Neuro-Cognitive Intervention for Working Memory:
Preliminary Results and Future Directions

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Introduction

The Motor Cognition²® Program (MC²) is a structured neurocognitive program designed to improve executive functioning and academic skills in individuals with executive function-based and related disorders, including Attention-Deficit/Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD), Traumatic Brain Injury (TBI), Learning Disorders, Alcohol/Drug Related Neurodevelopmental Deficit, and asynchronous development observed in children and adults with gifted intellect.

Purpose

People who have difficulty with attention/executive functioning deficit experience a variety of struggles that may include any combination of: inattention, distractibility, verbal and/or behavioral impulsivity, verbal and/or behavioral disorganization, poor ability to learn from experience, emotional dysregulation, poor initiation, inconsistent and/or poor academic performance, and social/interpersonal difficulties.

The MC² program uses a neuro-developmental approach to incrementally build foundation skills necessary for more efficient attention/executive functioning, and to build upon those foundation skill-sets in a manner that facilitates automation (procedural memory) of those skills. The MC² program integrates research-informed and empirically-validated strategies from the fields of occupational therapy, physical therapy, speech/language therapy, and rehabilitative medicine with current neurological and neuropsychological research on neuro-developmental disorders. In this manner, the MC² program offers a multi-sensory/multimodal approach to enhance how executive functioning skills mediate cognitive, emotional, and physical domains.

Program Structure

- Follows a detailed series of motor/cognitive exercises based on a level system (i.e. progressive skill development)
- One-on-one sessions, at least 3x/week for 1 hour per session
- Interactive, structured and consistent
- Targeted domains: attention, inhibition, perception-action coupling, working memory, balance, planning & organization, coordination & rhythm, and foundational academic skills & concepts
- Addresses character development while addressing executive functioning skills

Positive (a.k.a. attitude)

"Nothing can stop the man with the right mental attitude from achieving his goal; nothing on earth can help the man with the wrong mental attitude." Thomas Jefferson

Focus (a.k.a. focused)

"What do I mean by concentration? I mean focusing totally on the business at hand and commanding your body to do exactly what you want it to do." Arnold Palmer

Methods & Materials

- Participants included 38 children who completed the MC² program in 2012 and 2013
- All children completed pre-testing prior to beginning the MC² program, and completed post-testing following the completion of the program
- All children were voluntarily enrolled in the MC² program by their parents due to concerns about EF, attention, and learning difficulties
- Children attended session 3x/week for 1 hour each session, and completed all sections of the MC² program

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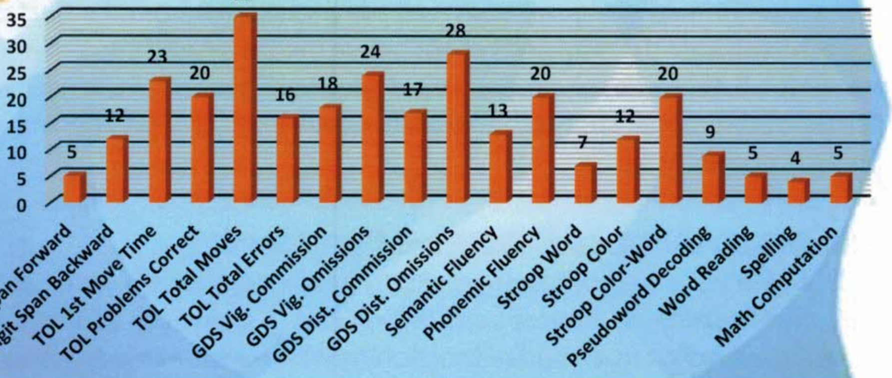
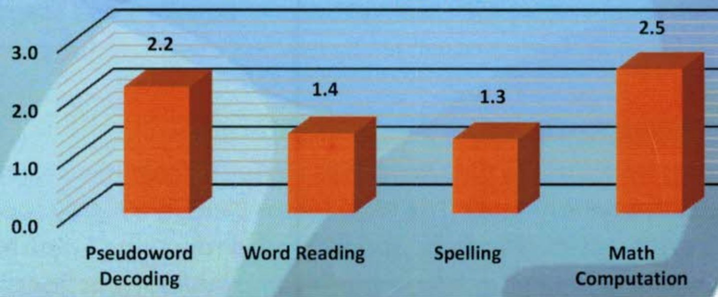
- **WISC IV Digit Span Backward** – Working Memory
- **Tower of London, 2nd Ed., Drexel University** – Inhibition & Visual Planning & Organization
- **NEPSY II Word Generation** – Language Planning & Organization
- **Stroop of Trail Making Test (x5)** – Perception-Action Coupling
- **Gordon Diagnostic System** – Sustained Attention
- **WIAT III Pseudoword Decoding** – Phonological Decoding
- **WRAT IV Word Reading** – Sight-Word Automation
- **WRAT IV Spelling** – Spelling Automation, Rules, & Handwriting
- **WRAT IV Math Computation** – Automation of Math Procedures

Findings

Mean Improvement in Percentile Rank
2012-2013



Mean Improvement in Grade Equivalent
2012-2013



Conclusion

Results of this preliminary research on the MC² program are compelling. They indicate an improvement in working memory capacity and increased reliability of working memory expression. Further, results indicate improvement in mathematic computation and phonological decoding without intervention directly focused upon building those skills. Therefore, it appears that this executive function intervention program offers benefits beyond executive function skills.

Nevertheless, potential limitations of this research include a small sample size, lack of a control group, as well as a comprehensive intervention program with numerous activities which may make factor analysis challenging. Further research is warranted to determine additional effects of this program on other executive function related skills, academic skills, and behavior. Independent research, the ideal key, would unlock the door to generalization.

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Motor Cognition^2 ®

The Motor Cognition^2® Program (MC^2) is a structured neurocognitive program designed to improve executive functioning and academic skills in children and adults with executive function-based and related disorders, including Attention-Deficit/Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD), Traumatic Brain Injury (TBI), Learning Disorders, Alcohol/Drug Related Neurodevelopmental Deficit, and asynchronous development observed in children and adults with gifted intellect. People who have difficulty with executive functioning experience a variety of struggles that may include any combination of: inattention, distractibility, verbal and/or behavioral impulsivity, verbal and/or behavioral disorganization, poor ability to learn from experience, emotional dysregulation, poor initiation, inconsistent and/or poor academic performance, and social/interpersonal difficulties. The MC^2 program uses a neuro-developmental approach to incrementally build foundation skills necessary for more efficient executive functioning, and to build upon those foundation skill-sets in a manner that facilitates automation (procedural memory) of those skills. The MC^2 program integrates research-informed and empirically-validated strategies from the fields of occupational therapy, physical therapy, speech/language therapy, and rehabilitative medicine with current neurological and neuropsychological research on neuro-developmental disorders. In this manner, the MC^2 program offers a multi-sensory/multimodal approach to enhance how executive functioning skills mediate cognitive, emotional, and physical domains.

The Importance of Executive Functioning

A child who has a neuro-developmentally based executive function deficit will not simply grow out of it. Executive functioning develops and improves as a child ages and matures; however, children who have a true cornerstone deficit in executive functioning will continue to experience difficulty throughout life. All of these interventions may be helpful; however, none of them directly address the root of the problem—the brain's poorly developed and/or poorly functioning neurological pathways. The blend of motor and cognitive exercises that MC^2 uses to intervene with brain processes develops and strengthens the neurological pathways necessary for a child to learn and more consistently express executive function skills.

Program Structure

The MC2 program follows a detailed series of motor/cognition exercises based on a level system (i.e. progressive skill development). The child learns skills in a highly specific and incremental manner to facilitate development, increased efficiency, and increased function of neurological pathways which are responsible for allocating and sustaining attention, initiating and inhibiting actions, planning and organizing motor movements and language, encoding information into memory, utilizing working memory, and overall learning. By teaching the child specific fine and gross motor, visual tracking, verbal organization, mental organization, reading, handwriting, and math reasoning skills in this incremental manner, the child not only learns individual skills, but also habituates basic skill sets to the point of automation that generalize to their home, school, and social environments. That is, the child can blend new and more complex skills into previously learned and habituated skills to show new learning.

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Neuro-Cognitive Intervention for Working Memory: Preliminary Results and Future Directions

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Definitions of working memory identify it as a function of the executive function system in which an individual maintains two or more pieces of information in mind and uses that information simultaneously for some purpose. In academics, working memory is necessary for a variety of functions, including attending to the information one's teacher presents and then using that information simultaneously for problem solving. Research indicates difficulties with working memory are observed in children with mathematics learning disorder (MLD) and reading disorders (RD). To improve working memory and other executive function difficulties, and as an alternative to medication treatments for attention and executive function disorders, the Motor Cognition$^{2®}$ (MC$^{2®}$)program was developed. Preliminary research on this program indicates statistically significant improvements in working memory, mathematics, and nonsense word decoding for reading. Further research on the MC$^{2®}$ program and its impact on working memory, as well as other areas of executive functioning, is warranted.

Key words: ***developmental, intervention, motor-cognitive, neuro-cognitive, working memory***

INTRODUCTION

In private pediatric neuropsychology practice, the authors frequently encounter children with weak or variable working memory and expression of executive functioning. The parents of these children would like to help them improve their expression of executive functioning. Though research (American Academy of Pediatrics [AAP], 2001, 2011; Biederman, Lopez, Boeliner, & Chandler, 2002; Brook, Brook, Zhang, Seltzer, & Finch, 2013; Multimodal Treatment Study of ADHD [MTA] Cooperative Group, 2004; Wolraich et al., 2001) has repeatedly shown medication can help improve the expression of sustained attention or inhibition, but may not necessarily improve the expression of other executive functions (e.g., working memory), parents are often concerned about the impact of medication on their child's brain development. In response to parents' concerns, Paul Beljan, PsyD, ABPdN, ABN developed the Motor Cognition^2 (MC^2) program—a neuro-cognitive intervention program designed to improve executive functioning in children. The program has been revised in recent years through the assistance of Kathleen D. Bree, PsyD and technicians who implement the program (Robyn Berry and Darrean Sweeney). Although the program addresses multiple domains of executive functioning, the current research focuses on the impact of the MC^2 program on children's expression of working memory.

Working Memory Theory

Working memory has been defined in many ways since its inception. Luria (1973) called working memory the human psychological workbench. More modern definitions of working memory indicate (a) it is the ability to encode and maintain two or more pieces of information in mind and to use those pieces of information simultaneously for some purpose, and (b) it is limited in size or capacity (Rapport et al., 2008; Sattler & Hoge,

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2006). Rapport et al. add that working memory serves a critical role in performing complex tasks, like learning, reasoning, comprehension, and planning; it plays a critical role in guiding our behavior. Goldberg (2001) indicates that working memory allows for future memory—the ability to establish a goal, to determine the objectives necessary to achieve the goal, and planning to meet the goal while sustaining attention and persistence to achieve the goal. He also explains that working memory allows us to draw on historical experiences to simultaneously inform current decision making. When these definitions are considered, it becomes clear that working memory is necessary for completing many academic tasks, as many academic tasks require an individual to encode information, manipulate it, and use it for a purpose while simultaneously maintaining and considering task parameters and prior learning.

Working Memory and Academics

Academic tasks, like working memory, are deceptively complex. Simply listening to a lecture and taking notes at the same time is just one example. To do so, a child must attend to the auditorily perceived information provided by the teacher, while simultaneously condensing that information into an outline form. The child also must use four distinct, consolidated skill sets (reading, handwriting, spelling, and written expression) to transcribe the summarized information. While the child executes these tasks, he or she must also attempt to relate the novel information presented by the teacher to previously learned information to generate new learning. It is the working memory process that allows these skills to be seamlessly and simultaneously executed.

Mathematics places similar demands on working memory in that novel information must be paired with habituated skill sets to generate new learning (e.g., a solution). An example would be that of a child encoding a verbally presented arithmetic problem, translating the English into math language, retrieving the appropriate math calculation operation from long-term memory while storing the arithmetic problem in working memory, and then using that information simultaneously to calculate and express a response to the question. In fact, research indicates deficits in working memory are often found in children who have a mathematics learning disorder (MLD; Geary, 1990; Geary, Brown, & Samaranayake, 1991; Geary, Hamson, & Hoard, 2000; Hitch & McAuley, 1991; Mabbot & Bisanz, 2008; Passolunghi & Siegel, 2001, 2004; Siegel & Ryan, 1989; Swanson, 1993, 1994; Swanson & Sachse-Lee, 2001; Wilson & Swanson, 2001), as are difficulties in retrieving addition facts from long-term memory (Geary et al., 2000; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Jordan, Hanich, & Kaplan, 2003; Swanson & Sachse-Lee, 2001).

A function involved in working memory and related to automated academic skills (e.g., note-taking, expressive writing, mathematic facts and procedures, etc.) is perception-action coupling (PAC). This is a relatively new term that might already be acquiring a reputation of lacking in any readily agreed upon definition or meaning.

One example of PAC, as we use the term, can be operationalized by our understanding of the learning of subtraction, after a child has automated the concept of addition and has automated the ascending sequence of numbers. Performing subtraction then requires the child to conceptualize the relationship between those numbers in a different manner (i.e., in reverse) and to utilize those numbers in a novel way (i.e., by subtracting). The child must inhibit the automated skill set of adding to perform this new function, but may rely on information learned from adding to assist with the performance of subtraction (e.g., the inverse principle: $a+b=c$; therefore, $c-b=a$). To do so requires the use of working memory, as the child must maintain the current problem in mind while accessing previously learned and automated information. Then the child must apply previously learned information to the current problem; however, the application of that previously learned information relies upon the child's automation of that previously learned skill set (i.e., perception-action coupling). The previously learned skill set must be automatically accessible, otherwise the child's short-term working memory, which has a limited capacity, may become overwhelmed. Being overwhelmed results in slow calculation of a formula that could be automated (e.g., $8\times7=56$ as opposed to $8\times7=8+8+8+8+8+8+8=56$). The same is true for other procedurally driven behaviors. Consider the first time you drove a car by yourself. You were hyper-vigilant and had to use intense concentration to drive the complex vehicle. Now consider how you last drove your car to work. The task is just as complicated, but the skill is consolidated. This consolidation frees your cognition to adjust the radio and contemplate thoughts while still performing the complicated task. That is how working memory works with procedural memory through PAC.

Although it has not been termed as perception-action coupling, research on MLD identifies difficulties with the perception-action coupling (i.e., automation) process. Mabbot and Bisanz (2008) report that, in mathematics calculation, "[s]olution latency and accuracy depend primarily on whether the answer is retrieved quickly or solved by means of a slower, 'backup' solution procedure (e.g., counting), which in turn depends on the distribution of associative strengths between a problem and possible answers in memory" (p. 16). Inefficient retrieval of addition and subtraction facts was found to be a common characteristic of MLD (Jordan et al., 2003), as were deficits in calculation fluency and mastery of basic mathematic facts (Geary et al., 2000; Geary et al., 2004;

Jordan et al., 2003). Research indicates that a lack of automation of basic mathematic facts results in a child having to repeatedly use backup procedures for calculation, rather than simply recognizing the answer to a basic mathematic fact or retrieving that answer from memory (Geary et al., 2000; Jordan et al., 2003). This likely increases the child's reliance on working memory, as the child must maintain the problem in mind while using backup or compensatory strategies (e.g., counting on his or her fingers) to calculate a response to the problem. This is problematic for children with MLD, as research indicates children with MLD perform worse on working memory tasks in comparison to typically achieving, age-matched peers (Geary, 1990; Geary et al., 1991; Geary et al., 2000; Geary et al., 2004; Hitch & McAuley, 1991; Swanson, 1993, 1994; Swanson & Sachse-Lee, 2001; Wilson & Swanson, 2001). This may be due to the child's working memory frequently being overloaded as they attempt to compensate for poorly automated mathematics skills (i.e., perception-action coupling deficit).

The concept of automation is a cornerstone of mathematics performance, but also a cornerstone for many other skills in life which require automation through learning and repetition. Goldberg (2006a) describes this process to illustrate how people in the later stages of their career can problem solve faster than a young professional. The older professional has a set of habituated skills that increase the speed and efficiency of problem solving, while the younger professional must still think through processes, using working memory, because those skills are not yet habituated.

Research further indicates a relationship between working memory and phonological processing/decoding for reading. Brady (2013) states "reading, in contrast to speaking and listening, requires explicit awareness of phonological segments, and [...] this awareness is difficult to achieve given the embedded nature of phonemes in syllables" (p. 129). Research indicates that poor readers struggle with phonological awareness, phonological processing for decoding, and working memory (Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977). With regard to working memory, research (e.g., Dempster, 1981) indicates children show a steady increase in the number of items they can recall (i.e., their encoding capacity) as they age. Two-year-old children, on average, can recall two items, whereas adults can recall approximately seven items. Notably, encoding capacity increases more slowly in children who are poor readers. Conversely, children with hyperlexia have been shown to have a strength in working memory, even with low intellectual functioning (Healy, Aram, Horowitz, & Kessler, 1982; Sparks, 2004). Baddeley, Thomson, and Buchanan (1975) found that the number of items an individual can recall is not fixed. It is related to the length of the item (i.e., the number of syllables) and the temporal duration of the item list on an encoding task. Additionally, presentation of unfamiliar stimuli on encoding tasks offsets the typical age-related increase in encoding capacity. Therefore, it seems likely that children who struggle to automate auditory phonemes and their symbolic representations (i.e., letters) would struggle more with decoding and reading lengthier words and passages. This is because the lengthier words and lengthier sequences of words in passages load working memory, and because the information appears novel each time due to limited automation of phonological processing for decoding.

Research supports claims that limited working memory capacity and/or consistency of expression are associated with reading difficulties. Brady (2013) notes that, when given a short list of items to recall (e.g., digits, letters, words, or nameable pictures), good readers recall more items than poor readers. She adds that this finding can be generalized across cultures with different reading formats (e.g., alphabetic writing systems and syllabic and logographic scripts), as demonstrated by Mann (1985) and Ren and Mattingly (1990). Furthermore, limited working memory in kindergarten children was predictive of later poor reading outcomes (Share, Jorm, Maclean, & Matthews, 1984). Baddeley (1966) and Conrad (1972) have hypothesized that poor readers struggle to use phonological representations in working memory, and poor readers cannot form phonological representations as well as proficient readers.

Implications for intervention

Theoretically, improving phonological awareness and decoding skills should improve reading skills; however, improving the operational efficiency of working memory also should improve reading skills, given the relationship between working memory and reading performance. Brady (2013) proposes that improving encoding (i.e., becoming more efficient and consistent) will allow memory and retrieval tasks to be performed more efficiently. She adds that "the difficulty observed in encoding phonological information is not restricted to memory tasks but occurs at a more abstract level, whenever it is necessary to create and maintain a phonological representation" (p. 135). It would logically follow that the same would be true for mathematics, as difficulty with mathematics has also been linked with difficulties with working memory. Supporting research includes Luce, Feustel, and Pisoni (1983), and Mattingly, Studdert-Kennedy, and Megan (1983), Geary (1990), Geary et al. (1991), Geary et al. (2000), Hitch and McAuley (1991), Mabbot and Bisanz (2008), Passolunghi and Siegel (2001, 2004), Siegel and Ryan (1989), Swanson (1993, 1994), Swanson and Sachse-Lee (2001), and Wilson and Swanson (2001).

EVALUATING WORKING MEMORY CAPACITY AND EXPRESSION

Determining appropriate assessments of working memory can be difficult, at times, as test descriptions and index names do not necessarily correlate with neuropsychological processes. A comprehensive review of all assessments of working memory is not feasible due to space limitations and the scope of this article; therefore, selected assessments will be discussed. For example, the Wechsler Intelligence Scales (*Wechsler Adult Intelligence Scale, 4th Ed.*; *WAIS-IV*; Wechsler, 2008; *Wechsler Intelligence Scale for Children, 5th Ed.*; *WISC-V*; Wechsler, 2014) Working Memory Indexes incorporate the Digit Span tasks and the Arithmetic task; however, research indicates different areas of brain activation when these tasks are performed. An investigation using positron emission tomography (PET; Wechsler, 1997) in adult normal control subjects during completion of Digit Span Forward and Digit Span Backward revealed similar and different areas of activity. During both tasks, the right dorsolateral prefrontal cortex (DLPFC), the bilateral inferior parietal lobule (IPL), and the anterior cingulate cortex (ACC) were activated; however, during Digit Span Backward, bilateral recruitment of the DLPFC and higher levels of activity in the IPL were observed. Cerebellar regions were also activated during these tasks. It should be noted that the frontoparietal network (FPN), which includes the DLPFC, the IPL, the ACC and other structures (for a more complete description, see Koziol, Barker, Joyce, & Hrin, 2014a, 2014b, 2014c, 2014d; Yeo et al., 2011), is assumed to be active in children; however, Koziol (2014) notes that older children tend not to fully recruit this network on tasks requiring mental manipulation of information. Koziol (2014) adds that children, when compared to adolescents, activate more ventromedial regions such as the caudate and insula, while adolescents activate more diffuse regions of the frontal and parietal cortices. Glascher et al. (2009) and Koziol (2014) note that the Digit Span subtest activates a different network than the Arithmetic subtest. Meyers and Rohling (2009) found that the Arithmetic task primarily activates the left parietal lobe, in addition to the FPN.

Because these tasks recruit different brain regions, though some brain regions are commonly activated across these tasks, the authors feel it is unwise to rely solely upon an index or composite score (e.g., the aforementioned Working Memory Index score). Rather, more information about an individual's working memory capacity and the consistency with which the individual expresses that capacity can be gleaned from reviewing qualitative errors, raw scores, and individual subtest scores—a sentiment also expressed by Lezak, Howieson, Bigler, and Tranel (2012), Koziol, Beljan, Bree, and Mather (in press), and others. Given the limited scope of this article, a more complete description of potential problems in relying on index names and index scores is not possible; however, the interested reader is referred to other sources (Koziol, 2014; Koziol et al., in press).

Qualitative differences between the tasks can also be observed. The Digit Span Forward task does not require mental manipulation of the numerical sequence the individual auditorily encodes, but instead requires immediate, rote, verbal recall of the sequence. The other portions of the Wechsler Digit Span subtests (i.e., Digit Span Backward and Digit Sequencing) appear to be more indicative of verbal working memory than immediate, rote, verbal recall, as they require manipulation of the encoded information. That is, the Digit Span Backward task requires the individual not only to encode verbally presented numerical sequences (one at a time), but to maintain the examiner's verbally presented instruction to mentally manipulate the encoded information to reverse it, and then to recall that information. Likewise, the Digit Sequencing task requires maintenance of the verbally encoded instruction to access the individual's previously automated sequence of ascending numerical order to then mentally manipulate the encoded information and to recall it in ascending numerical order, also while maintaining the examiner's verbally presented instructions. The Wechsler Letter-Number Sequencing subtest (also on the WISC-IV, WISC-V, and WAIS-IV) assesses working memory by requiring the individual to hold in mind the encoded alpha-numeric sequence while accessing his or her automated sequence of ascending alphabetical and numerical order to then mentally manipulate and reorganize the encoded information to recall it in ascending alphabetical and numerical order, also while maintaining the examiner's verbally presented instruction to do so.

The authors add that the Digit Sequencing and Letter-Number Sequencing tasks also rely on PAC, as the individual must utilize an automated skill in ordering alphabetical and ascending numerical sequences to then quickly, efficiently, and accurately retrieve those sequences to use them during the task. In these cases (i.e., Digit Span and Letter-Number Sequencing), the standardized outcome score is not necessarily as important as the highest number of digits reversed or sequenced if the individual performs the task reliably. For example, a child who recalls two, three, four, five, and six digits in the reverse order twice across two trials each has shown consistently expressed working memory capacity. Conversely, a child who recalls six digits twice across two trials, but recalls four and five digits once across two trials each has shown inconsistently expressed working memory capacity, which is more likely due to an attention problem than a working memory problem. It is not a working memory problem because the child's capacity for working memory is adequate; however, the child cannot reliably and consistently sustain attention to the information meant for encoding and/or cannot reliably sustain attention while mentally manipulating the information to consistently express his or her working memory capacity. This is a qualitative observation that transcends statistics and shows how poorly sustained attention can undermine and cause the irregular expression of an otherwise intact capacity for working memory.

As previously mentioned, the Wechsler measures also incorporate the Arithmetic subtest, which utilizes mental mathematic calculation to assess working memory. The individual must encode a verbally presented arithmetic problem, determine the relevant information in the problem, translate the English to mathematic language, determine the appropriate operation(s) to perform, calculate the response, and then provide the response, all within 30 seconds of the examiner reading the problem. Therefore, difficulties on this task could be attributed to difficulties in mathematic calculation skills, as well as to difficulty with sustained attention and/or working memory. Analysis of the individual's errors on the task may provide more information about whether the individual struggled with calculation, sustained attention, working memory, or some combination of the three.

Additional assessments of working memory exist, but are not necessarily marketed or described by test publishers as tests of working memory. For example, working memory is necessary on the *Tower of London, Drexel University, 2nd Edition* (*TOL*^{DX}; Culbertson & Zillmer, 2006a), as is inhibition. The individual must maintain two particular task rules in mind while engaging in problem solving. Making errors by failing to adhere to those rules can indicate impulsivity, as well as a working memory failure. Essentially, the individual has forgotten what he or she was doing while he or she was doing it.

Goldberg (2006b) has argued that the *California Verbal Learning Test, Children's Version* (CVLT-C; Delis, Kramer, Kaplan, & Ober, 1994) and the *California Verbal Learning Test, 2nd Ed.* (CVLT II; Delis, Kramer, Kaplan, & Ober, 2000) are the best tasks of working memory. He states that, because the individual is not told that semantic categories are embedded in the word learning list, individuals must use working memory to engage in problem solving simultaneous to the list being read to them to realize the presence of the semantic categories and to utilize those categories to encode the information more efficiently. We add that PAC is evaluated if the same individual applies semantic categorization to List B, because the individual generalized the knowledge from List A without being directed to do so.

Additional assessments of working memory exist, whether marketed specifically as tests of working memory or not. Due to the space limitations of this article, a full account of all available assessments of working memory is not feasible. The aforementioned assessments are offered simply as examples, though the CVLT is not presently used in the authors' MC$^{2®}$ research.

IMPROVING WORKING MEMORY: THE MOTOR COGNITION$^{2®}$ PROGRAM

The Motor Cognition$^{2®}$ (MC$^{2®}$) program is a structured neurocognitive program designed to improve executive functioning and, therefore, academic and vocational performance in children and adults with diagnoses including, but not limited to, Attention-Deficit/Hyperactivity Disorder (ADHD), executive function deficit (EFD), Autism Spectrum Disorder (ASD), mild Traumatic Brain Injury (mTBI), learning disorders (LD), and Alcohol/Drug Related Neurodevelopmental Deficit (A/DRND). It also addresses executive function-related asynchronous development observed in children and adults with gifted intellect.

The MC$^{2®}$ program uses a neuro-developmental approach to incrementally build foundation skills necessary for more efficient executive functioning to take place, and to build upon those foundation skill-sets in a manner that facilitates habituation and automation (procedural memory) of those skills. It does so by integrating research-informed and empirically-validated strategies from the fields of occupational therapy, physical therapy, speech/language therapy, and rehabilitative medicine with current neurological and neuropsychological research on neuro-developmental disorders. In this manner, the MC$^{2®}$ program offers a multi-sensory and multi-modal approach to enhance how executive functioning skills mediate the expression of cognition, emotion, learning, and movement.

Research (e.g., Koziol & Budding, 2009; Koziol, Budding, & Chidekel, 2013; Loher, Fatzer, & Roebers, 2014) indicates a client who has a neuro-developmentally based EFD will not simply grow out of it, and he or she cannot be talked out of expressing it. Executive functioning develops and improves as a client ages and matures; however, clients who have a foundational deficit in executive functioning will continue to experience difficulty throughout life. The individual will continue to develop executive function skills more slowly than same-age peers, and will continue to lag behind his or her peers.

Research on treatment methods for intervening in executive function disorders (American Academy of Pediatrics [AAP], 2001; 2011; Biederman et al., 2002; Brook et al., 2013; Multimodal Treatment Study of ADHD [MTA] Cooperative Group, 2004; Wolraich et al., 2001) indicates the following:

- Medication treatment of executive function-based disorders may reduce the child's expression of symptoms and difficulty, but the reduction will only last as long as the child takes the medication.

- Behaviorally-based interventions may improve a child's behavior within a highly structured environment, but one cannot train the child's behavior to the point that he or she will no longer express a brain-based disorder.
- Psychotherapy may improve the child's self-esteem and may help the child cope with the small and large failures experienced on a daily basis, but will not cause the child to express fewer failures.
- Social skills training may help the child learn and understand more appropriate social behaviors, but the child likely will not initiate these behaviors without prompting. Expecting the child to do so ensures failure.

All of these interventions may be helpful; however, none of them directly address the root of the problem—the brain's poorly developed and/or poorly communicating neural pathways. The blend of motor and cognitive exercises that MC^{2}® uses to intervene with brain processes is designed to develop, integrate, and strengthen the neural pathways necessary for a client (child or adult) to learn and more consistently express executive function skills, such as working memory.

The MC^{2}® program recruits motor and cognitive skills to complete exercises which are presented based on a level system (i.e., progressive skill development). These exercises, or skills, are allocated to specific domains of functioning, which include: gross and fine motor development, balance and coordination, visual tracking, mental organization, verbal organization, reading, writing (including written expression and handwriting), and mathematics. The client learns skills in a precise and incremental manner to facilitate development, efficiency, and function of neural pathways that are responsible for allocating and sustaining attention, initiating and inhibiting actions, planning and organizing motor systems and language, encoding information into memory, utilizing working memory, and engaging in learning in general.

The MC^{2}® skill exercises were developed and sequenced based upon findings in the child development and learning literature so that the program proceeds in a developmentally-informed, step-by-step manner. Lower level foundation skills must be mastered before more complex skills are taught and integrated into those foundation skill sets. All participants, regardless of age, complete all lower level skills in the same manner and in the same order to ensure any gaps or weaknesses in skill development are addressed. This is a crucial point, because when the program was first designed and implemented, it was qualitatively observed that skipping/omitting skills or levels had consequences for later, more complex skill attainment. (It should be noted that participants from the earliest iteration of the program were not included in the current study, as pre- and post-testing data from those participants is not available.) Certain skills were informed by those used in occupational therapy, physical therapy, speech/language therapy, and academic education, while other skills were created specifically for the program. Although the program includes reading, writing, and mathematics domains, it is not designed to be an intensive academic intervention program. Instead, foundation skills in the areas of reading, writing, and mathematics are addressed and repeated until they are mastered. Additionally, executive function-related MC^{2}® skills are performed to mastery, which in turn facilitates more consistent academic learning and performance.

METHOD

Participants

Participants included 45 children who completed the MC^{2}® program between November 2011 and March 2015. All of the children completed pre-testing prior to beginning the MC^{2}® program, and completed post-testing following completion of the program. They were voluntarily enrolled in the program by their parents due to concerns about executive functioning, attention, and learning difficulties.

Participants included eight females and 37 males who began the program between the ages of 6 years, 3 months and 13 years, 9 months (mean age at pre-testing: 8 years, 6 months) and who completed the program between the ages of 6 years, 10 months and 14 years, 8 months (mean age at post-testing: 9 years, 3 months). Participants required between 5 and 12 months to complete the program (mean time of completion: 7 months if attending 3 days per week, 1 hour per session). Some participants took breaks from the program when those breaks corresponded with school vacations. This caused them to require more time to complete the program. When breaks were taken, participants did not require review of previously learned skills, as their level of mastery of those skills was maintained.

Some participants had been previously diagnosed with executive function, developmental, and learning difficulties using criteria of the *Diagnostic and Statistical Manual of Mental Disorders (DSM), 4th Edition, Text Revision* (DSM-IV-TR; American Psychiatric Association [APA], 2000) and/or the *DSM, 5th Edition* (American Psychiatric Association [APA], 2013). Certain of those participants were diagnosed using DSM 4th and/or 5th Edition criteria based upon results of neuropsychological evaluations completed by the developers of the MC$^{2®}$ program, while others were diagnosed by psychologists and other medical/mental health professionals not associated with the MC$^{2®}$ program. Still other children were referred by their parents due to concerns indicating likely executive function, developmental, and/or learning difficulties. For those who had been previously diagnosed, those prior diagnoses included Attention-Deficit/Hyperactivity Disorder (ADHD; $n=29$), executive function deficit/perception-action coupling deficit ($n=8$), concussion/mild traumatic brain injury (MTBI; $n=1$), Autism Spectrum Disorder (ASD; $n=1$), Specific Learning Disorder (SLD) with Impairment in Reading ($n=8$), SLD with Impairment in Written Expression ($n=8$), SLD with Impairment in Mathematics ($n=5$), and/or intellectual giftedness with asynchronous development ($n=11$).

Exact data on the number of participants with specific prior diagnoses is not available because the MC$^{2®}$ was developed and implemented with these individuals to improve executive functioning and learning outcomes, and not necessarily with a future research study in mind; however, available data has been provided (above). Children who participated in MC$^{2®}$ and in specific academic intervention programs offered in conjunction with the MC$^{2®}$ program were excluded from the current research study due to concern that concurrent participation in an intensive academic intervention program (e.g., Lindamood-Bell reading interventions) might affect the researchers' ability to determine the impact of the MC$^{2®}$ program on the child's post-testing results.

Procedures and Materials

Participants completed all sections of the MC$^{2®}$ program, though some did not complete higher levels of the program. That is, participants who were developmentally and chronologically too young to complete the more challenging levels in the program did not complete those levels.

For pre-testing and post-testing, children were assessed individually in one session lasting between 60 and 120 minutes depending on the number of measures necessary. For pre-testing, children who had recently completed a comprehensive pediatric neuropsychological evaluation which included some of the pre-testing measures were not re-administered those measures, in an effort to prevent practice effects. Therefore, their scores from previous neuropsychological evaluation were substituted for re-administration of those measures. Participants who had not undergone recent neuropsychological evaluation were administered all pre-testing measures by psychologists and/or doctoral psychology students who were fully trained in administration and scoring of those measures. These psychologists/doctoral students were affiliated with the authors' private practice but were not directly affiliated with the MC$^{2®}$ program. All participants were re-administered the same measures during post-testing to assess the amount of change in their performance prior to completing MC$^{2®}$ and after completing MC$^{2®}$. As with the pre-testing, post-testing was completed by colleagues not directly involved in the MC$^{2®}$ program, but who were fully trained in administration and scoring of the post-testing measures.

It was predicted that participants would show improvement in the domains assessed following intervention with MC$^{2®}$. No less than 6 months had elapsed between pre-testing and post-testing; therefore, it is believed that practice effects were minimized. A list of measures included in pre-testing and post-testing is provided in Table 1. For the purposes of this article and due to space limitations, the authors will only discuss results of working memory measures, mathematics measures, and phonological decoding/reading measures. Results of other pre- and post-testing measures (e.g., sustained attention, inhibition, etc.) will not be discussed in this article, though those results are compelling.

Encoding and Working Memory Tasks

The Digit Span Forward subtest from the *Wechsler Intelligence Scale for Children, 4th Ed.* (WISC IV; Wechsler, 2003a) was used to assess general encoding capacity. This task requires the child to attend to verbally presented digits, encode them, and then recite them verbatim.

The Digit Span Backward subtest was used to assess general working memory capacity, or the specific amount of information the child is able to hold in working memory. This task has often been used to assess general working memory capacity and could be considered a traditional assessment of working memory (Koziol, 2014). It has also been used in research specifically aimed at studying working memory capacity and its relationship with MLD (Mabbot & Bisanz, 2008; Passoulunghi & Siegel, 2001, 2004). As previously mentioned, the

TABLE 1
Pre-testing and Post-Testing Measures

WISC IV Digit Span Forward
WISC IV Digit Span Backward
Tower of London, Drexel University, 2nd Ed. (TOL-DX) Children's Version
A Developmental Neuropsychological Assessment, 2nd Ed. (NEPSY II) Word Generation
Stroop Color-Word Test for Children
Gordon Diagnostic System (GDS)
Wechsler Individual Achievement Test, 3rd Ed. (WIAT III) Pseudoword Decoding
Wide Range Achievement Test, 4th Ed. (WRAT IV) Green & Blue Forms; Word Reading, Spelling, and Math Computation

TABLE 2
Means and Standard Deviations for Working Memory, Phonological Decoding, and Mathematics Measures Across Pre-Testing and Post-Testing

	Pre-Testing		*Post-Testing*	
	M	***SD***	***M***	***SD***
Working Memory				
WISC IV Digit Span				
Total Digits Forward	5	1.30	6.00	1.24
Digits Forward Percentile Rank	56	31.47	67.00	27.81
Total Digits Backward	3	1.00	4.00	1.11
Digits Backward Percentile Rank	63	26.00	81.26	20.98
TOL^{DX}				
Total Errors	3	3.67	0.00	0.71
Percentile Rank	20	26.10	57.00	14.94
Phonological Decoding				
WIAT III Pseudoword Decoding				
Total Nonsense Words Read	27	11.48	34.00	9.46
Percentile Rank	59	25.49	67.00	20.01
Mathematics				
WRAT IV Math Computation				
Total Problems Correct	29	8.62	35.00	9.71
Percentile Rank	74	25.63	78.00	25.26

examiner verbally presents a series of digits, and the child must encode those digits and mentally reverse them to repeat them in reverse order.

According to the *WISC-IV Technical and Interpretive Manual* (Wechsler, 2003b) the Digit Span Subtest, of which the Digit Span Forward task and the Digit Span Backward task are components, has good reliability ($r = 0.87$) and (corrected) stability ($r = 0.83$).

TOL^{DX} Errors

The *Tower of London, Drexel University, 2nd Edition* (*TOL*^{DX}; Culbertson & Zillmer, 2006a) was used to assess participants' use of working memory while involved in a more complex visual problem-solving task. This task requires the child to move three beads (one blue, one green, and one red) on three pegs (one small, one medium, and one large). The child begins each problem with his or her beads in the same starting position. From this starting position, the child is instructed to make his or her beads look just like the examiner's beads (which change with each problem) in as few moves as possible; however, the child is also instructed to follow two specific rules. First, only one bead may fit on the small peg at any time, while two may fit on the medium peg, and three may fit on the large peg. Second, the child may only remove one bead from the pegs at a time. At all times, at least two beads must remain on the pegs. The child must maintain these rules in mind while problem-solving to complete 10 problems on the TOL^{DX} task. When the child fails to adhere to either of these two rules, an error is committed. According to the *Tower of London Drexel University: 2nd Edition (TOL*^{DX}*) Technical Manual* (Culbertson & Zillmer, 2006b), the TOL^{DX} has somewhat limited test-retest reliability with regard to Total Rule Violations ($r = 0.24$; p was not reported) for individuals with ADHD. Most individuals with ADHD showed a decrease in errors from time one ($M = 2.1$; $SD = 2.4$) to time two ($M = 0.6$; $SD = 0.6$). Data on normal control subjects was not provided. Given the reported means and standard deviations, we expect to see a greater reduction in Total Rule Violations from time one to time two, because our participants engaged in an intervention between pre- and post-testing.

Mathematics

A computational mathematics task, the Math Computation task from the *Wide Range Achievement Test, 4th Edition* (WRAT IV; Wilkinson & Robertson, 2006a) was used to assess children's performance with solving mathematics problems ranging from simple addition facts (e.g., /1 + 2/) to more complex secondary school level problems (e.g., geometry, trigonometry, and calculus). The Green Form of the WRAT IV was used during pre-testing, while the Blue Form of the WRAT IV was used during post-testing so that participants would be provided with different math problems. This was done to reduce the likelihood of practice effects, as the two forms utilize different problems to assess the same skills, with a commensurate level of difficulty across problems. Although the *Wide Range Achievement Test, 4th Edition (WRAT-IV) Professional Manual* (Wilkinson & Robertson, 2006b) indicates the forms are meant to offer equivalent assessments of skill and ability, it should be noted that the forms are scored using different normative data. Therefore, completing the same number of items correctly on one form does not necessarily result in the same standard score for completing the same number of items correctly on the other form. For example, for a child who is 8 years, 2 months, earning a raw score of 29 on Word Reading on the Green Form results in a standard score of 98 (45th percentile; 2.6 grade equivalent), while a raw score of 29 on Word Reading on the Blue Form results in a standard score of 94 (34th percentile; 2.3 grade equivalent). Although the difference between these standard scores, percentile ranks, and grade equivalents may not seem like much, if the child completed the Green Form at pre-testing and the Blue Form at post-testing, and read the exact same number of words correctly, the child would appear to have "lost" some ability or declined in ability. This concern is important to note, as all of the participants in the present study were administered the Green Form at pre-testing and the Blue Form at post-testing. Unfortunately, this discrepancy in raw score to standard score/percentile rank/grade equivalent conversions was not known by the authors until data evaluation began.

Phonological Decoding

The Pseudoword Decoding subtest of the *Wechsler Individual Achievement Test, 3rd Edition* (WIAT III; Wechsler, 2010a) was used to assess children's ability to maintain rules of phonics and spelling in mind while decoding nonsense words to read them aloud. According to the *WIAT-III Technical and Interpretive Manual* (Wechsler, 2010b) the Pseudoword Decoding subtest has good reliability (Grade-Based: Fall $r = 0.96$; Grade-Based: Spring $r = 0.96$; Age-Based $r = 0.97$) and (corrected) test-retest stability (All Grades $r = 0.94$).

RESULTS

A paired-samples t-test was conducted to compare participants' performance on pre-testing measures prior to their completion of MC$^{2®}$ with their performance on post-testing measures following completion of the MC$^{2®}$ program. Therefore, for example, the participants' performance on the WISC IV Digit Span Backward task at pre-testing would be compared with their performance on the same task at post-testing. For certain tasks, raw scores at pre- and post-testing were compared, in addition to percentile ranks, as the participants' percentile rank may not have changed due to the nature of the normative data, despite the child showing a change in the number of items correctly completed on the task (i.e., raw score).

There was a statistically significant difference (i.e., improvement) in raw scores for WISC IV Digit Span Forward at Time 1 ($M = 5$, $SD = 1.30$) and at Time 2 ($M = 6$, $SD = 1.24$); $t(42) = -4.54$, $p = 0.000$. On average, participants encoded and recalled one more digit at post-testing than at pre-testing. There also was a statistically significant difference (i.e., improvement) in percentile ranks for WISC IV Digit Span Forward at Time 1 ($M = 56$, $SD = 31.47$) and at Time 2 ($M = 67$, $SD = 27.81$); $t(43) = -2.64$, $p = 0.011$. On average, participants' percentile ranks at post-testing were 11 points higher than at pre-testing.

There was a statistically significant difference (i.e., improvement) in raw scores for WISC IV Digit Span Backward at Time 1 ($M = 4$, $SD = 1.00$) and at Time 2 ($M = 5$, $SD = 1.11$); $t(42) = -6.51$, $p = 0.000$. On average, participants encoded and recalled one more digit at post-testing than at pre-testing. There also was a statistically significant difference (i.e., improvement) in percentile ranks for WISC IV Digit Span Backward at Time 1 ($M = 63$, $SD = 26.00$) and at Time 2 ($M = 81$, $SD = 20.98$); $t(43) = -4.24$, $p = 0.000$. On average, participants' percentile ranks at post-testing were 18 points higher than at pre-testing.

There was a statistically significant difference (i.e., improvement) in raw scores for Number of Errors on the TOL at Time 1 ($M = 4$, $SD = 3.67$) and at Time 2 ($M = 0$, $SD = 0.71$; $t(38) = 4.81$, $p = 0.000$. On average, participants made four fewer errors at post-testing than at pre-testing. There also was a statistically significant difference (i.e., improvement) in percentile ranks for Number of Errors on the TOL at Time 1 ($M = 20$, $SD = 26.10$) and at Time 2 ($M = 57$, $SD = 14.94$); $t(38) = -8.121$, $p = 0.000$. On average, participants' percentile ranks improved by 37 points from pre-testing to post-testing.

There was a statistically significant difference (i.e., improvement) in raw scores for Math Computation on the WRAT IV Green Form at Time 1 ($M = 30$, $SD = 8.62$) and the Blue Form at Time 2 ($M = 35$, $SD = 9.71$; $t(41) = -7.471$, $p = 0.000$. On average, participants correctly answered five additional problems. There was not a statistically significant difference (i.e., improvement) in percentile ranks for Math Computation on the WRAT IV Green Form at Time 1 ($M = 74$, $SD = 25.63$) and the Blue Form at Time 2 ($M = 78$, $SD = 25.26$); $t(44) = -1.623$, $p = 0.213$. On average, participants' percentile ranks improved by four points from pre-testing to post-testing. The lack of statistically significant change may be secondary to concerns about the raw score and subsequent percentile rank equivalence between the two forms of the WRAT IV.

There was a statistically significant difference (i.e., improvement) in raw scores for Pseudoword Decoding on the WIAT III at Time 1 ($M = 27$, $SD = 11.48$) and at Time 2 ($M = 34$, $SD = 9.46$; $t(36) = -7.534$, $p = 0.000$. On average, participants read seven more nonsense words correctly at post-testing than at pre-testing. There also was a statistically significant difference (i.e., improvement) in percentile ranks for Pseudoword Decoding on the WIAT III at Time 1 ($M = 59$, $SD = 25.49$) and at Time 2 ($M = 67$, $SD = 20.01$); $t(40) = -2.442$, $p = 0.019$. On average, participants' percentile ranks improved by eight points from pre-testing to post-testing. See Table 2 for pre- and post-test means and standard deviations.

DISCUSSION

The results of this pilot research on the MC$^{2®}$ program are compelling and warrant further and more detailed study. A viable non-medication intervention for ADHD and other neuropsychologically based disorders (e.g., ASD, MTBI, learning disorders, etc.) is highly desirable in light of parents' reluctance to consider pharmacological alternatives. Some of the improvements in participants' performance and behavior cannot be quantified. That is, it is not unusual for parents to tell MC$^{2®}$ staff that their child is behaving differently. For example, the child may have developed the ability to sit quietly at the table for dinner with the family, or the child may show a reduction in resistance to initiating homework. Teachers have been known to ask parents of children in the program if the child is taking medication, because the teacher observed drastic improvement in behavior and academic performance in the classroom.

Results of this preliminary research on the MC$^{2®}$ program are compelling. They indicate an improvement in working memory capacity and increased reliability of working memory expression. Further, results indicate improvement in mathematic computation and phonological decoding without intervention directly focused upon building those skills. Therefore, it appears that this executive function intervention program offers benefits beyond executive function skills. Nevertheless, potential limitations of this research include a small sample size, lack of a control group, as well as a comprehensive intervention program with numerous activities which may make factor analysis challenging.

Further research is warranted to determine additional effects of this program on other executive function-related skills, academic skills, and behavior. Independent research, the ideal key, would unlock the door to generalization. The benefit of a neuro-developmentally larger sample size might also identify age ranges that are critical for making decisions about one treatment strategy over another. Therefore, a program like this one can inform the way we think about "EF" and re-conceptualize its presumably critical components.

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