

Kanaka, N., Matsuda, T., Tomimoto, Y., Noda, Y., Matsushima, E., Matsuura, M. and Kojima, T. (2008), Measurement of development of cognitive and attention functions in *children using continuous performance test. Psychiatry and Clinical Neurosciences, 62: 135–141*

The use of various types of continuous performance tests (CPT) have been used to objectively assess cognitive function along with attention. In this study, 541 healthy girls aged 5–12 years were assessed using a CPT to examine the development of cognitive and attention functions.

Ten separate parameters were calculated and analyzed by age in order to examine the development of cognitive and attention functions during childhood. The results indicated that there were marked changes in inhibition function, inattention to stimuli, and stability of processing time observed at the age of 5 and 6 years. These parameters were related to the ability respond and appear to develop first in developmental progression. Discrimination ability subsequently increases based on these developments up to approximately 8 years of age. Finally, overall processing time was reduced up to approximately 11 years of age. Tables of normalized CPT data were created from the results.

*See Appendices for Tables of Normative Data

*Halperin JM, Wolf L, Greenblatt ER , Young G. (1991). Subtype analysis of commission errors on the continuous performance test in children..Dev. Neuropsychol , **7**: 207–217.*

Most investigators agree that errors of omission on the continuous performance test (CPT) reflect some aspect of inattention; however, there is less agreement regarding the significance of commission errors. Although many investigators believe that commission errors reflect impulsivity, others are skeptical. We proposed that CPT commission errors do not comprise a unitary measure and that subtypes can be distinguished based on the specific nature of the errors. Our investigation identified four subtypes of commission errors and found that reaction times associated with them differed significantly, in agreement with a priori predictions, suggesting that they reflect differential underlying psychological processes. Although certain commission errors appear to reflect impulsivity, the data suggest that others do not.

Rosvold, H. Enger; Mirsky, Allan F.; Sarason, Irwin; Bransome Jr., Edwin D.; Beck, Lloyd H. (1956). A continuous performance test of brain damage. Journal of Consulting Psychology, 20(5): 343-350.

The continuous performance test was used to detect differences between groups of brain-damaged subgroups and healthy controls, as well as measure the severity of the damage. Among the groups of subjects, the brain-damaged subgroups were significantly inferior to their non-brain-damaged controls on all measures yielded by the CPT. The CPT showed that the differences increased when the difficulty of the task was increased.

The authors suggest that the inferior performance of the brain-damaged subjects could be explained in terms of impairment in attention or alertness in the CPT performance.

SECTION TWO: FUNCTIONAL PERFORMANCE

In addition to the test battery provided in the C3 Logix Software, the inclusion of functional performance measures can be added to expand our understanding of motor control and development.

The three functional performance tests were chosen after consultation with Christie Powell and consulting the literature for tests that met our requirements. We were looking for functional tests that would push the edge of performance for each group to see were children dropped out. We also wanted tests that looked at all three planes of movement and tested force production, asymmetry, dynamic stability and motor planning and control.

Three Tests Chosen for Inclusion:

1) Single Leg Triple Hop for Distance
2) Single Leg Crossover Hop for Distance
3) Single Leg Figure 8 Hop for Time

The instructions for administration of these tests have been represented in the literature as early as 1982. The Single Leg Triple Hop for Distance has been shown to be both valid and reliable with the most representation in the literature. It is most often used to measure force production in each leg and for determining asymmetries in performance between the legs. The Single Leg Crossover Hop for Distance has less representation but has been used repeatedly in the literature since 1991. Of the hop tests with a lateral component, the Crossover Hop for Distance is less demanding than the others and more realistic to expect young children to complete. However, it is a strong edition to a test battery as it requires the participant to “stick” the landing for 2 seconds. This provides a measure of dynamic stability to the test. The Single Leg Figure 8 Hop for Time is less studied but provides a multidirectional component to a test battery, as well as a motor planning and strategy component. It is one of the more challenging hop tests in the literature but can effectively determining with a high sensitivity if there are deficits that may need to be addressed before engaging in intense physical activity or sport competition.

COMMON INSTRUCTIONS FOR ALL THREE TESTS:

- Each participant should perform a 5-minute warm-up of moderate intensity on a Borg Scale of RPE.
- Each test is timed with an electronic timer.
- Prior to testing a standardized video recording along with verbal instructions on how to perform each functional test will be shown.
- The dominant limb for each participant will be determined as the limb chosen to kick a ball.
- Participants can perform up to 3 practice trials of each performance test to familiarize themselves with the testing procedures.
- Participants will then complete 3 trials at maximal effort. The best of 3 trials is taken.
- The participants will rest for 1 minute between each individual trials.
- The order of administration for the functional performance test and the first limb tested will be randomized for each trial.

PROTOCOL REPRESENTATION IN THE LITERATURE

Single Leg Triple Hop for Distance

Augustsson J, Thomeé R, Hörnstedt P, Lindblom J, Karlsson J, Grimby G (2003). *Effect of pre-exhaustion exercise on lower-extremity muscle activation during a leg press exercise*. J Strength Cond Res, 17: 411–416.

Augustsson J, Thomeé R, Karlsson J. (2004). *Ability of a new hop test to determine functional deficits after anterior cruciate ligament reconstruction*. Knee Surgery, Sports

Traumatology, Arthroscopy. 12(5); 350-356.

Augustsson J, Thomeé R, Lindén C, Folkesson M, Tranberg R, Karlsson J (2006). *Single-leg hop testing following fatiguing exercise: reliability and biomechanical analysis*. Scandinavian journal of medicine & science in sports, 16(2): 111 - 120.

Barber-Westin S, Galloway M, Noyes F, Corbett G, Walsh C (2005). *Assessment of lower limb neuromuscular control in prepubescent athletes*. *American J of Sports Medicine,* 33(12): 1853-1860

Daniel KM, Stone ML, Riehl B, Moore MR (1982). *A measurement of lower limb function: the one leg hop for distance*. Am J Knee Surg, 1: 212–214.

Fitzgerald GK, Axe MJ, Snyder-Mackler L (2000). *A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture*. Knee Surg Sports Traumatol Arthrosc 8:76–82

Fitzgerald, GK; Lephart, SM; Hwang, JH; Wainner, RS (2001). *Hop tests as predictors of dynamic knee stability*. The Journal of orthopaedic and sports physical therapy. 31(10): 588

Greenberg EM, Greenberg ET, Ganley TJ, Todd J, Lawrence R (2014). *Strength and Functional Performance Recovery After Anterior Cruciate Ligament Reconstruction in Preadolescent Athletes*. Sports Health: A Multidisciplinary Approach, 6(4): 309-312.

Noyes FR, Barber SD, Mangine RE (1991). *Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture*. Am J Sports Med, 19: 513–518

Reid A, Birmingham TB, Stratford PW, Alcock GK, Giffin JR (2007). *Hop Testing Provides a Reliable and Valid Outcome Measure During Rehabilitation After Anterior Cruciate Ligament Reconstruction*. Physical Therapy, 87(3): 337-349.

Swearingen J, Lawrence E, Stevens J, Jackson C, Waggy C, Davis DS (2011). *Correlation of single leg vertical jump, single leg hop for distance, and single leg hop for time.* Physical Therapy in Sport, 12(4): 194-198.

SINGLE LEG CROSSOVER HOP FOR DISTANCE

Bolgla LA and Keskula D R (1997). *Reliability of lower extremity functional performance tests*. The Journal of orthopaedic and sports physical therapy. 26(3); 138.

Fitzgerald GK, Axe MJ, Snyder-Mackler L (2000) *A decision-making scheme for returning patients to high-level activity with nonoperative treatment after anterior cruciate ligament rupture*. Knee Surg Sports Traumatol Arthrosc 8:76–82

Noyes FR, Barber SD, Mangine RE (1991). *Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture*. Am J Sports Med, 19: 513–518

SINGLE LEG FIGURE 8 HOP FOR TIME

Caffrey E, Docherty CL, Schrader J, Klossner J (2009). The ability of 4 single-limb hopping tests to detect functional performance deficits in individuals with functional ankle instability. *JOSPT*. 39(11): 799-806

Chapter Six: Single Leg Hop for Distance

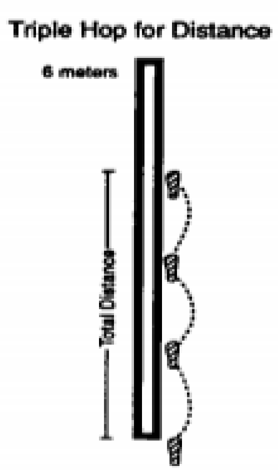
PROTOCOL AS SUBMITTED TO IRB

Instructions:

- Each participant stands on one leg with the heel positioned on a predetermined mark on the floor.
- Participants hop forward as far as possible, landing on the same leg.
- Participant is permitted to swing their arms freely and may use a self-selected countermovement without stepping prior to the jump.
- Upon landing, participant must maintain foot contact with the floor while the investigator marks the location of heel contact
- Use a standard roll-out tape-measure to record the horizontal displacement, in centimeters, from the heel starting position to the heel landing mark.
- The jump with the greatest horizontal displacement was used for data analysis.
- All 3 trials are performed on one leg. The subject then performs the test on the opposite lower extremity

(VIDEO LINK)

Figure 1 Noyes, et al (1991) Triple Hop for Distance

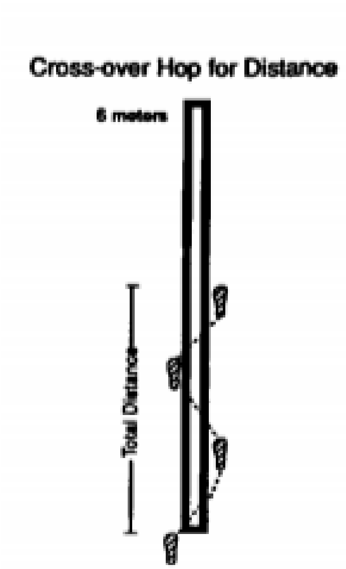


Chapter Seven: Single Leg Crossover Hop for Distance

- The subject is instructed to hop on one leg diagonally over the 15-cm-wide line, covering as much distance in 3 hops as possible
- The subject is required to keep his/her hands behind their back (hand in hand) at the level of the sacrum
- The subject must control the landing of the third hop, holding for 2sec balance
- A trial is regarded as unacceptable if the participant puts the contralateral foot down, falls, or does not completely clear the width of the line.
- The trial is repeated if not acceptable.

(VIDEO LINK)

Figure 2 Noyes, et al (1991) Cross-over Hop for Distance

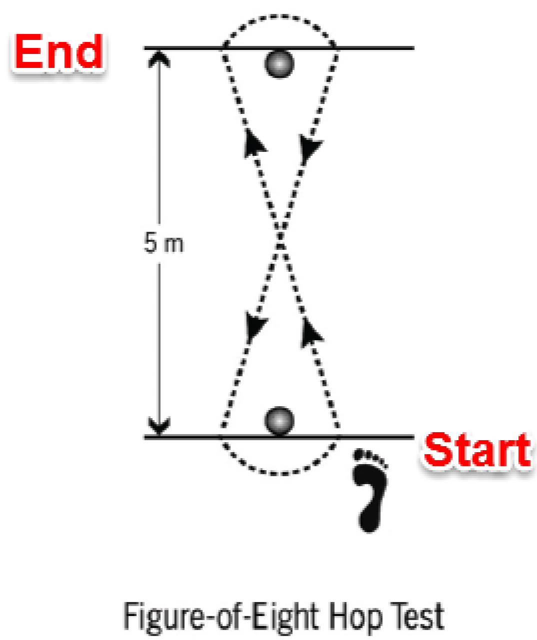


Chapter Eight: Figure-of-8 Hop for Time

- For the figure-of-8 hop test, a 5-m course outlined by cones is set up (Figure 2).
- Each participant was instructed to hop on one leg, twice around the course, as fast as possible.
- A trial is regarded as unacceptable if the participant puts the contralateral foot down, falls, or does not complete the course as outlined
- The trial is repeated if not acceptable.

(VIDEO LINK)

Figure 3 Cafferty, et al (2008) Figure-of-Eight Hop Test



Appendices: Tables of Normative Data

TABLE SET 1: VESTIBULO-OCULAR REFLEX

Casselbrant, M.L., Mandel, E.M., Sparto, P.J., Perera, S., Redfern, M.S., Fall, P.A., Furman, J.M. (2010). *Longitudinal Posturography and Rotational Testing in Children Three to Nine Years of Age: Normative Data*.

Table 4.

Estimated mean (SD) VOR sensitivity and time constant in seconds from model fit of rotational chair data obtained at 50 degrees per second at 0.02, 0.05, 0.1, and 0.5 Hz

Age (yrs)	N	Sensitivity	Time constant
3	24	0.52 (0.12)	17 (7)
4	45	0.61 (0.15)	16 (8)
5	53	0.62 (0.16)	17 (9)
6	37	0.71 (0.17)	16 (6)
7	17	0.76 (0.12)	16 (5)
8	24	0.79 (0.14)	17 (6)
		y = 0.38 + 0.053□Age	

□

The equation for estimating the VOR sensitivity, on the basis of age in years, is provided. The intercept and slope coefficients were significantly different from 0 ($P < 0.0001$).

Casselbrant, M.L., Mandel, E.M., Sparto, P.J., Perera, S., Redfern, M.S., Fall, P.A., Furman, J.M. (2010). *Longitudinal Posturography and Rotational Testing in Children Three to Nine Years of Age: Normative Data*.

Table 5

Estimated mean (SD) VOR sensitivity and time constant in seconds from constant velocity rotational chair data obtained at 60 degrees per second

Age (yrs)	**N**	**Sensitivity**	**Time constant**
3	10	0.33 (0.18)	13 (6)
4	25	0.47 (0.21)	16 (5)
5	40	0.56 (0.24)	14 (5)
6	32	0.63 (0.21)	15 (4)
7	10	0.73 (0.24)	17 (8)
8	20	0.77 (0.21)	15 (3)
		y = 0.11 + 0.087□Age	

□

The equation for estimating the VOR sensitivity, on the basis of age in years, is provided. The intercept and slope coefficients were significantly different from 0 ($P < 0.0001$).

TABLE SET 2: TRAIL MAKING TEST

Tombaugh, T.N. (2004). *Trail Making Test A and B: Normative Data Stratified by Age and Education*

Table 3: Percentiles for Trails A and B scores (s) for each normative group

Table 3.

Percentiles for Trails A and B scores (s) for each normative group

	Education 0–12 years		Education 12+ years		Total	
Percentile	Trail A	Trail B	Trail A	Trail B	Trail A	Trail B
Age group 18–24 (university students; *n* = 155)						
90					16	35
80					17	38
70					19	41
60					20	44
50					22	47
40					23	49
30					25	54
20					27	61
10					31	66
Age group 25–34 (*n* = 33)						
90					14	33
80					17	38
70					19	45
60					21	48
50					23	50
40					25	53
30					27	58
20					33	63
10					40	67

Age group 35–44 (*n* = 39)						
90					16	40
80					20	45
70					23	50
60					24	53
50					26	58
40					28	60
30					32	62
20					36	70
10					46	87
Age group 45–54 (*n* = 41)						
90					19	42
80					23	50
70					27	59
60					29	62
50					31	64
40					33	68
30					34	72
20					38	75
10					50	84

Periáñez, JA, et al (2007). *Trail Making Test in Traumatic Brain Injury, Schizophrenia, and Normal Aging: Sample Comparisons and Normative Data*

Table 6 Percentile ranks for healthy subjects (n = 223)

Percentile	TMT-A	TMT-B	B–A	B:A	B–A/A
Young group (16–24 years; *n* = 69)					
5	42.5	82	48	2.8	1.8
10	40	78	39	2.52	1.52
15	39	73.5	36.5	2.4	1.4
20	36	68	35	2.22	1.22
25	35	61.5	32.5	2.18	1.18
30	33	60	30	2.05	1.05
35	32	56.5	27	2.03	1.03
40	30	54	26	2	1
45	29	52	24	1.96	0.96
50	27	51	23	1.9	0.9
55	25.5	48	21.5	1.86	0.86
60	25	47	21	1.82	0.82
65	23.5	45	20	1.75	0.75
70	22	44	20	1.68	0.68
75	21.5	41.5	18.5	1.63	0.63
80	21	40	17	1.54	0.54
85	20	38.5	15	1.5	0.5
90	18	37	11	1.36	0.36
95	17	34.5	7.5	1.27	0.27

Percentile	TMT-A		TMT-B		B–A		B:A		B–A/A	
	0–12[a] (n = 24)	13+[a] (n = 65)	0–12[a] (n = 24)	13+[a] (n = 65)	0–12[a] (n = 24)	13+[a] (n = 65)	0–12[a] (n = 24)	13+[a] (n = 65)	0–12[a] (n = 24)	13+[a] (n = 65)
Middle-aged group (25–54 years; n = 89)										
5	48.25	43.8	160.25	88.8	118.5	61.7	3.85	3.61	2.85	2.61
10	45	36.8	125.5	79.4	81	55	3.29	3.07	2.29	2.07
15	44	32.3	94.5	76.1	54	46.1	2.88	2.95	1.88	1.95
20	41	31	91	70.8	51	42.8	2.6	2.75	1.6	1.75
25	39.5	30	81.75	65	46.25	31	2.45	2.5	1.45	1.5
30	37.5	28	76.5	59.6	41	27.2	2.29	2.32	1.29	1.32
35	36.25	26	72.75	54.8	40.25	27	2.26	2.25	1.26	1.25
40	36	26	66	51.6	40	25.6	2.2	2.08	1.2	1.08
45	32.75	25	65	49.3	38.5	25	2.11	2.04	1.11	1.04
50	31	25	64.5	49	36.5	24	2.09	2	1.09	1
55	30	22.7	59.5	46.7	31.5	23	2	1.96	1	0.96
60	29	22	56	45	25	21.4	1.89	1.9	0.89	0.9
65	27.75	22	54.5	42	23	20	1.85	1.85	0.85	0.85
70	27	21	53	41	22.5	18.8	1.81	1.72	0.81	0.72
75	26.25	20	52.25	39.5	19.75	17.5	1.66	1.61	0.66	0.61
80	26	20	52	39	19	16	1.58	1.56	0.58	0.56
85	24.5	19	48.5	37	17.75	13.9	1.52	1.5	0.52	0.5
90	23	18	43	35	12	11.6	1.39	1.44	0.39	0.44
95	23	17	36.75	34	8.5	10	1.24	1.33	0.24	0.33

Percentile	TMT-A	TMT-B	B–A	B:A	B–A/A
Elderly group (55–80 years; *n* = 65)					
5	82.8	221.7	169.1	4.77	3.77
10	61.4	165.8	117.8	4.11	3.11
15	53	140.4	89.4	3.78	2.78
20	49.8	125.6	74.8	3.55	2.55
25	47.5	105.5	64	3	2
30	42.6	100.4	54.4	2.59	1.59
35	40	91	50	2.5	1.5
40	38.6	90	46.6	2.28	1.28
45	37.3	85.3	42	2.21	1.21
50	37	79	38	2.13	1.13
55	35.7	74.1	34.7	1.98	0.98
60	35	69	32.4	1.9	0.9
65	33.1	66.1	31.1	1.82	0.82
70	31.6	62.8	29.6	1.72	0.72
75	29	60	28	1.69	0.69
80	27	55.4	25.2	1.63	0.63
85	25	54	22.7	1.56	0.56
90	22	50	18	1.5	0.5
95	20	43.2	14.3	1.43	0.43

a Education (in years).

TABLE SET 3: EXECUTIVE PERFORMANCE & PROCESSING TIME

Kanaka, et al (2008). *Measurement of development of cognitive and attention functions in children using continuous performance test*

Table 1: CPT accuracies (mean ± SD) by age group (5–12 years)

	CPT indexes					
	T-cancel	**N-cancel**	**Hit**	**False**	**Omission**	**Commission**
5 years (*n* = 35)	4.77 ± 9.36[a]	19.14 ± 38.29[a]	0.66 ± 0.23[a]	0.01 ± 0.02[a]	22.74 ± 16.45[a]	2.89 ± 4.25[a]
6 years (*n* = 42)	1.67 ± 1.57[b]	9.14 ± 6.19[b]	0.81 ± 0.12[b]	0.01 ± 0.01[b]	13.29 ± 8.65[b]	1.62 ± 2.00[a,c]
7 years (*n* = 78)	0.06 ± 0.89[b]	2.82 ± 3.36[b,c]	0.96 ± 0.04[c]	0.00 ± 0.00[b]	2.24 ± 2.48[c]	1.46 ± 1.48[b,c]
8 years (*n* = 82)	0.38 ± 0.64[b]	2.10 ± 2.25[b,c]	0.98 ± 0.03[c]	0.00 ± 0.00[b]	1.52 ± 2.05[c]	0.90 ± 1.22[b,c]
9 years (*n* = 86)	0.26 ± 0.49[b]	1.23 ± 1.83[c]	0.98 ± 0.02[c]	0.00 ± 0.01[b]	1.27 ± 1.63[c]	1.37 ± 1.82[b,c]
10 years (*n* = 88)	0.22 ± 0.49[b]	0.67 ± 0.93[c]	0.99 ± 0.02[c]	0.00 ± 0.00[b]	0.75 ± 1.38[c]	0.96 ± 1.10[b,c]
11 years (*n* = 80)	0.06 ± 0.24[b]	0.36 ± 0.90[c]	0.99 ± 0.01[c]	0.00 ± 0.00[b]	0.63 ± 1.07[c]	1.28 ± 1.56[b,c]
12 years (*n* = 27)	0.00 ± 0.00[b]	0.19 ± 0.40[b,c]	1.00 ± 0.01[c]	0.00 ± 0.00[b]	0.37 ± 0.74[c]	0.85 ± 1.17[b,c]
F (7,510)	16.103[*]	16.837[*]	116.580[*]	6.302[*]	104.275[*]	5.351[*]

*Figures with different superscript letters in the same row differ significantly with each other at P < 0.05. (P < 0.05). n, the number of subjects; T-cancel, the number of cancellations of the target stimuli; N-cancel, the number of cancellations of the non-target stimuli; Hit, hit rate; False, false alarm rate; Omission, the number of omission errors; Commission, the number of commission errors.

Kanaka, et al (2008). *Measurement of development of cognitive and attention functions in children using continuous performance test*

Table 2: CPT responses (mean ± SD) by age group (5–12 years)

CPT indexes				
RT	**CVRT**	**d′**	**lnβ**	
5 years (*n* = 35)	769.11 ± 57.74^{a}	35.34 ± 27.22^{a}	2.17 ± 1.15^{a}	1.22 ± 0.47^{a}
6 years (*n* = 42)	737.02 ± 53.22^{a}	22.94 ± 6.09^{b}	2.87 ± 0.67^{b}	1.27 ± 0.36^{a}
7 years (*n* = 78)	623.41 ± 68.84^{b}	18.79 ± 3.91^{b,c}	4.26 ± 0.67^{c}	0.86 ± 0.67^{a}
8 years (*n* = 82)	598.74 ± 66.20^{b,c}	17.81 ± 3.44^{b,c}	4.51 ± 0.57^{c,g,i,k}	0.83 ± 0.68^{a}
9 years (*n* = 86)	551.42 ± 59.92^{d}	18.00 ± 3.79^{b,c}	4.62 ± 0.54^{d,i,k}	0.88 ± 0.77^{a}
10 years (*n* = 88)	518.94 ± 55.95^{d,c,b}	17.73 ± 3.72^{b,c}	4.82 ± 0.39^{d,h,j}	0.94 ± 0.70^{a}
11 years (*n* = 80)	418.68 ± 52.43^{f}	16.22 ± 3.36^{c}	4.88 ± 0.38^{c,f,h,i}	0.87 ± 0.63^{a}
12 years (*n* = 27)	483.37 ± 61.10^{c,f,g,h}	17.15 ± 3.13^{b,c}	5.00 ± 0.31^{d,f,g}	0.93 ± 0.48^{a}
F (7,510)	153.815*	24.755*	132.438*	3.248*

*Figures with different superscript letters in the same row differ significantly with each other at P < 0.05. (P < 0.05). RT, mean reaction time for a correct response; CVRT, coefficient of variance of mean reaction time for a correct response; d′, the sensitivity index; and lnβ, the response criterion index.

40

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Vita

Charles Scott Frost was born in Morristown, New Jersey. As a youth athlete he earned a black belt in Oyama Karate and worked up the ranks in the Eastern Tennis Assoc. After a career ending injury to his shoulder, he turned from tennis to theater and dance. He graduated at the top of his class from Morristown High School in 2002 and entered the University of Pennsylvania in Philadelphia, PA. He received his Bachelor's degree in Neuroscience in 2006.

After graduation from UPenn, he went on to receive a scholarship to the Pennsylvania Academy of Ballet. He performed until 2010 in both Modern Dance and Ballet Companies. During this time, he worked as a part-time strength coach at UPenn. After retiring from dance, he worked as a movement and strength coach for Parisi Speed School, specializing in injury recovery. In 2012, he enrolled at Rutgers University in New Jersey to study Human Anatomy and Exercise Physiology.

In August of 2012, he entered the Graduate School at the University of Texas at Austin. While at UT, he worked for 2 years as a teacher assistant in Gross Human Anatomy, while focusing his studies on Biomechanics and Motor Control. He is currently the Mobility, Strength & Speed Coach of the USL Pro Austin Aztex Soccer Club and an Athlete Performance Coach at Champions Performance Physical Therapy. He is the owner and founder of TOP Training Co. and CoachScottFrost.com.

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This Report manuscript was typed by the author.