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Correlation between working memory, intelligence, and cognitive functions

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Abstract

While man has been fascinated with memory, intelligence, and cognitive abilities for thousands of years, it was the scientific study of memory that led to the current interest in understanding the consequences of deficits in working memory capacity and learning disorders. Researchers have found reliable correlations between working memory span and several other measures of cognitive functions, intelligence, and performance in school. Working memory deficits impact all learners with a neurodevelopmental learning disorder. Given the correlation between working memory and academic success, researchers have studied the effects of training working memory. However, the results suggest the interventions are not generalizing to academics in students with a neurodevelopmental learning disorder. Rather than focusing on the deficits in working memory, Reuven Feuerstein takes a broader perspective and examines the cognitive functions underlying intelligence and what is going on in the learner's mind. Feuerstein defines cognitive functions as "thinking abilities" that can be taught, learned, and developed. Feuerstein has categorized the cognitive functions according to the three major phases of the mental act: input, elaboration, and output. Although artificially separated into three phases, cognitive functions do not necessarily occur separately in life.

Keywords: Working memory, intelligence, Feuerstein, cognitive functions, neurodevelopmental learning disorders

Introduction

Developing one's mental capacities has been a valuable skill for thousands of years. According to Frances Yates (1899-1981), "In the ages before printing, a trained memory was vitally important; and the manipulation of images in memory must always to some extent involve the psyche as a whole" (1). The Greeks are credited with many inventions including the art of memory. Yates brings to mind how Cicero recalls the story of how Simonides invented the art of

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memory in *De oratroe* (1). Simonides was dining at the house of Scopas, a wealthy nobleman, at Crannon in Thessaly. After Simonides recited a lyric poem composed for Scopas, he requested to leave the table and proceed outside. During his absence, the roof of the banquet hall collapsed, crushing everyone who remained at the table. Their relatives and friends wanted to bury them. However, the bodies were unrecognizable. Simonides was the only one able to identify them by his recollection of the place in which each of them had been reclining at table. The event led to the discovery of the importance of mental images to enhance memory. He determined that persons desiring to train their memory must select localities and form mental images of the facts they wish to remember and store those images in the localities. The most complete pictures are formed in our minds of the things that have been conveyed to them and imprinted on them by the senses, according to Douglas Herrmann and Roger Chaffin (2).

Greeks continued to contribute to the understanding of memory, as Plato and Aristotle were the first memory theorists. Aristotle introduced the law of association and analyzed memory retrieval. He compared the brain to wax that receives and impresses images into the learner's memory. Like Plato and Aristotle, Augustine presented a theory that connected memories to emotions experienced during the event, according to Herrmann and Chaffin (2).

Interest in memory would decline during the fifth century and not return until Aquinas in the thirteenth century. Aquinas agreed with Aristotle: "To think is to speculate with images" (3). The importance of the brain forming images continued with Comenius. He sees the foundation of knowledge and thoughts through the organs of sight, hearing, smell, taste or touch. Comenius acknowledges the wisdom of God in this process when he says,

> "Who was able to arrange that the small mass of our brains should be sufficient to receive so many thousands of images . . . . which are daily multiplied as we daily see, hear, read, or experience something new, are all carefully stored up. What inscrutable wisdom of God lie here? . . . . and who will not marvel at this abyss of memory which exhaust all things, which give all back again, and yet is never overfull or too void" (4)?

Though some argue that certain people are not capable of gaining knowledge, Comenius disagrees. He says, "It is scarcely possible to find a mirror so dulled that it will not reflect images of some kind, or for a tablet to have such a rough surface that nothing can be inscribed on it" (4). Yet he does acknowledge the natural differences found in learners' intellects. He exhorts teachers to meet these learners of weak intellects where they are by extending patience to help and strengthen their minds, so that they will not become discouraged but will reach the maturity God has for them (4). In teaching them something new, knowledge must begin with illustrations from everyday life. First, exercise the learner's senses, then form memories through images that lead to comprehension and discernment of the information (4).

The scientific study of memory originated with Hermann Ebbinghaus in the late 1800s. He is credited with setting a standard of careful scientific work in psychology (5). Implementing a scientific and systematic approach, he identified the complex relationships between memory and learning. The success of Ebbinghaus's method led to the development of other memory tests which included tests for measuring the span of visual apprehension, memory for digits, for lists of words, for sentences, and so on according to psychologist, Florence Goodenough (5).

Another influential psychologist, William James, was also interested in knowing how long and how much information one could temporarily maintain. As early as 1892, in *Principles of Psychology*, William James stated, "Unlike the virtually unlimited amount of knowledge that can be stored in a person's secondary memory (long-term), only a small amount of information can be kept conscious at any one time in one's primary memory (short-term)" (6-7).

Working memory

Sixty years later in 1956, William James' views on memory ignited cognitive psychologist, George Miller, to organize and study these memory systems. The concept of working memory, as it is understood today, is found in *Plans and the structure of behaviour* (8). Miller, Eugene Galanter, and Karl

Pribram state, when we have decided to execute some particular plan, it is probably put into some special state or place where it can be remembered while it is being executed. It may be somewhere in the frontal lobes of the brain. We should like to speak of the memory we use for the execution of our Plans as a kind of quick-access, 'working memory' (8).

Miller is most known for "The magic number seven, plus or minus two," which states that most adults can store between five and nine items in their immediate memory. He recognized the importance of grouping or organizing the input sequence into units or chunks. Since the span is a fixed number of chunks, one can increase the number of bits of information that it contains simply by building larger and larger chunks, each chunk containing more information than before. This kind of recoding increases the bits per chunk and packages the binary sequence into a form that can be retained within the span of immediate memory (9).

Interest in the kinds of memory intensified during the 1960's, producing a wide range of memory models. Until 1968, memory models had primarily consisted of short-term and long-term memory. One key modification came when psychologists Richard Atkinson and Richard Shiffrin presented a multi-store model, which included three components: sensory memory, short-term memory, and long-term memory. In this model, information enters from the environment and is detected by the sense organs where it enters the sensory memory stores. If the individual pays attention to the information, it enters the short-term store or "working memory," capable of manipulating the information (10-11). The information is held between 15–30 seconds in short term memory. After it is rehearsed repeatedly, it proceeds to long term memory. If rehearsal does not occur the information is not retained (10-11). Their theory emphasized the importance of cognitive functions (12). Figure 1 illustrates their flow of information (10-11).

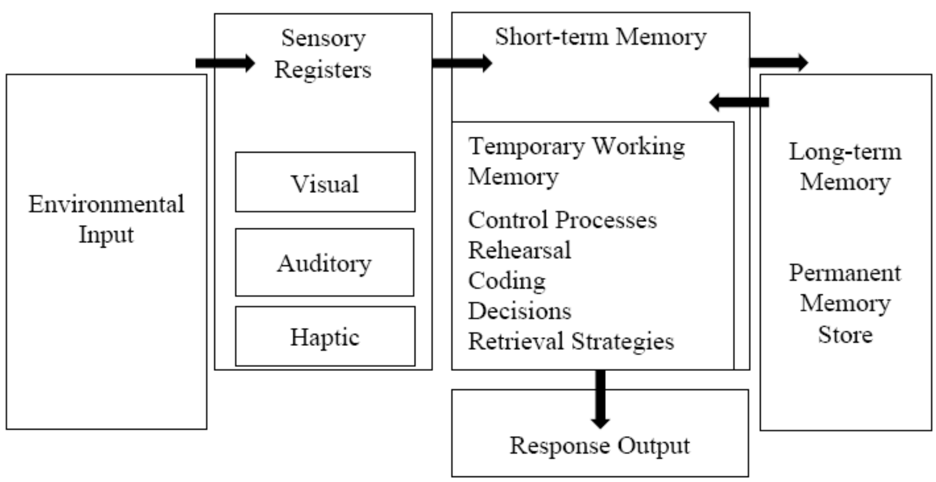

Figure 1. The flow of information through the memory system, Atkinson and Shiffrin.

While the multi-store model introduced the controlled process of transferring information from short-term to long term memory, two studies showed this model to be incomplete. According to Tan and Seng, "First, the model assumed that the longer information was maintained in short-term memory, the more likely it was to be transferred to long-term memory (12)." The first study, by Shallice and Warrington, examined a patient with brain damage who had a profound repetition defect, with his digit and letter span being reduced to two items or less on short-term memory test. However, the long-term memory system and retrieval appeared normal (13).

The second study, conducted by Craik and Watson on normal subjects, measured short-term memory storage times. Craik and Watson concluded that neither the duration of an item's stay or the number of times it was rehearsed in short-term memory was related to recall (14). From this Craik and Lockhart argued against Atkinson and Shiffrin's multi-store model for a non-structured approach. They explored the "depth of processing" information where greater "depth" allows greater cognitive analysis. They proposed a "levels of processing" approach focused on the role of coding or manner of processing in learning and the probability of subsequent retrieval (15).

Multi-component model of working memory

The UK Medical Research Council approved further research exploring the relationship between long and short-term memory in the early 1970s. Psychologist Alan Baddeley and Graham Hitch asked the question, "What is short-term memory for?" There was a consensus that its function was to serve as a working memory, a system that allowed several pieces of information to be held in mind at the same time and interrelated" (11). The term "working memory" evolved from the earlier concept of short-term memory (STM). STM provides a temporary storage where WM provides storage and manipulation (16). Baddeley and Hitch stated from the argument that working memory was a flexible and complex system with subcomponents (17). They proposed the existence of a core system or central executive who controlled the entire system. The subsystems of the visuospatial sketchpad (visual) and the phonological loop (verbal) would assist the central executive system (17). This multi-component model would be revised by Baddeley in 2000, and again by Baddeley, Allen, and Hitch in 2011; it is the most widely used model of working memory (16) and can be seen in Figure 2 (16).

The central executive

According to Baddeley, "The central executive component of working memory is assumed to be a limited-capacity attentional system that controls the phonological loop and visuospatial sketchpad and relates them to long-term memory" (11).

The phonological loop system

The phonological loop is the first storage system that stores and processes verbal information. It helps remember new words rather than recalling familiar words. The ability to form long-term representations of new phonological material is essential for the development of language. Learning new words impacts a child's cognitive development (18). Successful vocabulary acquisition has been claimed to be the single most important determinant of a child's eventual intellectual and educational attainments (19).

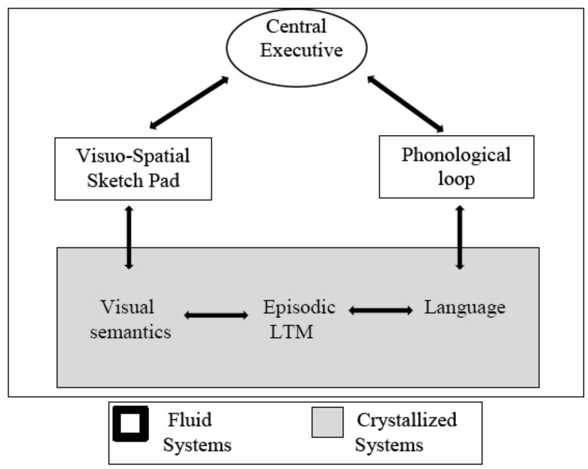

Figure 2. A modification of the original model to take account of the evidence of links between working memory and long-term memory.

The visuospatial sketchpad

The visuospatial sketchpad is the second short-term storage system responsible for binding and storing visual and spatial information. It can be divided into separate components: visual, spatial, and haptic. The visuospatial sketchpad is involved in recalling information or tasks, such as remembering the face of someone you just met or the location of items at the grocery store (20).

Episodic buffer

The episodic buffer was added by Baddeley in 2000 and is the third storage system. It acts as a buffer store, not only between the components of working memory, but also links working memory to perception and long-term memory. It was developed to explain the interaction between the phonological loop and visuospatial sketch pad, in addition to how working memory communicates with long-term memory. In 2011 Baddeley noted that it represents a limited capacity, storing integrated chunks of information or episodes. It is accessible through conscious awareness (21).

History of the measurement of intelligence

As man has been fascinated with memory, he has been equally fascinated with intelligence and the assessment of human cognitive abilities for thousands of years. Intelligence was first studied by Chinese emperors who used "large scale 'aptitude' testing for the selection of civil servants" circa 2200 BCE (22). These proficiency tests were given every three years. As the Chan dynasty began, candidates for public office were given a formal ability test (22).

Intelligence tests in the Eighteenth Century

Intelligence tests that examined the concepts of giftedness and intellectual disabilities began at end of the eighteenth century. The early pioneers were from France. First, Jean Esquirol explored the differences between mental illness and intellectual disabilities. He gave us the first modern mental test and was the first to label individuals as "idiots" based on this test (22). Next, French physician, Jean-Marc Gaspard Itard, was recognized as one of the founding fathers of special education (23). Itard is known for his work with the child referred to as "the Wild Boy of Aveyron" (24). He was the first physician to declare that an enriched environment could compensate for developmental delays caused by heredity or previous deprivation (25). Until this time, it had been assumed that people with an intellectual disability were uneducable. Itard's work with Victor "did away with the paralyzing sense of hopelessness and inertia that had kept the medical profession and everybody else from trying to do anything constructive for mental defectives" (26).

Itard's influence was extended through the work of his pupil, Eduard Séguin (22). Séguin improved and expanded Itard's sensory-training approach for those with intellectual disabilities. He developed methods of testing that were nonverbal and oriented toward motor activities and sensations based on Itard's work (22).

Intelligence tests in the Nineteenth Century

In the nineteenth century, scientists continued to study human intelligence. British scientist, Sir Francis Galton, studied the differences between monozygotic (identical) and dizygotic (fraternal) twins. His findings examined the nature versus nurture elements of mental abilities and leaned heavily on the genetic predisposition to abilities. He is recognized as the "father of behavioral genetics," or "differential psychology," the study of the differences in psychological traits. Galton was also the father of psychometrics (27). He was the first to demonstrate that "normal distribution" could be applied to human intelligence. Galton demonstrated that mental abilities are distributed in a bell-shaped curve. He established the world's first mental testing center in which a person could take a battery of tests and receive a written report of the results on mental ability (27). Galton's theory also stated that individuals take information through their senses, and intelligence would increase if sensory abilities could be increased (22).

Intelligence tests in the Twentieth Century

In 1904, Charles Spearman, a British psychologist, was the first to observe a pattern of positive correlations on various cognitive tests. Examining the grades of children in six academic disciplines, he conducted a statistical method called factor analysis. These six measurements could be reduced to correspond to a single mental ability known as a general factor, or Spearman's *g,* which continues to be used a century later (28). In a study by PC Kyllonen on the individual differences in working memory capacity and psychometric intelligence (or Spearman's *g*), he observed, "This finding of the centrality of the working memory capacity factor leads to the conclusion that working memory capacity may indeed be essentially Spearman's g" (29). However, there are three main ideas of what *g* truly means: (1) *general* cognitive ability; (2) a reflection of the correlation among several different but related abilities; (3) a statistical artifact (20). Spearman also introduced the *specific* factor which correlated to an individual's unique or specialized abilities (5).

In 1905, Frenchman Alfred Binet, along with colleagues Victor Henri and Theodore Simon, produced the first intelligence test. Observing his two daughters, Binet noticed that the older daughter could perform tasks that the younger could not. These differences led him to the concept of "mental age," which examines the relationship between cognitive abilities and age. The Binet-Simon scale included many tasks: pointing to body parts, defining words, naming objects in a picture, repeating digits and complete sentences, describing the differences among similar items, saying a list of rhyming words in a minute, telling time on a reversed clock, and cutting a shape from a folded piece of paper. This scale was designed to deal with general intelligence. Binet recognized problems with the test and believed it should only be used as one part of determining intellectual functioning (20). Binet states, "Some assert that an individual's intelligence is a fixed quantity which cannot be increased. We must protest and react against this brutal pessimism" (30).

Binet's assessment spread to the United States with HH Goddard and Stanford's Lewis Terman. By 1916, Terman had revised an American version and the "Stanford-Binet" was born. This new assessment was geared to American culture and was no longer limited to testing children but included adults. Terman presented a new total score called the "Intelligence Quotient (IQ)," which is used today (22). In 1922, Terman stated, "There is nothing about an individual as important as his IQ, except possibly morals" (31). The Stanford-Binet had become the standard for IQ testing in the United States.

Table 1. Origin of WISC-IV subtests

Verbal Comprehension Index (VCI)	Historical Source of Subtest
Vocabulary	Stanford-Binet
Similarities	Stanford-Binet
Comprehension	Stanford-Binet/Army Alpha
(Information)	Army Alpha
(Word Reasoning)	Kaplan's Word Context Test (Kaplan, 1950)
Perceptual Reasoning Index (PRI)	Historical Source of Subtest
Block Design	Kohs (1923)
Matrix Reasoning	Raven Progressive Matrices (1938)
Picture Concepts	Novel task (Psychological Corporation)
(Picture Completion)	Army Beta
Working Memory Index (WMI)	Historical Source of Subtest
Digit Span	Stanford-Binet
Letter-Number Sequencing	Gold, Carpenter, Randolph et al (1997)
(Arithmetic)	Stanford-Binet/ Army Alpha
Processing Speed index (PRI)	Historical Source of Subtest
Coding	Army Beta/Army Performance Scale
Symbol Search	Schneider & Schiffrin (1977)
(Cancellation)	

Intelligence testing spread during World War I as the U.S. Army used the assessment to determine who would be fit for military service. In 1917, David Wechsler, a student of Charles Spearman and Karl Pearson, began working for the army as a testing examiner using the Stanford-Binet scale to assess soldiers. The Stanford-Binet/Army Alpha system had a verbal scale and the Army Beta system had a performance scale (5). Noticing the inadequacies in the assessment, Wechsler believed that the deficiencies found in soldiers were due to a lack of education rather than a lack of intelligence (32). In

1932, Wechsler began working as the chief psychologist at the Bellevue Psychiatric Hospital in New York. During this time, he created a test that was based on his definition of intelligence, which, in his terms, was "the capacity of the individual to act purposefully, to think rationally, and to deal more effectively with his environment" (5). Wechsler believed it was necessary to measure verbal and performance intelligence, as well as global intelligence. This idea was revolutionary. The Wechsler-Bellevue scale was created in 1939 and developed into the Wechsler Intelligence Scale for Children (WISC) in 1949 and the Wechsler Adult Intelligence Scale (WAIS) in 1955. Both tests have been revised four times with the most significant change in the alternative set of summary scores organized into four domains of cognitive functioning: verbal comprehension, perceptual reasoning, working memory, and processing speed index (5). The composite scoring and origin of the subtests are seen in Table 1 (33). In 2003, shortly after Wechsler's death, the WISC-III was updated by the Pearson Company into a fourth edition. The WISC-IV was similar to the WISC-III but was revised to reflect increased attention to working memory and processing speed (33).

Correlation between working memory and intelligence

The measure of working memory capacity has a strong correlation to most intelligence tests. While a century has passed since the first IQ test was developed, there is still disagreement as to what intelligence really means, beyond a marker of an individual's intellectual ability (20). In many theories of intelligence, a distinction is made between fluid and crystallized intelligence. Fluid intelligence comprises the set of abilities involved in coping with novel environments and especially in abstract reasoning. It is measured by tests of matrix problem, figural analogy, and classification. Crystallized intelligence is the product of the application of these processes and is measured by vocabulary and general information testing (34).

In recent years "working memory" has been a key factor in determining fluid intelligence (35). Numerous studies have shown that an individual's working memory capacity predicts performance in both language and mathematical skills on national curriculum tests (36-38). Furthermore, low working memory capacities in children with or without learning disabilities result in academic difficulties (39-42). Working memory is considered the "workbench of cognition" and directly impacts an individual's performance on high-level cognitive activities; working memory is a good predictor of human cognitive functioning (42-44).

WISC IV working memory index

The Working Memory Index (WMI) on the WISC-IV is comprised of three subtests: digit span forward, digit span backward, and letter-number sequencing. For the digit span forward, examinees are required to recall a series of numbers presented to them by the examiner. For the digit span backward, the examinee is presented with a series of numbers and is required to repeat them in reverse order. The new subtest, letter-number sequencing (LNS), requires examinees to recall numbers in ascending order and letters in alphabetical order from a given number and letter sequence. The intention of the Working Memory index score is to determine how well the student gains information, manipulates it, and produces the correct answer (33).

Alloway working memory assessment, 2nd ed. (AWMA-2)

The *Alloway Working Memory Assessment*, 2nd ed. (*AWMA*-2) was developed by Tracy Packiam Alloway. Alloway reported that the WISC-IV and *AWMA*-2 are highly correlated (45-46). The *AWMA*-2 is a fully automated computer-based assessment of working memory skills standardized for learners ranging from five years to 79 years of age. There are three versions of *AWMA*-2: (1) *AWMA*-2 Screener: two working memory tests; suitable for screening individuals with suspected working memory difficulties; (2) *AWMA*-2 Short Form, which comprises four tests; recommended to screen individuals who are suspected to have memory difficulties, but the specific area of their difficulties is not known; (3) *AWMA*-2 Long Form: all eight tests; recommended for confirmation of significant working memory problems (45). Table 2 illustrates the eight tests which comprise the *AWMA*-2.

Table 2. Test included in the *AWMA*-2

VERBAL STM Digit Recall Letter Recall	*VERBAL WM* Backward Digit Recall Processing Letter Recall
VISUOSPATIAL STM Dot Matrix Block Recall	*VISUOSPATIAL WM* Mr X Backward Dot Matrix

Neurodevelopmental learning disorders and working memory

Over the last forty years, research on working memory has provided a deeper understanding of developmental cognition and neurodevelopmental disorders. Working memory deficits impact all learners with a NLD (47). According to the *DSM*-5, "The disorders are characterized by developmental deficits that produce impairments of personal, social, academic, or occupational functioning. The range of developmental deficits varies from very specific limitations of learning or control of executive functions to global impairments of social skills or intelligence" (48). There are six categories of NLD with varying diagnostic criteria.

Attention deficit hyperactivity disorder (ADHD)

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder defined by inappropriate levels of inattentive and/or hyperactive/impulsive behaviors that persist across more than one environment. ADHD is typically characterized by three subtypes including hyperactive-impulsive behavior, inattention, or a combination of these behaviors. The primary cognitive impairments associated with ADHD are deficits in executive functioning, in particular behavioral inhibition, which involves suppressing a prepotent (automatic) or irrelevant response (46). Individuals with ADHD typically perform within age-expected levels for verbal short-term memory; however, they fall below the average range in measures of verbal working memory and visuospatial short-term memory and working memory. This profile is consistent with previous findings that visuospatial deficits are more marked than verbal ones as they are less automatic and so demand more cognitive resources (49-50).

Autistic spectrum disorder (ASD)

Autism spectrum disorder was revised in the *DSM*-5. There was a spectrum of clinical profiles associated with this diagnosis ranging from autism, Asperger syndrome, and pervasive developmental disorder not otherwise specified (PDD-NOS) which are now integrated into the broad category of ASD (51). General ability (measured by IQ tests) plays an important role in determining where an individual falls in this spectrum. Students with ASD perform within age-expected levels for visuospatial, short-term and working memory. However, they fall below the average range in measures of verbal short-term memory and working memory. This profile is consistent with the idea that verbal memory may be linked to deficits in communication (52).

Intellectual disability (intellectual developmental disorder)

An intellectual disability includes deficits in intellectual and adaptive functioning in conceptual, social, and practical domains. The term *intellectual disability* replaces the term *mental retardation*. There are four levels of severity which include mild, moderate, severe, and profound (48). An IQ score of 65–75 (70 + or – 5) is the criterion for the diagnosis and further assessments by a clinician are needed to determine the severity level (48).

Communication disorders

Specific language impairment (SLI) is a relatively common communication disorder, also known as developmental language disorder, language delay, or developmental dysphasia. It is estimated to occur in approximately seven percent of the population, with boys being more affected than girls. It is characterized by a disproportionate difficulty in learning language despite having normal hearing, normal intelligence, and no known neurological or emotional impairment (46). SLI children typically have below-average performance in tests of verbal short-term memory and working memory (53). Their visuospatial memory skills are not impaired and performance is at the same levels as their peers in tests of both visuospatial, short-term memory and visuospatial working memory. This suggests that the difficulty that SLI children have in processing and storing information is specific to the verbal domain (46).

Motor disorders

"Motor disorders" replaces the previous categories of developmental coordination disorder (DCD) and tic disorders (51). Motor disorders refer to individuals who have a marked impairment in motor skills that affect daily activities at home and in the classroom. DCD is present from birth and affects the individual's ability to plan and control movements, which can lead to associated problems with language and perception. The typical memory profile of individuals with DCD indicates that they are able to cope with tests involving short-term storage of verbal information (54). However, once they also have to process verbal information, their performance drops as they struggle with the combination of processing and storing information as part of the verbal working memory tests. The most striking deficits are evidenced in visuospatial memory tests where they perform below average compared to their peers. Their poor visuospatial, working memory skills reliably discriminate them from those with SLI (55). Rooijen and colleagues found non-verbal intelligence and working memory were associated with the growth rate of arithmetic performance from 7–9 years of age, highlighting the importance of non-verbal intelligence and working memory to the development of arithmetic performance of children with cerebral palsy (56).

Specific learning disorder (SLD)

Specific learning disorder (SLD) combines the diagnoses of dyslexia or reading disorder, mathematics disorder, written expression disorder, and learning disorder not otherwise specified. Dyslexia is a specific learning disability characterized by unexpected difficulties in accurate and/or fluent word recognition, decoding, and spelling. Performance is comparable for both verbal and visuospatial, short-term memory tests: there are usually no signs of deficits in these measures. However, working memory scores show a different pattern. Specifically, there are verbal working-memory impairments, but relative strengths in visuospatial working memory. These verbal working memory deficits impact reading ability as reading requires considerable working memory "space" to keep all the relevant speech sounds and concepts in mind. This process can exceed the capacity of the dyslexic individual and ultimately result in frustration when they encounter new vocabulary words or challenging texts (46).

Dyscalculia, or mathematics disorder, is where students struggle to learn or understand mathematics. An estimated 5-8 percent of children are dyscalculic, with an equal representation of boys and girls affected. Students with dyscalculia find it difficult to decipher math symbols (e.g., +, -), understand counting principles ("two" stands for 2, for instance), and solve arithmetic problems. They also struggle with telling the time and recognizing patterns. Poor verbal working memory is usually only linked to dyscalculia in younger children (57), and once they reach adolescence, verbal working memory is no longer significantly linked to mathematical skills (58). Visuospatial, working-memory problems are linked to dyscalculia as it supports number representation, such as place value and alignment in columns in counting and arithmetic tasks (59). Poor working memory is thought to be one explanation for dyscalculia, because it limits the ability to remember mathematical rules, from basic concepts like counting in ascending and descending order to more complicated algebraic functions (60).

Cognitive functions

The review of NLDs show a deficit in working memory abilities for learners diagnosed with ADHD, specific learning disorders, motor disorders, communication disorders, autism spectrum disorders, and intellectual disabilities. While this correlation has led many psychologists to focus on working memory training, Reuven Feuerstein takes a broader view and examines the cognitive function underlying intelligence and what is going on in the learner's mind. Feuerstein defines cognitive functions as "thinking abilities" that can be taught, learned, and developed (61). Feuerstein has categorized the cognitive functions according to the three major phases of the mental act: input, elaboration, and output. Although artificially separated into three phases, cognitive functions don't necessarily occur separately in life. However, the subdivision is useful to analyze and describe thinking as well as to determine what factors might negatively affect thinking (61). Teachers and parents can use this model to better understand and help the learner who is experiencing difficulties with a particular task. By having a working knowledge of the cognitive functions, teachers (62) can differentiate between errors due to a lack of knowledge or from a deficient cognitive function (61). For example, if the learner fails in the task of classification, it is not enough to comment on the learner's poor intelligence or inability to classify, but rather the underlying causes of the difficulty (which can be found in one of the three phases of thinking) should be sought. The inability to classify, for instance, may be due to underlying underdeveloped functions, such as imprecise data gathering at the input phase or poor communication skills at the output phase. A detailed analysis of a learner's cognitive functions requires an in-depth understanding of the three phases of the mental act (63).

Deficient cognitive functions and corrections needed: Input level

The following list identifies and describes the deficient cognitive functions that Feuerstein's Instrumental Enrichment (FIE) seeks to correct in learners with neurodevelopmental learning disorders and learning disabilities. Understanding the degree to which the learner is affected directs the mediation process for cognitive modifiability (61).

1. Blurred and sweeping perception of essential information occurs. The learner struggles to gather the correct information. Correction: The learner learns to focus and perceive the data through his senses.
2. Difficulty in temporal and spatial orientation occurs. The learner lacks the ability to organize information realistically and to describe events in terms of where and when they occur. Correction: The learner learns the critical concepts of right, left, front, and back to know where they are positioned in space.
3. Deficient skills in precision and accuracy are present. Correction: The learner collects the correct information.
4. Inability to identify an object when there is a change in size, shape, quantity, or orientation, though it is the same object. Correction: The learner is able to decide what characteristics stay the same even when change happens.
5. Lack of capacity for considering two or more sources of information at once is present. This is reflected in dealing with data in a piecemeal fashion rather than as a unit of organized facts. Correction: The learner's able to keep two ideas in his mind at the same time and compare them.
6. Impulsive and unplanned exploratory behavior is present. Correction: The learner is able to systematically approach new information and objects (61).

Deficient cognitive functions and corrections needed: Elaboration level

1. Lack of ability to recognize the existence and definition of an actual problem. Correction: The learner can define the problem.
2. Inability to select relevant vs. non-relevant cues or data in defining a problem is present. Correction: The learner can recognize what is relevant to the problem and what can be ignored.
3. Difficulty in comparative behavior is present. This may be due to slow processing and inability to make comparisons between two or more things. Correction: The learner can see the similarities and differences between two things.
4. A narrow mental field is present. There is an inability to combine, group, and coordinate information. Correction: The learner can recall and use several pieces of information.
5. The projection of virtual relationships is impaired. The ability to perceive the relationship between events is difficult. Correction: The learner can understand relationships, apply conceptual labels, and categorize objects. He understands the main idea.
6. The absence of or need for logical evidence, inferential-hypothetical thinking, and hypothesis development occurs. Correction: The learner is able to use hypothetical thinking to test a hypothesis. He can see cause-and-effect relationships and use logical evidence.
7. Inability to visualize and create mental images is present. Correction: The learner is able to move away from concrete thinking to visualization.
8. Difficulty defining goals, planning behavior, and taking steps in problem solving occurs. Correction: The learner is able to form problem-solving strategies, make a plan, state the steps, and provide the reasons (61).

Deficient cognitive functions and corrections needed: Output level

1. Egocentric communicational modalities are present. It is difficult for the learner to relate to others and to see things from another's perspective. Correction: The learner is able to consider another person's point of view.
2. Lack of ability to repeat an attempt after a failure or blocking is present. Correction: The learner is able to persevere and overcome blocking.
3. Difficulty in projecting virtual relationships. Correction: The student is able to see virtual relationships such as two women can be cousins or four dots can be a square.
4. Use of trial-and-error responses, which leads to failure to learn from previous attempts, is present. Correction: The learner is able to stop and think through a plan of action.
5. Lack of, or impaired tools for communicating adequately elaborated responses. Correction: The students is able to give a thoughtful response.
6. Lack of, or impaired, need for precision and accuracy in communicating one's responses. Correction: The student is able to be precise and accurate when communicating.
7. Lack of self-control, impulsive, or acting-out behavior is demonstrated. Correction: The student exhibits self-control in speech and behavior.
8. Unable to visually transport information from one place to another, or unable to see the missing part. Correction: The learner is able to see the relationship between things that are not present (61).

Feuerstein has sought to identify and correct these deficits to enable students to reach their full cognitive potential, as well as to increase their internal motivation and personal confidence. By using mediation, these deficient functions can be corrected, formed and modified in significant ways (64).

Dynamic assessments

Feuerstein developed a complex set of dynamic assessment techniques, which are used to identify the gaps in human cognitive development. The Learning Propensity Assessment Devise (LPAD) is a battery of instruments that evaluates the way an individual learns and identifies the development of cognitive functions. The LPAD allows educators and psychologists to observe and record how a person learns. This reveals what kind of teaching is required to respond more successfully, as well as the amount of observed learning that is retained when new and more difficult tasks are presented. The assessment provides a picture of an individual's cognitive modifiability and learning potential (64).

The LPAD differs from traditional educational and psychological evaluations in four ways: (1) the assessment tools; (2) the assessment situations; (3) the emphasis of a process rather than a product orientation; (4) the interpretation of the outcome of the assessment. See below.

1. *Assessment tools differences*. The traditional assessments are static and focus on what the student knows rather than what they can know. Static tests do not allow learning to take place. Dynamic assessment allows learning and thinking to occur. The focus is on the learning process. "We are not concerned with informational questions that the learner might know. Such questions do not offer the opportunity to modify one's ability to deal with new situations," according to Feuerstein, Feuerstein, and Falik (64).
2. *Assessment situation differences*. The traditional test assessor looks at what is fixed, permanent, and unchanging in the student. The environment must be void of variations for different students. The situation must be repeated in different places with different students and different assessors. The dynamic assessment does not standardize the environment. While there are consistent guidelines when diagnosing, the student is compared only to himself. "In dynamic assessment, assessors will do everything in their power to create in the examinee the experience of modifiability," the authors said (64).
3. *Emphasis of a process rather than a product orientation*. The dynamic assessment looks at the cognitive functions of the input, elaboration, and output phases. The process the student utilizes is the focus. A static assessment focuses on the answer, or product. The student's success is based on his ability to give the correct response in the allotted time. The dynamic assessor asks, "What is the process through which the examinee can be modified? How can we bring about change in him or her" (64)?
4. *The interpretation of the outcomes of the assessment*. Static assessment utilizes quantitative terms using norms which consider the number of correct and incorrect answers. The dynamic assessment does not consider percentiles and standard scores. "The goal of the assessment is to uncover the individual's learning potential and to address ways in which learning can be facilitated to manifest real learning potential," according to Feuerstein, Feuerstein, and Falik (64).

Cognitive abilities profile

As psychologists and educators saw the benefit of a dynamic assessment, the initial work on the Cognitive Abilities Profile (CAP) began in 2002. It was developed by a group of educational psychologists in the United Kingdom to introduce the concepts and methods of dynamic assessment (12). The CAP is based on the tripartite learning model which has three elements, including the student, the mediator, and the task. According to Tan and Seng, "When the task, teacher, and learner are all of equal significance and are equally subject to intervention and analysis, the risk of making judgments about the abilities of the learner based on partial information is avoided" (12). The CAP aimed to measure the cognitive changes in the learner and focused on the learner's cognitive strengths and difficulties, measured the learner's response to teaching strategies, and used the mediating adult or teacher as the key agent to bring about cognitive change in the student (12). However, the assessment was not without challenges. There was insufficient time to assess cognitive strengths and deficiencies; in addition, a high level of training and experience was required, and the interpretation of the assessment with classroom implications was difficult (12).

As technology has changed, educators must adapt to focus on the thinking process and problem, not product and content. Tan and Seng state, "These processes can empower the learner to become independent, flexible, and adaptable in order to meet the challenges of change. These processes not only impact curriculum skills, but also lifelong learning related to social, work, and community environments" (12).

Conclusion

While man has been fascinated with memory and cognitive abilities for thousands of years, it was the scientific study of memory that led to the current interest in understanding the consequences of deficits in working memory capacity and learning disorders. Over the last twenty years, research on working memory found reliable correlations between working memory span and several other measures of cognitive functions, intelligence, and performance in school (65). Recent studies on individual differences in mathematical abilities show that aspects of working memory contribute to early arithmetic performance (66). Further studies examine the relationship between working memory, reading, and comprehension (67-68). The key to intelligence is being able to put those facts together, prioritize the information, and do something constructive with it. Working memory is the skill that gives an individual the advantage of managing all this information and is a stronger indicator of a learner's academic and personal potential than an IQ test (69-70).

Working memory deficits impact all learners with a NLD (47). According to the *DSM*-5, "The disorders are characterized by developmental deficits that produce impairments of personal, social, academic, or occupational functioning. The range of developmental deficits varies from very specific limitations of learning or control of executive functions to global impairments of social skills or intelligence" (48). This was the basis for Brown's presupposition of the causative effect of working memory on verbal and nonverbal abilities, IQ composite, and academic abilities, which proved to be wrong.

The current study contradicts the idea that working memory is a stronger indicator of a learner's academic and personal potential than an IQ test and the research of Alloway et al. which demonstrated gains in working memory which generalized to verbal, nonverbal, and spelling in 8 weeks. The current research demonstrated that working memory training does not seem to have a causative effect in relationship to verbal, nonverbal, and academic abilities when using *EMCDC* for 30 hours of intervention and removes this limitation for learners with a SLD (71). This finding adds to the importance of Feuerstein's emphasis on deficient cognitive functions rather than deficient working memory alone.

Moreover, the findings from the current study are consistent with Feuerstein's research that training cognitive functions can have significant impacts on cognitive and academic abilities**.** The *Equipping Minds Cognitive Development Curriculum* (*EMCDC*) is a method of cognitive skill development in the areas of processing, working memory, comprehension, and reasoning, which are based on correcting the deficient cognitive functions as described by Feuerstein.

Feuerstein examines the cognitive function underlying intelligence and what is going on in the learner's mind. Feuerstein defines cognitive functions as "thinking abilities" that can be taught, learned, and developed (61). Feuerstein has categorized the cognitive functions according to the three major phases of the mental act: input, elaboration, and output. Although artificially separated into three phases, cognitive functions do not necessarily occur separately in life. However, the subdivision is useful to analyze and describe thinking as well as to determine what factors might negatively affect thinking (61). Teachers and parents can use this model to better understand and help the learner who is experiencing difficulties with a particular task. By having a working knowledge of the cognitive functions, teachers (62) can differentiate between errors due to a lack of knowledge or from a deficient cognitive function (61). For example, if the learner fails in the task of classification, it is not enough to comment on the learner's poor intelligence or inability to classify, but rather the underlying causes of the difficulty (which can be found in one of the three phases of thinking) should be sought. The inability to classify, for instance, may be due to underlying underdeveloped functions, such as imprecise data gathering at the input phase or poor communication skills at the output phase. A detailed analysis of a learner's cognitive functions requires an in-depth understanding of the three phases of the mental act (63).

Cognitive developmental exercises could be incorporated into the teaching curriculum for every learner in the school, church, and home. Strengthening cognitive abilities with the FIE and *EMCDC* has far transfer effects to academics.

Feuerstein has sought to identify and correct these deficits to enable students to reach their full cognitive potential, as well as to increase their internal motivation and personal confidence. By using mediation, these deficient functions can be corrected, formed and modified in significant ways (64). *EMCDC* seeks to correct these deficient cognitive functions through the cognitive developmental exercises implemented in the current research study.

Additionally, this present study demonstrated that it possible to use *EMCDC* to raise the cognitive abilities of learners to an extent that has previously not been linked to learners with these disorders in 30 hours over 7 weeks. The current research found that training in working memory, processing, comprehension, and reasoning with *EMCDC* does provide convincing evidence to the generalization of verbal abilities, nonverbal abilities, and IQ composite. Similarly, far transfer effects to academic abilities in science were substantiated with significant gains using *EMCDC*. The results support the theories of MLE and SCM and the research of Feuerstein. *EMCDC*'s use of a human mediator and cognitive developmental exercises, which are based on a biblical worldview and Feuerstein's cognitive functions, have a greater impact than working memory training by a computer program alone.

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