AN INVESTIGATION OF THE CHANGES ON WORKING MEMORY AND PROCESSING SPEED IN CHILDREN ENROLLED AT LEARNINGRX

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
IQ	Intelligence Quotient
ADHD	Attention Deficit Hyperactivity Disorder
WM	Working Memory
PS	Processing Speed
ACTIVE	Advanced Cognitive Training for Independent Vital Elderly
IMPACT	Improvement in Memory with Plasticity-based Adaptive Cognitive Training
ADL	Activities of Daily Living
HRQoL	Health Related Quality of Life
TIADL	Timed Instrumental Activities of Daily Living
WISC-IV	Weschler Intelligence Scale for Children IV
WMI	Working Memory Index
PSI	Processing Speed Index

ABSTRACT

The purpose of this research is to investigate a face-to-face cognitive training program through LearningRX, a company that provides individualized cognitive skills training. The goal was to evaluate changes in working memory (WM) and processing speed (PS) within six to eight weeks, or 30 hours of the intervention. A sample of ten children and adolescents between 8 and 14 years participated in training. A WM and a PS subtest were administered at pre-testing, and a different WM and PS subtest were administered at post-testing. Two separate one-way ANOVAs were run to examine if changes in the mean were statistically significant. Scores for WM and PS did now show a statistically significant change from pre- to post-test. While these findings are not statistically significant, the efficacy of the program though LearningRX should be further investigated, especially though completion of the program and to identify if gains can be demonstrated and maintained.

I. INTRODUCTION

Cognitive ability has been measured since the early 1900s through an Intelligence Quotient (IQ), and has been found to be relatively stable across time in a variety of samples and longitudinal studies (Beaver et al., 2013; Deary, Whalley, Lemmon, Crawford & Starr, 2000; Gow et al., 2011). In recent years, there has been an increase in research examining cognitive skills training. This increase has particularly focused on training specific cognitive skills, such as Working Memory (WM) or Processing Speed (PS) with the hope of showing significant improvements through neuropsychological tests for those skills (Edwards et al., 2002; Edwards et al., 2005; Holmes, Gathercole & Dunning, 2009; Holmes et al., 2010; Holmes & Gathercole, 2013). There has been a focus on such populations as aging adults, and children and adolescents with Attention Deficit Hyperactivity Disorder (ADHD). These populations are all similar in that they suffer from cognitive deficits. Having low cognition can affect many aspects of life, such as school and being able to learn at the pace that is being taught, the ability to work by making it difficult to meet or exceed expectations, or affect home life by making it difficult to practice in appropriate self-care or remember to take medications. The goal for working with these particular populations is to ameliorate or slow cognitive decline, to improve academic success, or to address symptoms such as inattention and impulsivity without using medications.

WM is the ability to temporarily store and manipulate a set of information in order to carry out tasks. Some examples of tasks that require the use of WM are performing mental calculations, hearing a set of numbers and saying them backward, or taking notes in a classroom. According to Baddeley (2003), WM is part of a subsystem of short-term memory, which has three components: the central executive, the phonological loop, and the visuospatial sketchpad. These three components work together to process and store information as well as contribute to successfully completing cognitive tasks such as reading, comprehension, learning, and reasoning (Baddely, 2003). PS is the rate at which the brain retrieves, transforms or encodes information (Conway, Cowan, Bunting, Therriault & Minkoff, 2002). There are arguments that processing speed is an integral part of the relationship between fluid intelligence and WM capacity. Faster processing leads to more information that can be held within WM capacity (Conway et al., 2002). Tasks that measure PS have a time component to measure the rate at which one can accurately process the information required for completion of the task. The ability to identify as many of a certain item within a group of other similar items within the time specified would be an example of a PS task. There has been a specific emphasis on the cognitive skills WM and PS due to the importance of these skills with necessary cognitive processes such as learning, and abstract thinking. If an individual had difficulty holding the necessary amount of information in WM or processing information in a given amount of time by PS, their cognition is limited. This affects if, and how a task is accomplished.

LearningRX

LearningRX is a company that provides individualized one-on-one training to people of all ages who are seeking to improve their cognitive skills and learning. For those entering a LearningRX program, baseline cognitive testing is conducted prior to beginning training by using parts of the Woodcock-Johnson III Tests of Achievement and Woodcock-Johnson III Tests of Cognitive abilities (Woodcock, McGrew & Mathers, 2001a; Woodcock, McGrew & Mathers, 2001b). The initial assessment is comprised of measures of intellectual functioning, working memory, and processing speed, as well as a number of additional cognitive measures.

Once the assessment has been conducted, the results are discussed with the parents and a particular program type and length is recommended based on the areas and level of cognitive deficiency. The results are provided to the student's trainer, who will then focus on the skills that were determined to be the weakest. Trainers conduct each session specific to the student and their needs with the goal of maintaining a relatively high level of cognitive demand throughout the training session. At the end of every session a trainer will require the student to name at least one improvement that they have noticed outside of LearningRX since their last session, and set weekly goals for personal development. Addressing personal development is not meant to affect cognitive performance; rather, it is meant to work on improving the student's character, manners, study skills, behaviors at school and home.

LearningRX offers four programs for ages six and up: ThinkRX, ReadRX, MathRX, and Einstein. ThinkRX is the core for all of the programs and every student completes this program, which includes 27 different procedures that increase in difficulty and intensity as one progresses through the program. Each procedure is focused on a broad cognitive skill, but can train on multiple skills. For example, Attention Arrows (similar to Stroop task) initially focuses on training attention, and as training progresses will aid in developing divided attention, processing speed, selective attention, sustained attention, visual manipulation, visualization, and working memory as the difficulty and intensity of the procedure increases. Divided attention is the ability to put attention towards one or more tasks while selective attention is the ability to attend to certain stimuli while ignoring other unimportant stimuli. Sustained attention is the ability to maintain concentration during a task for an extended period of time. Visualization is the ability to create an image in one's mind, as it would appear if it were actually there, being able to mentally manipulate that image by turning, flipping, or changing parts of it would be visual manipulation. The ReadRX program focuses on improving reading through increasing auditory processing abilities and lasts at least 24 weeks. The MathRX program focuses on improving the skills involved in critical thinking, logic and reasoning, and math, and lasts at least 20 weeks. The Einstein program lasts 32 weeks and consists of all the previously mentioned programs. Parents are able to choose their level of involvement in their child's training. The Partner Program is where the parents are providing half of the training, and the trainers provide the other half, which is usually about three hours a week from parents and three hours from the trainer per week. The Pro Program is where a trainer at the center does all of the training for five hours a week. The cost of receiving training varies depending on the length and type of program that is chosen, but starts at $5,300 for 14 weeks and can go into the $15,000+ range.

The goal of each program is to train on areas of cognitive weakness while maintaining the level of intensity at the threshold of an individual's cognitive abilities throughout the session. This is ensured through trainers maintaining minimal gaps between procedures using mental activities, such as arithmetic problems and having students state their answers to the beat of a metronome. A tenant of this training is that having a student constantly engaged in a mental task or requiring answers in a certain amount of time is how a high level of cognitive demand is maintained. Distractions are frequently used to maintain cognitive demand during tasks in order to ensure attention is maintained. Distractions vary depending on the task and the trainer. A few examples that trainers use are counting, talking, or providing other interference.

Most procedures in a program have multiple levels where the instructions for the task change in order to increase difficulty. In addition, the majority of the procedures have medal levels, starting at ribbon, bronze, silver, and ending with gold, which determines the intensity of the task for each level. An example of increasing intensity would be increasing the beat of the metronome or decreasing the amount of time allowed for completion. Students must pass a level based on standardized criteria that are set for each procedure before the trainer is allowed to move to the next level or increase the intensity through increasing medal level.

The biggest difference between the studies that will be discussed in the literature review is that the trainings are computer based whereas each LearningRX student engages in face-to-face training with a trainer who follows them throughout their entire program. Another difference is that the program by LearningRX utilizes various cognitive skills aiming to increase IQ score, not just PS or WM. However, both methods of training focus on advancing cognitive skills, thus making it is possible that IQ will be affected. In LearningRX, trainers establish a system of positive reinforcement and rewards personalized for each student. Examples of this are brain games in between procedures or after training, earning snacks, or earning Brainy Bucks to spend on prizes.

A trainer is able to modify procedures, making them easier or more difficult based on what is needed for the student to master the skill or level. An example of modifying a procedure to be easier may be taking out a timing component, or by breaking it down into briefer components until the procedure can be completed more than once without modifications. A way that a trainer could make a procedure more difficult is by requiring the student to work faster, by distracting them during the procedure, or by making them perform other mental activities such as arithmetic. Trainers have the opportunity to focus on behavior modification if necessary, which could address complaints brought up by teachers or parents, or behaviors that are disruptive to the session. Many common interventions might focus on decreasing excessive talking, being fidgety, fear of failure, touching objects, negative comments or attitude, addressing poor social skills, or bad posture. In addition, the trainer attempts to build rapport with each student, which can be beneficial for students who lack communication and social skills, or who are in need of a positive role model or excessive reinforcement. On the other hand, if rapport cannot be established, a different trainer may be assigned.

After a student's training is complete, they are tested once again using the previously described assessment. According to data from 2009, those that had severe cognitive weaknesses (i.e., at or below the 24th percentile on cognitive measures) before training had improved an average of 30 percentile points after training. Those that had moderate cognitive weakness (in the 25th-50th percentile) before training improved an average of 28 percentile points after training, and those that were above average (51st-100th percentile) before training had improved an average of 10 percentile points after training (LearningRX, 2011). LearningRX reports that in 2009 the average increase in IQ depended on the length of the training program; those that were enrolled in programs 12-24 weeks gained an average of 15 IQ points after training, and those that enrolled in programs 24-32 weeks gained an average of 20 IQ points after training (LearningRX, 2011). They also report that these gains in IQ were retained a year later, and after training students scored higher on the battery they use comprised of tests from the Woodcock-Johnson III Tests of Cognitive Abilities and Woodcock-Johnson III Tests of Achievement (LearningRX, 2011).

Problem Statement

Being able to improve cognitive function at any age would have many advantages for an individual, their family, and society. The current study will investigate the effects on cognition of LearningRX, an individualized one-on-one cognitive training program. Although it has been claimed that LearningRX increases IQ points by an average of one standard deviation, there is currently no published peer-reviewed research to substantiate this claim. The current study will measure changes in WM and PS from pre-test to post-test after six weeks of the intervention.

Research Hypothesis

It is predicted that there will be improvements in WM from pre-test to post-test. It is predicted that there will be improvements in PS from pre-test to post-test.

II. LITERATURE REVIEW

The purpose of this literature review is to examine current cognitive training methods used to improve WM and PS, results from training, possible benefits to training, and the limitations. At this time, there is a deficiency of supporting peer-reviewed literature investigating the intervention to be studied through this research. However, to address this gap in current research an understanding of how other training programs document significant findings, measure changes in cognitive skills, procedures for training, and the current critiques will still be of relevance.

Training Programs

The majority of current research examines a computer-based intervention called Cogmed, which is aimed at training WM (Benninger & Benninger, 2010; Holmes & Gathercole, 2013; Holmes, Gathercole & Dunning, 2009; Klingberg, Forssberg & Westerberg, 2002; Westerberg & Klingberg, 2007). In addition, a separate study with a large sample of older adults, called Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE), focused on training reasoning, PS, and memory in the elderly (Ball et al., 2002). There is little to no research investigating the training of multiple skills at once, or training that is face-to-face and not computer-based.

In order to discuss the effects of training, the terms near transfer and far transfer will be used throughout the document. Near transfer is when the skill that is being trained shows improvement on measures of that particular skill. Far transfer is where improvements are evident after the training on skills that are related, yet were not the focus of the intervention.

Cogmed. Cogmed is a computer-based WM training program that has been extensively studied. In Cogmed training, participants train for 25 to 30 minutes, four to five days per week for five to six weeks, totaling around 25 sessions (Klingberg et al., 2002). Cogmed consists of four tasks, with 30 trials for each task, with an algorithm that automatically increases task difficulty based on performance in order to maintain the optimum level of cognitive demand of a training session and to not let the tasks become too easy or too difficult. The goal is for the participant to train at their maximum WM capacity. For the purposes of research there is also a non-adaptive version of Cogmed without the algorithm, which is implemented as a control condition. The non-adaptive version does not increase demand on WM capacity, thus an improvement is not anticipated for individuals in this condition.

According to Shipstead, Hicks, and Engle (2012a) there are three Cogmed programs for different age ranges: Cogmed JM for preschoolers, Cogmed RM for children above preschool age, and Cogmed QM for adults. Cogmed JM and RM have tasks masked as video games incorporating asteroids or robots. Cogmed QM presents tasks without the themes of the version for children. Cogmed software manages task administration, requiring minimal human administration. This allowed for studies to be conducted where parents or teachers administered Cogmed instead of researchers, and the results were similar to studies where Cogmed was administered by researchers (Benninger & Benninger, 2010; Holmes, & Gathercole, 2013). Cogmed also comes equipped with motivational features such as positive feedback displayed on screen, displaying the best scores obtained, and how much ‘energy’ has been gained. The ‘energy’ level is accumulated based on one’s performance and can be spent on a racing game after training as a positive reinforcement (Holmes et al., 2009).

ACTIVE. There has been a substantial research initiative called ACTIVE, which consists of five centers across the United States that have collected extensive data on over 2,000 individuals, aged 65 and over, who had not yet experienced substantial cognitive decline (Ball et al., 2002; Jobe et al., 2001). The aim of ACTIVE is to evaluate the effectiveness and persistence of three separate cognitive training interventions focusing on memory, processing speed, and reasoning, along with a control group. According to Jobe et al. (2001), the training provided for memory and reasoning focused on teaching and practicing strategies that could be used to improve each construct and the transfer of those skills to ADLs. The memory and reasoning trainings do not meet criteria for training due to teaching the participants strategies. Developing strategies aids in changing how the task is performed and does not focus on changing the cognitive processes, as training should (Jaeggi et al., 2010; Shipstead, Redick, and Engle, 2012b). For this reason, they will not be reviewed here.

The sample population consisted of 2,832 participants aged 65 or over who were living independently, had not experienced a substantial loss in cognition or functioning, and had not been diagnosed with any medical condition that would lead them to experience functional or cognitive decline or cause mortality in the near future

The intervention for PS is relevant to the literature review due to it being an adaptive computer based training. Task 1 required participants to identify objects, with the exposure time of the object decreasing with achievement. Once mastery was met at the shortest exposure time, Task 2 would begin. Attention was divided between identifying a stimulus in the center of the monitor and localization of a different stimulus in the periphery. The program adapted to become more difficult by decreasing the amount of time the stimulus would be on screen and expanding the area for the peripheral stimulus to present itself. Task 3 would begin after mastery of the previous task, which added visual distracters. Task 4, the final level, added an auditory identification task to the exercise. Each intervention group received ten sessions in a group setting, which lasted an hour to 75-minutes per session, over a period of six weeks. Follow-up testing was done within ten days after training was completed, and then 12 months and 24 months after training was completed. An offer of four booster sessions was relayed to a 60% random sample 11 months after initial training (Ball et al., 2002; Jobe et al., 2001).

According to Ball et al. (2002), the study had primary, proximal, and secondary outcome measures. Primary outcomes were the improvement on daily tasks needed for independent living that are cognitively demanding. Specifically for PS training, primary outcomes were daily speed and driving habits. Proximal outcomes are measures of the ability that is being trained. It was assumed that improvements on proximal outcomes would mediate improvements on primary outcomes. Secondary outcomes were health related quality of life (HRQoL), health service utilization, and mobility (number of falls, the distance one travels from their residence, and car accidents). In the study, HRQoL was measured by using the Short Form-36, which asks participants to rate themselves on different domains that effect HRQoL such as social functioning, mental health, physical functioning and limitations due to one’s physical functioning, body pain, vitality, perceptions of health, and limitations caused by emotional problems (Wolinsky et al., 2006a). It was hypothesized that regardless of the intervention a participant was in, they would all improve on primary and secondary outcomes, and that improvements on proximal outcomes would mediate improvements on primary outcomes.

WM Training

WM is linked to tasks that require high cognitive functioning such as reading, comprehension, reasoning, and planning, which are necessary for academic achievement. This is a possible explanation as to why WM has become subject to the vast research on cognitive training. The theory would then be that if WM can be increased, academic performance and intelligence should improve.

WM training for ADHD. Those that have a diagnosis of ADHD can be inattentive, hyperactive, and impulsive. They may also have difficulty with tasks involving reasoning, organization, goal setting, following directions, persistence, and planning, all of which require executive functioning and use of the frontal lobes, which are related to WM capacity (Benninger & Benninger, 2010; Holmes et al., 2010; Klingberg et al., 2002). In a study by Klingberg et al. (2002), a group of children and adolescents diagnosed with ADHD, and a group of adults in their twenties with no WM impairments and without a diagnosis of ADHD went through the Cogmed training. Motor activity correlates with ratings of hyperactivity was measured through tracking head movement. It was found that those that were diagnosed as having ADHD showed a decrease in head movement by 74%, and had significant improvements on both the trained WM tasks and the untrained tasks of visuo-spatial WM, attention, and complex reasoning. However, Shipstead et al. (2012a) stated that while the first few studies such as Klingberg et al. (2002) saw improvements in reasoning abilities, they were unable to replicate the results, and he discusses that more replications are necessary, especially those that indicate ADHD symptoms can be alleviated. He notes that only a facet of hyperactive behavior (head movement) was reduced, and that this finding was not replicated. Similar results were also found for the group of adults, which showed that in order for an increase in WM capacity to occur, it is not necessary that there be a deficit in the first place. Benninger and Benninger (2010) investigated whether Cogmed was effective while being administered at home by the participant's parent. They found that intense WM training was beneficial and effective at reducing symptoms of ADHD, such as inattention, in children and adolescents. However, these measure of improvement in ADHD symptoms were subjective, as they were ratings from parents. According to Shipstead et al. (2012a), results of decreased ADHD symptoms should be taken lightly, as expectation-of-outcome provides an explanation. There was also an increase in executive function performance, and the gains were still evident at the 4-month follow up.

Holmes et al. (2010) found during a study on children with ADHD that WM significantly improved, specifically on tasks that worked visuospatial WM and executive functioning. Objective measures were administered to track improvements, which included an extensive WM battery and an abbreviated intelligence scale. They also reported sustained gains six months later.

WM training for academic success. While some studies have supported the effectiveness of Cogmed for those that have ADHD, Cogmed has also been examined in populations without ADHD to see if Cogmed can be applied as a tool for improving academics. Holmes and Gathercole (2009) were the first to look at the educational significance of Cogmed in order to see if enhancing WM helps overcome learning difficulties that are due to low WM in children without ADHD. The study evaluated how much WM training would boost academic performance and WM based on a standardized battery of WM tasks, measured after training as well as six months later. They found that of those who had received the adaptive training, 68% improved their scores to within their range of age equivalency compared to 25% of those in the non-adaptive group. Those results were also seen at the six-month follow up. In addition, they observed a significant improvement in mathematics performance for those in the adaptive group, indicating that the gains can transfer to untrained academic related tasks.

In a more recent study done by Holmes and Gathercole (2013), their aim was to see if the results typical of Cogmed could be replicated by having a teacher administer the program. In the first trial, results from a class of 8 to 9 year olds showed that those with lower WM scores at pre-intervention showed the greatest gains. In the second trial, a group of 9 to 11 year olds that had low performance in English and math from the previous year participated in training. Those who completed the training made significant gains in both math and English. In both samples, the gains transferred to untrained WM tasks. Gains were also seen in the National Curriculum assessments that were given for English and math, which suggests that WM training may be used to improve academic success. Additionally, having teachers administer the program led compliance rates to be about 10% higher than those in a laboratory setting

There has been other research in the area of cognitive skills training that does not use Cogmed as the intervention and instead the researchers designed their own interventions. Jaeggi Buschkuehl, Jonides, and Shah (2011) conducted a study with children that used an adaptive spatial single n-back task in order to train WM. A spatial single n-back task consists of participants being shown a sequence of stimuli at designated locations with three seconds in between. The participants were asked to press a key at the moment when the stimulus that is actively on the screen was at the same spot as the stimulus n items previous. They found that the level of transfer to untrained tasks of WM and executive functioning was dependent on the level of gains that a participant had during training. Additionally, they found that the participant's perceived difficulty of training was influential; those that had the largest gains rated the training to be difficult yet not overwhelming, whereas those that improved the least rated the training as too difficult and requiring more effort. This is important because the adaptive feature should have each individual reaching their threshold for cognitive demand, yet should not be perceived as too difficult to complete (Jaeggi et al., 2010; Jaeggi et al., 2011). Just like Holmes and Gathercole (2013) found, the gains were still evident three months later, and those who had lower skills initially experienced the most gains after training. Those who did not experience large gains were believed to have already been performing close to or at their WM capacity.

Many studies have been unable to link WM training to effects on IQ (Holmes et al., 2009; Holmes et al., 2010; Jaeggi et al., 2011). However, one study has been able to link WM training to increased fluid intelligence (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). In this study, a computer-based dual n-back task was used to train WM. This task is similar to the spatial single n-back task described above, however, there is an added auditory n-back task being presented simultaneously with the visual task. There were four different intervention groups, which differed on the number of sessions that were provided; 8, 12, 17, and 19 sessions. Results showed that training on this WM task exhibited far transfer to fluid intelligence. More importantly, they found that the amount of training received was directly correlated with higher intelligence gains.

Effects of training on the brain. Research has shown tasks which require WM and tasks requiring reasoning skills both rely on the prefrontal cortex, which is associated with higher levels of functioning (Halford, Cowan & Andrews, 2007; Klingberg et al., 2002). Additionally, Halford et al. (2007), proposed a framework to study the improvement of fluid intelligence through a working memory task. They posit that in the frontoparietal area of the brain there is a commonly shared network. In this, they examined an underlying limit to the capacities or "chunk limit" in working memory and reasoning.

Olsen, Westerberg & Klingberg (2004) and Westerberg & Klingberg (2007) used fMRI to measure changes in the brain after WM training. Both studies found that WM training transferred to both the trained WM tasks and untrained tasks of reasoning. Olsen et al., (2004) also found improvements on tasks that measured response inhibition and impulsivity. Olsen et al., (2004) found an increase in brain activity in the prefrontal and parietal cortices after training, and Westerberg & Klingberg (2007) found that there was an increase in brain activity in areas of the prefrontal cortex. The authors explain that the changes seen through the fMRIs are possibly due to an increase in neurons and neuronal responsiveness related to cortical plasticity induced by the training (Olsen, et al., 2004; Klingberg & Westerberg, 2007). These studies exhibit another possible way to measure the effects of cognitive training on the brain, with neuronal plasticity accounting for the observed improvements.

Training PS

The speed at which one can process information is another targeted skill in the cognitive training research due to the relevance of PS in everyday tasks. Especially as age increases, some of these daily tasks that require PS include maintaining independence through decreasing the risk for falls, maintaining driving ability, and the radial distance one travels from their home (O'Connor, Hudak & Edwards, 2011). Research has also found that increased PS is strongly correlated with fluid intelligence (Coyle, Pillow, Snyder & Kochunov, 2011; Fry & Hale, 2000). Fluid intelligence is the ability to use abstract reasoning, and it has been shown to correlate with academic and professional success (Jaeggi, et al., 2011). As such, an increase in PS should presumably yield an increase in scores on fluid intelligence, improved academic achievement, professional success, improved problem solving, and faster completion of tasks.

PS training for ADLs. The results of the ACTIVE study showed that participants improved on the particular skill on which they were trained, that the gains were maintained five years later, and that higher gains were achieved when booster sessions were given (Ball et al., 2002; Willis et al., 2006). Participants in the intervention groups reported being able to complete ADLs with more ease than those in the control group, even five years after the training, showing that cognitive training may aid in decreasing age-related cognitive decline and may prolong independence (Willis et al., 2006). According to Ball, Edwards, and Ross (2007), those in the PS training group, compared to the control group, completed the Timed Instrumental Activities of Daily Living (TIADL) test with more accuracy and effectiveness. Tasks that are part of this test include latency to find a number in a phone book, locate and read ingredients on a food label, locate and read the directions on medications, count out money, and locate specific food items in a crowded pantry. Ball et al. (2007) had similar findings to studies that used Cogmed to train WM, in which those that were lower on PS had the most gains after training. PS training was shown to help those who have completed at least eight sessions continue to drive, while 14% of those in the control group stopped driving (Edwards, Delahunt & Mahncke, 2009).

PS training for HRQoL. PS training may also contribute to improved mental health and HRQoL. The elderly are susceptible to depression, but Wolinsky et al. (2009b) and Wolinksy et al. (2009c) found that those in the PS training group were 30% less likely to develop depression than individuals in the control group. Additionally, the authors found that those in the PS group were the least likely group among all treatment groups at both the 1-year and 5–year follow-ups to have depressive symptoms. However, those that were suspected to have depression at baseline did not improve significantly. Participants assigned to the PS group in the ACTIVE study self-reported higher heath status scores and higher HRQoL scores (Wolinsky et al., 2006a; Wolinsky et al., 2006b; Wolinsky et al., 2010). In addition, self-ratings of health were significantly higher and less likely to decrease for individuals in the PS training group when compared to the control group throughout the one, two, three, and five year follow ups (Wolinskey et al., 2010). The HRQoL of participants that were in the PS training group were protected against a significant decline two years (Ball, Edwards, & Ross, 2007) and five years after training had been completed (Wolinsky et al., 2006a). Those that were in the PS training group had 35.7% lower odds of decline in HRQoL when compared to the control group (Wolinsky et al., 2006b). Wolinsky et al. (2009a), found that in the first year after training, medical costs decreased about $240 per person for those that were in the PS training group, and there was no significant improvement in costs by those in the other treatment or control groups. However, five years after the initial training the costs only decreased by about $140, which made it no longer significant. These findings suggest that through the right cognitive skills training regimen, and possibly starting before age 65, overall health and HRQoL could be positively affected and in turn help to decrease health care costs.

Limitations

The studies described above have shown that cognitive skills training has been shown to frequently improve some cognitive skills as well as functional abilities. The literature critiquing WM training focuses on how the studies being conducted can improve the validity of their results, improving how the effectiveness of the interventions are measured, and whether the training is the actual reason for the observed improvements. Shipstead et al. (2012a) and Shipstead et al. (2012b) assert that there is not enough evidence of an actual increase in WM capacity as shown through near transfer, which is enhanced performance on tasks that measure a specific ability. They argued that there must be near transfer to multiple untrained tasks that specifically measure WM capacity and could not be attributed to improvements in other abilities. They also discuss the necessity of alternate versions for pre and post-tests, eliminating practice effects by avoiding tasks that are similar to training or that measure short-term memory (Conway et al., 2002), avoiding no-contact or non-existent control groups, and needing larger batteries which measure WM to provide definitive evidence of an increase in WM capacity. Morrison & Chien (2011) argue that there should be a consensus on which battery should be used to measure each construct and which type of control group should be incorporated. Having guidelines for these studies to follow regarding research methods and measuring changes would be beneficial, eliminating extraneous variables.

Summary

Based on the data that have been found by numerous studies, training one's cognitive skills may be useful for many reasons. Cognitive training has yet to definitively improve IQ, but there is evidence that it can affect performance of daily activities, school performance, and physical and mental health for all ages. The research discussed shows that training WM and PS may lead to significant improvement in abilities on both trained and untrained tasks, showing near and far transfer. Cognitive skills training seems to be helpful to all, whether it be those struggling in school, individuals with a disorder that inhibits learning, or the aging population experiencing natural cognitive decline. The purpose of this study is to briefly examine the effects on PS and WM in children following a course of LearningRX cognitive skills training.

III. METHOD

Hypothesis

The purpose of this research is to evaluate the effects of a cognitive skills training program at LearningRX on processing speed (PS) and working memory (WM) after six weeks (about 30 training hours) of training. It is hypothesized that there will be a significant improvement in both WM and PS from pre-test to post-test.

Participants

The researcher recruited the participants by initially obtaining informed consent from their parents during the orientation process, which takes place prior to a student beginning the training program, or during the participant's first week. Participants and their parents were informed that their participation in the research study was voluntary and they could drop out at any time. There were a total of 10 participants, 60% male and 40% female, between the ages of 8 and 14 years old, with a median age of 9.8 years. Fifty percent of the participants were Caucasian, 40% were Latino, and 10 % Asian. Families that claimed to have an income of greater than $100,000/year was 80%, 10% claimed $75,001-$100,000, and 10% claimed a yearly income of $35,001-$60,000. The demographic data are presented in Table 1.

Incoming students were ineligible for the study if they had previously been enrolled in a program at LearningRX, if they were to be a client of the researcher, and if they were older than 16 years of age. Four participants had been diagnosed with ADHD prior to coming to LearningRX. One participant of those four had been diagnosed with cerebral palsy and right hemiplegia, one participant had been diagnosed with dysgraphia, and six participants had no previous diagnoses. The parents of the participants were asked for their reason for enrolling their child and some of the responses included: to make learning easier, to help with inattention, for faster processing, to help with school (decrease time spent studying, to aid with test performance, to help with poor grades, to decrease frustration), low confidence, memory issues, and for academic advancement. The reasons for enrolling were not used for data analysis purposes.

Table 1

Demographics

Age (SD)	Gender	Ethnicity	Parent income	ADHD diagnosis	ADHD medication
11.23 (2.51)	F= 4 M = 6	W = 5 H = 4 A = 1	$35,001-60,000 = 1 $75,0001-100,000 = 1 > $100,000 = 8	n = 4	n = 4

Note. n = 10; F = female; M = male; W = White; H = Hispanic; A = Asian

Measures

Primary outcomes consisted of WM and PS, which were both measured by using subtests from the Wechsler Intelligence Scale for Children IV (WISC-IV) (Wechsler, 2003). WM was measured by administering either Arithmetic or Digit Span from the Working Memory Index (WMI) of the WISC-IV. PS was measured by administering either Symbol Search or Cancellation from the Processing Speed Index (PSI). To avoid practice effects associated with administering the same subtest twice, one PS subtest and one WM subtest was administered at pre-testing, and the other at post-testing. Subtest administration was randomized using a random number generator, and is shown in Table 2 (Urbaniak & Plous, 2013). The reasoning for this comes from a study conducted by Etherton (2014) where Arithmetic and Digit Span from the WMI and Coding and Symbol

Search from the PSI were counterbalanced across the participants. As part of the analysis he subtracted any decline in performance during the intervention from pre-intervention scores and averaged the differences. Both subtests from each index measure the same ability, and while they are not identical, they comprise the constructs of WM and PS. Thus, they can be used to find an average decrease in the mean. This can be applied to the current study in that the administration of subtests is similar, and in the study conducted by Etherton (2014), the intervention did not affect performance on the subtests and significant differences in the mean were not found. For the current study it suggests that counterbalancing subtests can be effective and that there would be no significant difference between the means that are not due to the intervention. Reliability coefficients for each subtest being used ranging, from .79 to .88, are shown in Table 3.

Table 2

Subtest Administration

WM		PS	
Time 1	Time 2	Time 1	Time 2
n = 6 Arithmetic	n = 6 Digit Span	n = 5 Cancellation	n = 5 Symbol Search
n =4 Digit Span	n = 4 Arithmetic	n = 5 Symbol Search	n = 5 Cancellation

Table 3

Reliability Coefficients of the Subtests

Subtest	r_{xx}
Arithmetic	.88
Digit Span	.87
Cancellation	.79
Symbol Search	.79

Note. Data obtained from Williams, Weiss & Rolfhus, (2003).

The Arithmetic subtests consists of asking the participant a series of word problems, which they are to solve using mental math within 30 seconds of hearing the problem. Digit Span is a two-part task, with the first part requiring one to simply repeat a string of numbers, and the second asks one to repeat a string of numbers backward.

As part of the PSI, Symbol Search is a task that is time constrained where a symbol is provided along next to a row of additional symbols, and the participant is instructed to indicate whether there is a match. Cancellation is a two-part task, where the participant is presented with pictures of objects and animals on two pages, and are instructed to circle as many animals as they can in a limited amount of time. For the first part of the task the pictures are scattered, and are presented in rows for the second part.

Procedure

The study is a quasi-experimental repeated measures design utilizing quantitative data. Participants were recruited at LearningRX San Antonio NE after they were determined to meet the eligibility criteria, and parents had agreed to enroll in a program. One of the center directors asked parents during orientation or before their child's first session if they would like to have their child in the research study. Participation in this study was contingent on parents providing consent and children giving assent. Parents received a copy of the consent form, which provided them with the appropriate contact information to contact the researcher. Parents were asked to complete a pre-test questionnaire, presented in Appendix A, which asked for demographic information and about their reasons for enrolling in a program. Reasons for enrolling were not used in data analysis.

Pre-testing and post-testing was conducted solely by the researcher and lasted between 10 and 15 minutes. Testing was only conducted when participants were at the center for scheduled training and was administered in a private office at the center. Pre-testing was administered either immediately before the first session or during the orientation process. Post-testing was administered either before or after their training session, dependent upon whether the student was there early or not (so as not to interfere with training schedules), or the work schedule of the researcher. The researcher administered the two predetermined subtests from the WISC-IV at pre- and post-testing, assessing WM first and then PS.

Each participant was assigned a trainer based on schedule availability and compatibility. Each student was to train for an average of five hours per week; however, if a session was missed, it was to be made up at another time. At the beginning of each training session the trainer has the student "warm up" for the first five minutes with brainteaser cards. The first few sessions consist of the trainer and student getting to know each other, and the trainer trying to get through as many procedures and levels as possible in order to identify the point where each procedure becomes too challenging to pass right away. After this the trainer proceeds through each session by working mainly on the skills that were found to be the weakest for that student as well as on the procedures that a student may be having the most difficulty with. Between six to eight weeks after pre-testing or when 30 program hours was completed, the researcher administered the post-testing items. At post-testing, parents were asked to answer one question regarding positive or negative changes; however, this was not used for data analysis.

An average of 29.8 hours of training was completed per participant. The shortest program is 14 weeks or 70 hours of training, and the longest program is 32 weeks or 160 hours of training. That being said, collecting data after an average of 30 hours of training is only 43% of the program if the length is 14 weeks, and 19% of the program if the length is 32 weeks. This will be addressed further in the discussion portion of this paper.

IV. RESULTS

After the data were collected all WMI and PSI raw scores were converted to scaled scores using the WISC-IV manual. Scores are presented in Table 4. Two separate one-way repeated measures analysis of variance (ANOVA) (one for WMI and one for PSI) were conducted to test for differences in either WMI or PSI performance over six weeks of cognitive training. There were no outliers, and the data was normally distributed, as assessed by boxplot and Shapiro-Wilk test ($p > .05$), respectively. WMI scaled scores increased from pre-intervention ($M = 10.10$, $SD = 2.28$) to post-intervention ($M = 11.90$, $SD = 3.28$). The LearningRX cognitive skills training intervention did not lead to any statistically significant changes over six weeks for WMI, $F(1,9) = 4.45$, $p = .064$, partial $\eta^2 = .331$. PSI scaled scores were almost identical from pre-intervention ($M = 7.20$, $SD = 4.57$) to post-intervention ($M = 7.70$, $SD = 4.08$). The LearningRX cognitive skills training intervention did not lead to any statistically significant changes over six weeks for PSI, $F(1, 9) = .047$, $p = .834$, partial $\eta^2 = .005$. These findings suggest that six-weeks of the intervention through LearningRX does not yield a statistically significant improvement on the WMI and PSI as measured through the WISC-IV. Subsequent research may focus on other skills, using a larger battery, or increasing the time between pre-test and post-test. This will be further discussed in the next section.

Table 4

Scaled Scores and Means

N	WM 1	WM 2	PS 1	PS 2
1	11	14	3	6
2	14	14	9	4
3	11	15	7	11
4	11	10	11	6
5	8	9	1	10
6	12	10	6	15
7	10	17	16	6
8	8	11	4	12
9	6	6	4	5
10	10	13	11	2
Mean	10.10 (2.28)	11.90 (3.28)	7.20 (4.57)	7.70 (4.08)

Note. 1 = Time 1; 2 = Time 2

V. DISCUSSION

This study aimed to examine the possible cognitive benefits on WM and PS, six weeks into the LearningRX training intervention. It was hypothesized that there would be a statistically significant difference between the scores from pre-test to post-test. There was not a statistically significant difference between the means of the WMI; however, it was a marginally significant difference. There was not a statistically significant difference between the means of PSI. Previous research has shown that training of WM or PS yields significant improvements on near transfer measures. The current results show that cognitive training effects may not be as robust as previously published research suggests.

A profound limitation of this particular study is that it was infeasible to follow participants through completion of the intervention due to the amount of time that it consumed. Unlike many of the other studies, LearningRX cognitive training focuses on multiple skills being trained. This may affect the rate at which gains are seen. Trainers are told that most of the gains due to the intervention are evident after the first half of the program and are more pronounced toward the end. Program length was not controlled for in this study. As mentioned in the methods section, data were collected at six weeks, or an average of 30 hours, which is less than half way through the shortest program. Depending on the program length and type, 30 hours may be as small as 19% of the intervention. This suggests that the absence of gains at six weeks should not be considered as sufficient evidence to test the efficacy of LearningRX.

It is also important to note that the sample size, $n = 10$, was small compared to 2,900 participants in 2009 that trained at LearningRX. Other research has varying sample sizes from four to upwards of 2,000. The small sample size is due to the slow intake of eligible participants. It is important to test experimentally the claims of publishers of commercial cognitive training programs.

The design of this study, a repeated measures quasi-experimental design, was the most appropriate design for this research. The participants were already choosing to enroll in the program, and it was not feasible to arrange a well-matched control group as well as delay treatment due to the slow influx of eligible participants. Disadvantages to this type of design include lack of randomization of subjects, absence of a control group and a threat to internal validity.

Due to the design of the study requiring new clients, each participant had a different trainer. Each trainer is able to come up with his or her own modifications and techniques, and each has a different approach to conducting a session and what tasks are trained for the day. Trainer differences could account for some variance, however, this is not something that can be ameliorated. Trainer differences will always be present if the intervention continues to be face-to-face.

Pre-testing items were all administered before the intervention began, but post-testing administration was not controlled in regards to having it administered before or after a training session. In future experiments, post-testing should be administered before a training session due to participants possibly experiencing experimental fatigue, making it difficult to put full effort and cognitive resources into extra tasks. In addition to these confounds, the time of the year that students were receiving training and engaged in the study could be of importance. If a participant was training over the summer, the lack of utilizing their cognitive skills except for the training time may have accounted for not being able to see an improvement. If a participant was training during the school year, they are engaging in daily tasks that would utilize WM and PS, thus making it more likely for one to maintain gains and show improvement. One of the largest limitations to the intervention is the cost; it is more cost effective and easier to reach a large population with computerized training. It is also of importance to note that the cost increases with the length of the program; so wanting to help more individuals with lower cognitive skills requires a lengthier program and more financial resources.

Even though the results of this study were not statistically significant, it is still important to look into cognitive skills training through LearningRX to build the literature and to further investigate the claims that are made by the company, including improved IQ scores and percentile rank. The results of the current study do no support the claims made by LearningRX. While scores for PSI stayed relatively the same, there was a slight increase in scores for WMI. Research needs to be continued to see if statistically significant gains in WM, PS, IQ scores and percentile rank can be found. Future research needs to investigate through to completion of a training program in order to improve the possibility of measuring gains and finding statistically significant results.

If the results had been statistically significant, there would be explanations that could have affected that outcome. One would be the Hawthorne effect, where an individual improves their performance because they are aware of an intervention being administered (Nicholson, Schuler, Van de Ven & Blackwell, 1998). Students in the program are asked daily to name an improvement that they have noticed in their daily life. Parents are also encouraged to do this regarding their child's improvements. Thus, a placebo effect may be occurring, and future research should address this through using active control groups.

The human interaction that comes with the intervention at LearningRX is distinct when compared to Cogmed or most other interventions. Having face-to-face interventions may be preferable to some individuals or necessary to help with certain disabilities, and this is something that could be further investigated. One of the participants in this study had a diagnosis of cerebral palsy and right hemiplagia, which caused physical limitations with being able to move her arms and hands at full capacity. These limitations impacted her being able to perform some procedures, requiring modification. Modifications allow for one to perform the task when otherwise unable to, so she was still able to train on that task based on her ability. However, there is a possibility that physical limitations may affect one's ability to benefit from this program. The above statement could be true for a computer-based intervention, as well. An individual's physical limitations could create difficulty in using a mouse or keyboard effectively.

To summarize, cognitive skills training has become increasingly popular due to the claims that cognitive abilities can be improved, with the potential to ameliorate issues that are related to low cognitive skills, aging, or ADHD, and improve performance on tasks that use those abilities. Effects of cognitive skills training purportedly carry over to performance of daily tasks such as learning, driving, reading, and mental calculations, making it an important research topic. The current study did not find that the intervention had an effect on the primary outcome measures. This was a brief study that investigated a previously unexamined intervention to evaluate the claims that LearningRX makes for improvements. This study can pave the way for how future research examining the

LearningRX intervention can improve implementation and results. Future researchers should examine the effects of the intervention with a greater time lapse between pre- and post-testing. Allowing for more time to obtain larger samples and to follow participants through completion of their program may be able to provide statistically significant results. Doing so may be able to substantiate claims and show efficacy for the program. Future research should also investigate maintenance of any gains, use a larger battery for more comprehensive testing, control for confounding variables, and use a different research design to maintain greater internal validity with active control groups.

APPENDIX SECTION

LearningRX Participant Questionnaire

1. Name of participant:

2. Age of participant:

3. Sex of participant:

4. Please circle the race the participant identifies most with:

    a. Caucasian b. Latino c. African-American d. Asian e. Other

5. Please circle the one that best describes the household income:

    a. Less than $35,000/yr b. $35,001-$60,000/yr c. $60,001-$75,000/yr

    d. $75,001-$100,000/yr e. greater than $100,000/yr

6. Please list any medical or psychological condition or disability that the participant has been diagnosed with that may affect cognitive ability:

7. Please list any medications the participant is on, and the frequency of which it is taken:

8. Please list all reasons for enrolling the participant in a LearningRX program:

9. Please list any positive and/or negative changes that you have seen in your child, and you believe to be based on the training. (POST-TEST ONLY)

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