A DOSE-RESPONSE ANALYSIS OF A COMPUTER-BASED EXPLICIT TIMING INTERVENTION

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Abstract: Educational technology has shown an increase in use over the years as a method of remediating student academic deficits. While educational technology demonstrates various benefits for students in schools, there is still limited research depicting what amount of intervention students should receive through educational technology. To ensure schools are utilizing resources and time efficiently, it is important usage of educational technology is evaluated in terms of dose. The present study sought to establish the threshold of a mathematical intervention by evaluating three doses of a computer-based explicit timing intervention with third-grade students. Forty-three third-grade students were randomly assigned to one of the three dosage conditions, which were defined by opportunities to respond (OTR). Students assigned to the 1 OTR group received one repetition of a set of subtraction from 12 problems, the 8 OTR group received the same set of problems at eight repetitions, and the 12 OTR group received the problems at twelve repetitions of the problems for 26 school days. Results of the study indicate group assignment of OTR dose was predictive of students' digits correct per minute growth over time. Limitations of the study and future implications for research are discussed.

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CHAPTER I

INTRODUCTION

Throughout the years of practice and research in school psychology, there has been a shift surrounding the traditional "test and place" model when determining special education eligibility for students (Kroeger, Brown, & O'Brien, 2012). No Child Left Behind Act in 2001 and the subsequent amendment to the Individuals with Disabilities Education Act (IDEA) in 2004, required the use of evidence-based practices and interventions in schools across the United States [614 (b)(6)(B), IDEA, 2004]. As a result, multi-tiered systems of support (MTSS), such as the response to intervention (RTI) model have been implemented widely across schools. With RTI explicitly calling for the accountability and monitoring of students' response to intervention, research on effective academic interventions is crucial for educators to make informed decisions regarding the implementation of interventions. Specifically, research focused on effective components of interventions (i.e., intensity, complexity) is necessary to identify evidence-based treatments that are effective, appropriate, and resource efficient. Overall, the focus on academic intervention components assists in furthering the field through a problem-solving approach (Kroeger, Brown, & O'Brien, 2012).

Evidence Based Interventions

Since the creation of a task force in 1999, the field of school psychology has pushed for a focus on evidence-based interventions (EBIs) to assist educators in identifying effective interventions and practices (Kratochwill & Shernoff, 2004). Nationally funded clearinghouses and organizations such as What Works Clearinghouse and National Reading Panel provide access to effective and appropriate interventions for an array of academic deficits without overextending resources or time (Kratochwill & Shernoff, 2004). The application of EBIs in schools provides an objective standard to compare student performance and growth against in addition to various benefits. Specifically, EBIs have been demonstrated to improve academic performance (Whitney et al., 2015), save instructional time, improve quality of services (Bramlett et al., 2010), and offer a more precise system for arranging service delivery (Codding et al., 2016).

The continued research of EBIs and evidence-based practices (EBPs) offers insight into the complex interactions of intervention variables as they can alter treatment outcomes (Codding & Lane, 2015). Yeaton and Sechrest (1981) identified treatment integrity and treatment intensity as two variables that can impact the overall effectiveness of academic interventions. Further research from Durlak and Dupre (2008) identified eight variables of implementation that can alter treatment outcomes (i.e., fidelity, dose, quality, participant responsiveness, program differentiation, monitoring of conditions, program reach, and adaptation of interventions). Practices that are based in research are crucial for students to be provided with appropriate services and interventions.

Instructional Hierarchy

Despite EBIs providing educators with the ability to easily choose interventions that are supported in producing student growth, academic interventions generally do not follow a “one-size fits all” approach. To address this issue, IDEA legally requires schools to provide empirically supported interventions that are highly intensive and individualized for at-risk students prior to pursuing special education placement [614 (b)(6)(B), IDEA 2004]. Individualized instruction consists of evaluating the student’s current instructional level, matching an intervention accordingly, and has been studied for its effectiveness across reading and math domains. Haring et al. (1978) established the instructional hierarchy as a framework to assist educators in identifying a student’s instructional level across four progressive skill categories (acquisition, fluency, generalization, and adaptation). When used to create individualized instruction, the instructional hierarchy ensures appropriate interventions for effective academic skill remediation are implemented as defined by IDEA and academic research.

Within the instructional hierarchy framework, skill development is based on the premise that foundational skills are required for students to develop more complex skills. In this process, students begin in the acquisition phase where slow task completion is expected to increase a student’s accurate response to teacher prompts. Common strategies used in the acquisition phase to improve accurate responding include prompts and cues paired with error correction and modeling techniques. Once a student has demonstrated adequate accuracy and competency of the content they enter the second instructional phase, fluency. Fluency is the ability to correctly respond to a prompt in a rapid manner and traditionally includes the repetition of items (drill and practice). Research has identified fluency as an essential component of a student gaining proficiency and maintenance of a skill (Haring et al., 1978). Upon mastering accurate and fluent responding to academic prompts, the student will work on transferring skills across similar educational contexts in the generalization phase. After generalization is acquired, the student enters the final stage of the instructional hierarchy, adaptation. The adaptation phase involves the student transferring their acquired skills to novel contexts and demands, which allow them to engage with more complex tasks. All of these components of the instructional hierarchy are crucial to developing and implementing evidence-based interventions that are effective (Haring et al., 1978).

Despite the ease and usefulness of EBIs and EBPs, empirical support does not necessarily indicate an intervention will be appropriate for all students. Utilizing EBIs in addition to the instructional hierarchy improves school selection of interventions and assures educators, practitioners, and researchers of effective and appropriate intervention selection. Even among EBIs, there is variability among intervention components, making it necessary for researchers to continue to consider the different variables of interventions that impact their effectiveness. To adequately implement academic interventions, the effectiveness, appropriateness, and variables of the intervention should be discussed.

Dose-Response Model

While the study of EBIs and their application regarding students' needs are important, little research currently exists on how much of an intervention is needed for necessary growth. Information on the various intervention variable combinations has been covered throughout research, however it does not guarantee student growth or provide information on required time frames for implementation. In the medical field, knowing the level at which a treatment option is effective is crucial to ensuring beneficial outcomes for the client. In the absence of this information, an EBI may be implemented at insufficient levels that can ultimately result in the absence of growth and the potential of lost instructional time in schools. As the dose-response relationship is a crucial factor of treatment among pharmacology and other medical-based fields, its use within educational settings should be considered and evaluated among research (Greenwood, 2009).

In the medical-based fields, the dose-response model is often used to determine the appropriate dose of a treatment to produce necessary outcomes for a patient (Calabrese & Baldwin, 2003). Yeaton and Sechrest (1981) were the first to address the relationship between treatment strength and treatment effectiveness, reporting that out of a set of treatment options, one of the options may be more effective and efficient at achieving a particular outcome for the client. In regard to pharmacological treatment, specifying the dose of a medication is crucial to providing effective treatment as it can have differing outcomes. This model includes a dose-response curve, which assists in demonstrating the relationship between a dose and the effect of the treatment. At the bottom of the curve is the threshold in which the lowest dose of treatment at which therapeutic effects exist lies in the dose-response curve (Calabrese & Baldwin, 2003). Dose levels above the threshold are identified as the therapeutic window where a range of doses that produce effective results exist. The top of the dose-response curve is defined as the plateau and is the highest dose level where therapeutic effects occur. Doses beyond the plateau do not produce additional benefits and are considered to be outside of the therapeutic window. The final component of the curve is the point of diminishing return, and it indicates the point at which treatment effects are lost (Calabrese & Baldwin, 2003). Beyond the medical field, one use of the dose-response model with behavioral interventions was found. Glenn et al. (2013) conducted a study in which the dose of a cognitive behavioral therapy (CBT) treatment package was evaluated in relation to anxious symptomatology presented by the participants. In this study participants were divided into a high dose group and a low dose group for treatment comparisons. At the end of the treatment period, the researchers reported that participants in the high dose group were more likely to demonstrate a reduction of anxious symptomatology (Glenn et al., 2013).

As demonstrated through medical research, the dose-response model and curve can be extremely informative in understanding the required dose of a treatment for client benefits. While the application of this model has been utilized throughout different fields, it’s utility within the school psychology literature needs to be further explored.

Dose-Response model in education. Despite the potential benefits to evaluate treatment, the dose-response model has not been thoroughly examined in its relationship with student outcomes. Adequate research exists on treatment effectiveness, however few studies have attempted to identify the proper amount of treatment necessary for academic interventions to produce desired results. While continued research on EBIs is necessary for the field, the role of dose in student treatment outcomes can provide additional information on what makes an intervention effective.

Greenwood (2009) acknowledged the potential impact of dose-response within schools by identifying treatment strength as an important variable for consideration when evaluating behavioral and academic intervention within schools. Additionally, Skinner (2008) recommended research should manipulate the time or dose of treatment to provide crucial information for deciding the best intervention strategies. This study indicated treatment dose is a critical variable when considering the effectiveness of an intervention as well as its allocation of limited school resources (Skinner, 2008). However, despite this push for the examination of the dose-response relationships with academic interventions, a gap in research still exists. A potential caution of its use in school settings centers around the various definitions of dose in research schools (Greenwood, 2009). Among the literature, dose has been identified as the quantity of treatment during a fixed time period (Duhon et al., 2020), intervention session duration (Duhon et al., 2009), intervention schedule (Codding et al., 2016), learning trials completed, and the number of active responses to a set of instructional stimuli (Mellard, McKnight, & Jordan, 2010). As there is not one agreed upon description of treatment dose for school use, Greenwood (2009) urges researchers to do so to provide a systematic manner of examination.

Of the few studies of the dose-response model within academic interventions, Duhon et al. (2009) evaluated the effects of dose variations on student learning. Specifically, Duhon et al. (2009) examined the effects of increasing doses per day of a class-wide math intervention on math fact fluency of nonresponding students. The intervention implemented included one 2-minute computation practice per day over a course of 21 school days. The dose variation in this study included the intervention being delivered 5 times a day and 10 times a day. At the termination of the study, results demonstrated how the simple increase of dose per day resulted in all students achieving growth in digits correct per minute. Additionally, when the appropriate dose was implemented, less than three intervention sessions were required for students to achieve the set criteria. Duhon et al. (2009) provided a starting point of how insufficient intervention dosages can directly impact students' response to intervention.

Codding et al. (2016) also examined the variation of dose for a math intervention with elementary students' math fact fluency. The dose variable was split into the following: once a day, once a week, twice a week, and zero times a week (control). The results of this study indicated individuals in the four days treatment group showed more learning than students in the other treatment groups. While this study varied the number of times the students engaged with the intervention, it primarily focused on the effects of distributed practice and treatment schedules. All students in the study received the same amount of intervention that was provided on different treatment schedules. The results of this study provided further information on altering treatment variables to improve student outcomes, however it does not further our understanding of the dose-response relationship in academic interventions. A study by Duhon et al. (2020) did measure the dose-response model in relation to student mathematical fluency performance. The results of this study indicated a 2-minute intervention that was delivered once per day qualified as the threshold (or minimum dose for therapeutic effect) of the intervention. Doses below once per day fell below the threshold and did not show significant effects on student growth. The highest cumulative dose in this study was given 8 times a day and did not produce significant growth, indicating no plateau was demonstrated in this study. Of the therapeutic range the researchers aimed to complete, the study only identified the threshold of the therapeutic range of the curve. Overall, the results indicated the threshold for a 2 minute per day intervention for multiplication sums to 81 facts is eight doses for 20 consecutive school days. Any treatment below that dose would not result in significant effects, however an increase in dose to higher levels within the range may increase growth as demonstrated by Duhon et al. (2009).

An additional study that will serve as a reference for the present study is Hernandez-Nuhfer et al. (2020), in which three different doses of an explicit timing intervention was examined to compare DCPM growth across instructional set size (ISS). The aim of this study was to determine if a superior dose existed for a variation of ISS. The ISS included 9 items, 18 items, and 36 items across dosage groups of 2 minutes, 4 minutes, and 8 minutes. The results of this study showed that the ISS of 9 and 18 items showed statistically significant effects when administered as the 2-minute dose. For the ISS of 36 items, a significant dose was unable to be identified, although the 8-minute dose level showed potential for growth. The overall results of this study demonstrated how providing insufficient intervention time when implementing explicit timing can impact student growth.

Using the studies by Duhon et al. (2020) and Hernandez-Nuhfer et al. (2020) as references, the author of the present study will examine the dose-response curve to identify the top of the curve of a computerized explicit timing intervention. The purpose of this study is to attempt to find the top of the dose-response curve of a computerized explicit timing intervention and determine at what level is growth determined for students. Examining these interactions will assist schools and researchers in determining what levels of this intervention is necessary for student growth.

Current Study

Evaluating the relationship between the intensity of an intervention and student growth can be a valuable tool for educators in providing effective academic interventions. Knowing how much of an intervention (dose) a student requires for growth is necessary to successfully remediate academic concerns and use school resources efficiently. The outcomes of this study could provide educators and professionals with the knowledge of (1) the impact of opportunities to respond for effective intervention delivery, (2) the minimum dose required for academic growth, and (3) the dose level in which additional learning no longer occurs. In addition, future research should expand on this topic to provide further information of the impact varying doses of opportunities to respond has on academic intervention growth. The results of this study may additionally be used to assist schools in distributing resources appropriately to prevent and remediate academic deficits.

The purpose of the current study is to evaluate the impact of various doses of a computerized math intervention on elementary students' math fact fluency. Specifically, the experimenter aims to examine if any differences in student growth are demonstrated for students receiving a set of 12 subtraction items at different repetitions. For the present study we hypothesize that the 12 OTR condition will produce student growth that is significantly different from the 1 OTR condition. The current study's research questions are the following:

Research Questions

1. Do varying levels of OTRs produce differential effects on student growth in math fact fluency?
2. What is the DCPM rate of growth when using an ET intervention with a set of 12 subtraction items across doses of 1 repetition, 8 repetitions, and 12 repetit

CHAPTER II

REVIEW OF LITERATURE

Intervention Intensity

One component of intervention effectiveness is evaluation of intensity of the intervention. A question common among treatment intensity research is when to adjust intensity based on the student's response to intervention (Barnett et al., 2004). The simplest treatment intensity adjustment often made in schools and research is the addition of time to sessions, per week, or total time of intervention delivery (Duhon et al., 2009). Intensity can also be adjusted through addition or subtraction of components (Codding et al., 2011; Daly et al., 2007). Rhymer et al. (2000) demonstrated this adjustment through a single-case study of four students with math performance deficits in which time was varied and several components were added (peer tutoring, practice with overcorrection, and performance feedback. Study outcomes indicated minor growth in students' math performance in the less intensive intervention group, while more growth was shown with students in the more intensive (performance feedback) group. Traditionally, intensity in research has been described in relation to time and effort for the intervention and has not necessarily been evaluated in relation to the treatment outcomes (Duhon et al., 2009).

The Dose-Response Model in Education

In the medical field, examining treatment strength and dose are standard protocols as demonstrated through the dose-response model. Doctors often prescribe medication doses in terms of total numbers of days, times taken daily, side effects, and most appropriate time of day to ensure patient outcomes are as expected. As school psychology attempts to incorporate more evidenced based approaches, it is important to acquire more specificity about the interventions being selected for students with academic deficits, and what factors impact the effectiveness of the interventions (APA Presidential Task Force on Evidence-Based Practice, 2006). Without this information, teachers may implement an intervention at a rate that is insufficient and/or unnecessary, which can lead to negative outcomes, such as increased resistance to intervention, reduced motivation from students, and resistance from interventionists (Barnett et al., 2004). Additionally, if an intervention is delivered at too high of levels, resources could be used ineffectively, and may reduce acceptance from the school as well as reduce a students' access to intervention supports (Barnett et al., 2004; Mellard, 2010). The goal of dose-response models is to identify the smallest dose at which a benefit is detected or a maximum dose in which benefits stop occurring (International Conference on Harmonisation of Technical Requirements for Registration of Pharmaceuticals for Human Use, 1994).

Of the research on dose-response within academic interventions, a majority focused on the increase of frequency. Codding et al. (2016) compared the frequency of a small group math intervention delivered weekly (once, twice, or four times) with a control condition while controlling for total duration. The study included 101 students ranging from second to fourth grade who were identified at risk. Students in the study were randomly assigned to a condition after being assessed through universal screening and skill-based assessments. The results showed that treatment sessions occurring four times a week demonstrated positive effects, and all students in the treatment groups outperformed the control condition (Codding et al., 2016). Duhon et al. (2009) also examined the effects of frequency increase on student mathematical performance. Through a multiple baseline design with three students at-risk for math, they demonstrated how additional time for daily practice improved fluency for all students and resulted in maintenance for two of the students. All but three students demonstrated growth in the original intervention given once a day, however, to show adequate gains the intensity needed to be five to ten times greater. This study emphasizes the use of intensifying interventions across tiers to address concerns and academic deficits and may be an appropriate method of increasing dose for students with fluency deficits.

Schutte et al. (2015) added to research on fluency in a study of dose conditions among third-grade students' math fact fluency. Schutte et al. specifically examined the differential effects of the following doses: one massed session of four 1-minute trials, two sessions of two 1-minute trials twice a day, and four 1-minutes sessions four times a day. Students in this study performed significantly better in the distributed practice groups over the massed practice groups. While the results of Schutte et al. (2015) primarily focused on the differences between massed and distributed practice, it presents methods in which dose can be manipulated with academic interventions.

While the use of the dose-response model is currently not at the forefront of school psychology research, it demonstrates potential to be integrated into widely implemented school practices, such as multi-tiered systems of support (MTSS). MTSS, such as RTI, are tools for educators to deliver and evaluate interventions in a systematic manner. Within these frameworks, the intensity of services is varied and administered based on the tier placement of students, which can be considered as dose. Following the implementation of supports, RTI requires the monitoring of a student's response to determine if further interventions are required. This model of service delivery can be aligned with the dose-response model, which emphasizes the identification of proper dosage of a treatment for appropriate responses to treatment (Greenwood, 2009).

Opportunities to Respond

Within educational research, opportunities to respond are a primary component of effective instruction and intervention. Opportunities to respond (OTRs) are traditionally defined as the interaction between a behavior or academic prompt (i.e., verbal, visual, or written) and a student's response (MacSuga-Gage & Simonsen, 2015; Whitney et al., 2015). Research has suggested that increasing the rate of OTRs in instruction can lead to improved academic performance, (Christle & Schuster, 2003; Lambert et al., 2006), higher rates of on-task behavior during instruction (Christle & Schuster, 2003; Haydon et al., 2010), and decreased disruptive behavior during instruction (Haydon et al., 2010; Lambert et al., 2006). As OTRs require the engagement of every student, its use in instruction has been related to an efficient and simple intervention to address challenging behaviors and academic deficits (Lambert et al., 2006). The versatility of OTRs allows for its use across grades, ranging from preschool (Godfrey et al., 2003), elementary-age students (Haydon et al., 2010; Lambert et al., 2006), and secondary-age students (Haydon & Hunter, 2011). Additionally, OTRs have shown to be successful among students with significant behavior challenges (Haydon et al., 2003), moderate to severe disabilities, and in inclusive classrooms (Skibo et al., 2011).

The mechanism of OTRs responsible for its extensive benefits centers around repeated practice. Teacher directed OTRs are the most common use of OTRs and involve the presentation of a prompt, a student's response, and feedback of the delivered response (Menzies et al., 2017). This implementation of OTRs allows a cycle of practice for students, which improves accuracy of responding and increases fluency. The recommended rate or dose of OTRs is varied throughout research. The Council for Exceptional Children suggests a rate of 4 to 6 responses per minute for new material and 8 to 12 OTRs for reviewed material, specifically for students with high incidence disabilities (i.e., learning disabilities). Researchers have argued that the specific population of this recommendation makes this unrealistic for implementation in the general education setting and suggests at least 3 OTRs per minute for improved academic and behavioral outcomes (Scott et al., 2011; Stichter et al., 2006). This particular recommendation is further supported through a systematic review of 15 studies by MacSuga-Gage and Simonsen (2015), in which most studies indicated 3 to 5 OTRs per minute are associated with positive student outcomes. Ensuring adequate implementation of OTRs in schools ensures the maximum benefit of its use and is a core component to remediating academic deficits.

As national legislation (i.e., NCLB and IDEA) has increased teacher responsibility for proficiency in reading and mathematics, incorporating OTRs into academic instruction can be a valuable tool. As discussed previously, OTRs provide ample opportunities for students to communicate their knowledge, which allows teachers the ability to formatively assess individual student learning, and adapt instruction accordingly (Whitney et al., 2015). Further research within this area is warranted to understand the specific mechanisms of OTRs in relation to academic content areas, such as mathematics.

Opportunities to respond and math. Although complex, one reason for low mathematics performance among students in the U.S. is the quality and quantity of repeated practices in classroom instruction (NMAP, 2008; Codding et al., 2019). As instructional time in schools is limited, it is necessary to determine ways in which educators can optimize instruction and increase retention (Bramlett et al., 2010). Opportunities to respond is one variable that can increase student performance within these academic areas (Codding et al., 2019).

In a study by Wilson, Majsterek, and Simmons (1996), computer-assisted instruction (CAI) and teacher-directed instruction were compared with four elementary students with learning disabilities in mathematics. These two forms of instruction were compared through their number of OTRs and success rates. The results of this study indicated students mastered more multiplication math facts within the teacher-directed condition due to the higher rates of OTRs and success rate. The researchers determined that the teacher-directed condition allowed for a quicker pace, immediate and direct feedback, and greater opportunities for practice. As the current study will examine a computer-based intervention, it is important to note that the technology used in the previous study is likely to be significantly different from modern day technology, therefore the effectiveness of computer-based instruction should be interpreted with caution. Warren et al. (2007) further emphasized the use of OTRs in suggesting the evaluation of interventions be conducted beyond the number of sessions or total duration of treatment. The authors called for clearly defining teaching episodes in terms of OTRs per session, number of trials, and instructional delivery (i.e., isolated drill and practice). The findings of this study indicated insufficient OTRs within educational settings were related to negative impacts on student performance.

In a more recent study, Codding et al. (2019) compared the impact of distributed versus massed practice and the number of OTRs on students' multiplication math fact fluency. 112 students in second and third grade were randomly assigned to one of four dose conditions (massed, low OTR; distributed, low OTR; massed, high OTR; and distributed, high OTR). Within each session, students were instructed to complete Cover-Copy-Compare probes for subtraction from 1 to 20. After controlling for prior math knowledge, the researchers reported that instructional level and number of OTRs were significant predictors of students' final performance. Students in the low OTR conditions exhibited lower performance over time when compared to students in the high OTR conditions. Specifically, students in the low OTR conditions computed 2.8 digits correct per minute less in each session than students in the high OTR group. The placement in massed or distributed conditions did not demonstrate significant effects on the students' performance, which may be directly related to students' high accuracy of the skill prior to intervention. The results of this study suggest that focusing on increased OTRs may be more efficient for mathematical interventions than scheduling spaced practice sessions.

Math Performance

Math performance among students in the United States has demonstrated a decline over the last two decades. Despite the academic accountability mandated in the No Child Left Behind Act for all students to be proficient in math by 2014, national reports (i.e., the National Center for Education Statistics and the National Mathematics Advisory Panel) have reported continual decreases in performance throughout grade progression (NAEP, 2000, 2003, 2005, 2007, 2009; PISA, 2000, 2003, 2006, 2009; TIMSS, 2003, 2007). In a report from 2009, the National Center for Education Statistics reported that only 39% of fourth-grade students and 34% of eighth-grade students achieved at or above proficient levels of performance on the National Assessment of Educational Progress in math.

Students in the U.S. have also demonstrated low consistent performance in math when compared to students in other countries. In 2009, the Program for International Assessment reported that the overall math performance of U.S. students was significantly lower than other nations (Organisation for Economic Co-operation and Development, 2004). Since mathematical knowledge is cumulative, a weak foundational knowledge of early math skills may hinder students' future opportunities for success in math subjects and STEM career pathways (National Council of Teachers of Mathematics, 2000). Unaddressed mathematical deficits have the potential for significant detriments to student academic performance and life outcomes. In consideration of these potential effects, researchers and educators have directed their focus to determining effective and efficient strategies to remediate students' mathematics achievement (Poncy, Skinner, & Axtell, 2010; Musti-Rao et al., 2015).

The first goal in addressing low mathematic performance, is to identify the core factors affecting student performance. In 2008, the NMAP indicated children in the U.S. show consistent difficulty with solving single-digit math problems (i.e., addition, subtraction, multiplication, and division) quickly and efficiently when compared to students from other countries. National reports and research suggest a major component of mathematical performance is computational fluency or math fact fluency. Math fact fluency is recognized as a critical component of math achievement and is a foundation for the development of complex math skills introduced in middle and high school (Gersten et al., 2009; National Mathematics Advisory Panel [NMAP], 2008). Additionally, these reports suggest computation fluency may be the core deficit impacting student performance in math (Berrett & Carter, 2018). The National Mathematics Advisory Panel (2008) and various researchers have identified math fact fluency as a critical skill for math achievement (Fuchs et al., 2016; Codding et al., 2019). Fluency is crucial for students to quickly complete math facts and utilize working memory and other cognitive abilities to other skills (Mabbott & Bisanz, 2008). Elementary students who struggle with math tend to engage in less automatic recall of math facts, choosing instead to utilize more intensive strategies such as finger counting or tallies (Woodward, 2006). Failure to achieve math-fact fluency can also impact student's motivation to complete math-related tasks and make them more likely to avoid math tasks as they may be perceived as too difficult (Skinner et al., 2005).

The NMAP (2008) recommends students should be fluent in addition and subtraction facts by the end of third grade. The Common Core State Standards Initiative (2012) agrees with the NMAP and adds the ability to fluently perform all four skills by the end of fifth grade. Beyond elementary, mastery of math fact fluency serves as a foundation for the development of more complex math skills and has a major impact on student performance throughout higher grades (Fuchs et al., 2014; Siegler et al., 2012). Steel and Funnell (2001) further suggested that students who are not fluent in math by the end of fifth grade are unlikely to develop fluency in later grades, stressing the importance of intervening early. Carr and colleagues (2008) and (2011) conducted studies to demonstrate the importance of math fact fluency development and overall student performance. In their 2008 study, Carr et al. (2008) found a significant relationship between 241 second-grade students' fluency of single-digit math problems and overall math ability. A follow-up study by Carr and Alexeev (2011) examined the growth trajectories of 240 of the students from the initial study and found the fluency was the biggest predictor of growth in math performance.

To address one's fluency for any academic task, research has revealed that students need to engage with the individual items repeatedly (Ysseldyke et al. 2005). This was demonstrated by Szadokierski and Burns (2008) in which the amount of repetition of instruction was most closely related to retaining the new material. Additionally, Burns (2005) discovered when students identified with a learning disability in math were provided frequent practice and exposure to multiplication facts, they were able to retain, generalize, and increase their fluency levels to typical grade levels. One hypothesis for continued low performance in math in the U.S. has been related to the quantity and quality of practice opportunities provided in the classroom (NMAP, 2008). Specifically, Daly et al. (2007) has reported teachers are not providing adequate OTR, and there are insufficient amounts of activities for math fact fluency incorporated into textbook curricula (NMAP, 2008). As schools experience resource constraints, opportunities to learn math need to be carefully identified and implemented to produce the best outcomes within the limited instructional time available (Skinner, 2010; Codding et al., 2019).

Math fact fluency interventions. Various strategies, ranging from flashcard interventions, goal setting, and timed activities to interventions have been studied throughout academic research for improving math fact fluency (Codding et al., 2009). To best address math fact fluency, research has recommended interventions include modeling (Codding et al., 2011), immediate and corrective feedback (Codding et al., 2009; Codding et al., 2011), appropriate ratio of unknown to known facts, and drill and practice with high rates of response (Musti-Rao et al., 2015). In terms of interventions for fluency, the most established include explicit timing (ET; Van Houten & Thompson, 1976), cover, copy, and compare (CCC; Skinner et al., 1989), taped problems (TP, McCallum, Skinner, & Hutchins, 2004), and flashcard drill procedures (Nist & Joseph, 2008). While all of these have been shown to be effective in addressing fluency, Explicit Timing is the most commonly used for students within the instructional-level range, working on fluency.

Explicit timing. Often within behavioral domains, fluency research has utilized explicit timing (ET) to provide students repeated practice of skills to increase fluency among students. ET traditionally involves the presentation of a task to be completed within a set amount of time (Gross et al., 2013). Using ET procedures to increase rates of responding with math tasks and digits correct per minute (DCPM) performance has been replicated across a variety of studies (Duhon, House, & Stinnett, 2012; Poncy et al., 2010). While many studies have been completed to empirically test ET and math fact fluency interventions, no comparative intervention studies have been conducted to determine the optimal conditions under which to use a computer-based explicit timing intervention. For example, ET as an antecedent timing procedure could be completed using different lengths of time (e.g., 1-min, 2-min, or 4-min blocks), different opportunities to respond, and different frequencies (sessions per day). Given the ease of implementation of ET procedures (teachers tell students they are going to be timed and time them), specific recommendations could benefit educators to maximize student learning rates. Further, Forbinger and Fuchs (2014) expressed concern with typical fluency procedures as they may not be engaging for students and may result in students opting for less efficient strategies, such as finger counting. To best address the concerns of implementing ET interventions in the classroom and allocation of resources, researchers need to continually strive to identify intervention strategies and methods to increase overall student achievement (Skinner et al., 2013).

Educational Technology

According to the United States Department of Education (2005), there is on average one computer available for approximately every four students in public schools in the U.S. A program called the Enhancing Education Through Technology (E2T2) established in 2009 by Congress, expanded the access to technology through providing $650 million for educational technology (SETDA, 2010). In fact, schools have begun a widespread adoption of one-to-one computers, where each student is provided a laptop computer or tablet (Amin, 2010). Through these developments over the last decade, traditional paper-and-pencil practices may be a less appealing method for education to students and educators. Teachers across the nation are utilizing digital education programs and applications to provide instruction and practice for students in and out of the classroom. Educational technology involves various programs or applications that are technology-based and used to provide learning materials to students of all ages (Cheung

& Slavin, 2013). The use of technology in schools has been demonstrated to increase on-task behavior, increase motivation, provide immediate feedback, improve academic performance in reading and math, and provide promising approaches to efficiently delivered tiered intervention model (Burns et al., 2012; Duhon, House, & Stinnett, 2012; Kanive et al., 2014; Musti-Rao et al., 2015). Large scale studies have specifically shown positive results favoring the use of computer-based math interventions with elementary students (Burns et al., 2012; Ysseldyke et al. 2005) and overall increased math skills (Ysseldyke et al., 2005). Lastly, technology for interventions provides a more efficient mechanism for collecting, managing, and analyzing data (Wayman, 2005).

Educational technology and mathematics. Research has recommended the integration of technology with mathematics to increase math performance across students (Amin, 2010). Some academic studies have shown a significant positive correlation between technology, student learning, and mathematics achievement (Amin, 2010; Rosen & Beck-Hill, 2012). In 2000, the National Council of Teachers of Mathematics referred to technology as an essential tool to be used during mathematics instruction. Researchers have noted that a benefit of using technology is that it can easily be used to select appropriate target skills, provide progress monitoring, and increase student engagement with academic tasks (O'Malley et al., 2014). Within mathematics, Burns et al. (2012) demonstrated through the use of technology, students with significant skill deficits who are at risk for math failure demonstrated improvement in overall math performance.

Further research has found that technology is an effective supplementary tool for improving addition, subtraction, multiplication, and division fact fluency in students (Musti-Rao et al., 2015). Burns et al. (2012) studied the effects of a computer-based math fluency intervention on third and fourth-grade students at risk for math difficulties. The intervention was implemented on average three times a week for 8 to 15 weeks and resulted in students in the treatment group demonstrating significant gains when compared to the control group. Additionally, students who initially performed at or below the 15th percentile rank and at severe risk for math difficulties, demonstrated growth that was equal to the students who initially performed between the 15th and 25th percentiles. In two studies, Burns et al. (2012) and Kanive et al. (2014) continued an evaluation of computer interventions for math fact fluency for four students in elementary school. Burns et al. (2012) demonstrated moderate effects for third and fourth grade students, and Kanive et al. (2014) indicated moderate effects for fourth and fifth grade students.

In a study focusing on multiplication math facts, Berrett and Carter (2018) examined the use of an app, Timez Attack and reported improved performance after the first use of the app as well as maintenance effects after the discontinuation of the intervention. Ysseldyke et al. (2005) conducted a randomized study of a computer-based math intervention by examining Math Facts in a Flash (MFF; Renaissance Learning, 2003). The study found that MFF was effective in improving mathematics achievement and students who used MFF longer showed greater gains in mathematics achievement. Additionally, students in the computer-based intervention group showed greater retention scores than students in the control group, suggesting computer-based programs are more effective for fact fluency than classroom instruction only Additionally, 90% of teachers reported positive feelings toward the intervention. The results of these studies provide further support for the use of computerized math interventions for students across various skill levels, grade levels, and educational placement.

While educational technology has demonstrated benefits for its use in math performance, math-based computer programs seem to fall short when it comes to generalizing the skills learned to paper-and-pencil methods. Duhon, House, and Stinnett (2012) conducted a study to reassess students' ability to transfer math knowledge learned from a computer-based program to paper-and-pencil assessments. Both modalities of intervention were reported to be effective in improving students' subtraction fact performance. Additionally, the paper-and-pencil intervention participants demonstrated generalization to performance on the computer-based program. However, the computer intervention practice did not result in generalization to the paper-and-pencil performance. This finding is important when evaluating the use of technology for providing academic interventions in math. While research exists demonstrating the effectiveness of computerized interventions, the generalizability of student knowledge is crucial to improved performance on traditional school assessments. As further research is warranted on the use of technology for delivery of math interventions, the present study aims to address several of the gaps identified through existing research.

CHAPTER III

METHODOLOGY

Participants and Setting

Participants included 52, third-grade students from a rural elementary school in the Midwest region of the United States. Seven students were excluded from the study due to attendance being below 70% and two more were excluded due to an initial accuracy less than 80%. After attrition and exclusion of participants who did not meet criteria, the total sample included 43 third-grade students. The 43 students spanned across three different classrooms. Each intervention session occurred in the respective third-grade classroom for each teacher.

Prior to the implementation of the intervention, the experimenter provided three separate instances of training to participants on using the computer program. Following training procedures, the students were monitored practicing the chosen skill on the computer program for three separate sessions. During these sessions students received instruction on how to login to the computer program and complete their assigned set of problems. Students also received instruction on the expected behavior for the sessions. A script for the practice sessions can be found in Appendix A. The inclusion of training and practice with the computer program allowed for students to become familiar with the program and controlled for a relearning effect that may have occurred upon implementation of the intervention.

Materials

Materials for this study included a computer-based Explicit Timing program created by university faculty for the purpose of research. For the paper-and-pencil assessments, 8x9 mathematics probes were created by the examiner using an Excel sheet. An example of a paper probe that was used is included in Appendix B.1. Once the students completed their assigned set of problems for the day, they were directed to an academic task unrelated to computational fluency on their assigned computers. This was provided to the students prior to the implementation of the intervention by their respective teacher.

Dependent Variable

The dependent variable in this study is the rate of growth measured by the mean of the digits correct per minute (DCPM) completed during intervention sessions. The web-based computer program scored student performance through digits correct per minute for each session completed. The computer program database housed intervention data including the date of the session, the student's identifier, a list of all problems attempted with the answers provided, time taken to complete problems, and a score of digits correct. The computer program automatically calculated DCPM based on students typing the correct number as an answer for a mathematical fact. The program scored a digit correct if it was placed in the corresponding column. For example, a student would be scored as having two digits correct if they answered "4" for "6-2". If the student answered "3" for "6-3", they would be scored as only having one digit correct as only one column had the correct number. Lastly, a student would receive zero digits correct if they answered “4” to “3-2”. The rate of growth was gathered by comparing each student’s DCPM during the progress monitoring sessions over the six weeks of implementation.

Independent Variable

The independent variable in this study is the dose of the ET intervention, which is defined by the number of OTRs presented using the computer program. One dose of OTRs occurred when a set of 12 subtraction items was presented one time. During the intervention, a subtraction item was presented to the student via the web-based computer program and the student had two seconds to type the answer. When the student typed in their answer, they received feedback in the form of visual and auditory feedback. Visual feedback consisted of either a large green check mark or a red X presented to the right of the problem immediately following each student response, depending on the accuracy of the response. Accurate responses were followed by a green check mark, and inaccurate responses were followed by the red X. Auditory feedback consisted of a ‘‘ding’’ or a ‘‘buzz’’ presented immediately following each student response delivered simultaneously with the visual stimulus. Similar to the visual stimulus, the auditory stimulus was delivered based on accuracy of responding, where accurate responses are followed by the ‘‘ding’’ and inaccurate responses are followed by the ‘‘buzz.’’ The feedback remained on the screen until the student produced the response for the next problem, which was then followed by feedback for that response.

The implementation of the intervention sessions was conducted across three groups for 26 school days, with the students in each group receiving a specified amount of OTRs. Each condition group consisted of the computer program presenting one set of mathematical problems at the set amount of OTRs for the students' assigned group. Specifically, the chosen set of subtraction problems was presented to the participants once for the 1 OTR condition, eight times for the 8 OTR condition, and 12 times for the 12 OTR group.

Procedure

The procedures of this study qualified under the realm of standard educational practice, therefore individual parent consent is not required (Protection of Human Subjects, 2018). Prior to the implementation of the study, a permission letter was provided to the school site to send home with each student. The permission letter outlined the study and provided parents with the opportunity to contact the experimenter with questions, concerns, or comments.

Subtraction problem set identification. The subtraction problems selected for the study were identified by visually examining frequently missed problems on the computer assessment. The examiner selected twelve Subtraction from 10 problems that were commonly missed across students' pretests. A list of the included subtraction problems is included in Appendix B.2.

Baseline. Prior to the first day of intervention, students were administered a pre-test and their scores were recorded as their baseline point. Students were assessed on Subtraction to 10 problems on the computer program and on a paper probe. To ensure consistency between the computer intervention and paper-and-pencil interventions, students were tested on both the computer program and paper probes. For the paper-and-pencil administration each student received a set of subtraction probes to complete within a 1-minute period. Students were instructed to complete as many problems as they could without making mistakes within the 1-minute. After the 1-minute period was over, students were instructed to stop and put their pencils down. The paper-and-pencil administration was repeated for three consecutive math probes to establish a baseline performance for each student. For the computer administration, students completed a single computer-based subtraction probe in which they did not receive feedback. Probes were also 1 minute in duration and no incentives or instructions other than "complete as many problems as you can without making mistakes" and "do your best" were given. This procedure was repeated three times until all students completed three pretest assessments on the computer. The computer and paper pre-tests were administered on two separate days. Following the administration of the pre-test, the median DCPM was calculated and chosen for each student's pre-test score. Any student performing below 80% accuracy was excluded from the study as accuracy below this level is insufficient for independent practice (Gettinger, 1995). Although the one student who performed below 80% accuracy was not included in the data analysis, they were allowed to engage in the intervention sessions. See Appendix C.1. for protocol.

Training and practice sessions. Prior to the implementation of the intervention, the examiner trained participants on how to operate the math program accurately. Students were provided with a link to the math program through their respective classroom's management system. From here, students were instructed to click on the link and insert their login information. All students were instructed on their login information during these sessions to allow for ease of logging in. Once students were provided with their logins, they were instructed on how to operate the intervention program. The examiner walked students through four sessions to ensure they were familiar with the program. Students were then provided with three separate practice sessions where they practiced addition problems. These practice sessions occurred over three different days and students were provided with procedural feedback during the sessions. The training and practice sessions allowed for students to become familiar with the intervention program prior to implementation to control for relearning effects. A protocol for the training and practice sessions can be found in Appendix A.

Intervention

For the daily computer intervention, the graduate research assistants followed a standardized protocol for administering the intervention. At the beginning of each intervention session, students were instructed to gather their assigned computers. Next, students were instructed to access the computer program through their classroom management system and login. Once students were logged in, they were instructed to complete their assigned set of problems. At the end of each students' intervention session, they were directed to a non-related academic task on their computers by their teachers to ensure instructional time was not wasted, and students were not distracted. All students were instructed to remain quiet and in their seats until instructed to by the researcher or teacher. These procedures occurred once a day for a total of 26 school days.

Assignment to groups. The students in this study were rank ordered according to DCPM scores on the pre-test. The students were then randomly assigned in blocks of three to one of the three doses. To do so, the first three students in the ranking of DCPM were randomly assigned to one of the three doses, and then the second group of the ranked students were randomly assigned. This process was repeated until all students were assigned to groups to control for initial fluency levels among participants.

Progress monitoring. Data points for progress monitoring were collected during treatment on every fourth day of intervention for all participants. This involved delivering one paper math probe with the selected 12 subtraction problems. Students were given one-minute to complete as many problems as they could without making mistakes. These probes served as progress monitoring data points to track the growth of each group. Intervention data collection for the study occurred for six weeks. To ensure the paper probes did not confound intervention sessions, the administration of the computer and paper portions were switched every week. For example, the paper probe was delivered before the computer intervention the first week. The second week, the computer intervention was administered prior to the paper probe. This continued throughout the six weeks, with the sixth week being the final progress monitoring data point collected for the study. After the study was completed, the data points collected from each week were statistically analyzed using multilevel modeling (MLM) to answer the examiner's research questions. See Appendix C.1. for protocol.

Procedural Integrity and Interscorer Agreement

Each teacher and graduate research assistants were trained to conduct the intervention by the experimenter. The experimenter and the graduate research assistants administered the intervention for 85% of the intervention sessions (22 days), and each teacher was trained on the procedures to deliver when the experimenter was not present. A script outlining the intervention procedures was created and dispersed to each teacher and graduate research assistants (See Appendix C.2.). Procedural fidelity was monitored by the experimenter and graduate research assistants for 85% of intervention sessions and was 100% for all recorded sessions. Procedural integrity of treatment sessions was measured using a checklist of the treatment protocol. The percentage of integrity was calculated by dividing the number of steps completed by the total number of steps and multiplying it by 100%.

Experimental Design

This study used a longitudinal randomized design. Using this design increased power as data points were collected across time for each subject, while analyses across groups were able to occur (Shadish, Cook, & Campbell, 2002). Multilevel modeling (MLM) was conducted using the HLM 8 Student software package. MLM was chosen since the primary purpose of the study is to determine whether alterations in group conditions differentially affected DCPM performance on weekly progress monitoring.

The daily intervention, the independent variable, has three levels, which include the 1 OTR, 8 OTR, and 12 OTR a day dosage. The second independent variable of time, which is represented as progress monitoring data for the study, has seven levels, which includes data collected from the seven progress monitoring points across all conditions. Data from participants were blocked by fluency level using a random assignment procedure, where students were first ranked by fluency level (e.g., highest fluency to lowest fluency) and then randomly assigned to one of the three treatment groups.

Data Analysis

Two-level multilevel modeling (MLM) was conducted using the HLM 8 Student software package. Education research often uses hierarchical data as students are nested in classrooms, classrooms are nested in schools, etc. Accounting for the nesting structure in the data prevents several errors that may decrease validity and generalizability of the results (e.g., incorrect standard errors, aggregation bias, etc.). MLM was conducted to determine significance across dosage groups and if significant growth across time occurred. HLM uses information from clustered samples to explain between- and within-cluster variability for an outcome variable. Using HLM controls for violations of independence, assesses change in an outcome variable over time, and allows the modeling of slope and level differences in relation to selected predictors by considering the repeated measure (level 1) nested within individual students. Multilevel modeling provides benefits for research that include, improved estimates of individual effects, hypothesis testing of cross-level effects, and ability to partition variance-covariance components (Raudenbush & Bryk, 2002).

For the present study, three models were developed using HLM 8 to determine the model best fit for the current data and predictors. First, an unconditional model was fitted to the data to determine the initial values for deviance and parameters. The unconditional model was then compared to an unconditional growth model with the predictors for time of observation (OBS) and the dose groups (OTR). The chi-square test indicated no significance for the unconditional growth model; therefore, the random slopes model was used to allow the TIME predictor slope to vary. Uncentered predictors were used in this model as the OBS predictor was set for baseline to be 0, then five subsequent measurements were taken following this step (scale of 0-6). Due to the OTR groups being classified as an ordinal variable, rather than a ratio variable, centering was not used as it would complicate the interpretation of the current study. Based on the information collected from the three models, the uncentered method was deemed the most appropriate for this data. Therefore, uncentering was used for all variables in each model.

The restricted maximum likelihood method was used for all estimation procedures and the chi-square variance-covariance test was used to assess the successive models in comparison to the unconditional model. Homogeneity of variance was assessed for in HLM 8 and the assumption was violated, indicating that the data were variable from each other. Normality was assessed in SPSS; however, the Shapiro Wilk test produced a value of .002, which also indicates this assumption was violated. Independence of level 1 predictors of the level 1 residuals was assessed for in SPSS and demonstrated the two were independent of one another. Further, level 2 residuals' independence from level 2 clusters were assessed and determined to be normally distributed. As homogeneity of variance and normality were violated in the analyses, results from this study should be verified with a larger sample in the future that meet these assumptions.

CHAPTER IV

FINDINGS

Table 1.1 displays descriptive statistics. A total of eight data points were observed in this study and included in the analysis, including pre-test and post-test. Table 1.2 displays the pre-test and post-test mean scores for each dose group.

Table 1 *Weekly Data and Total Participants per Condition*

	1 OTR			8 OTR			12 OTR		
Time	N	M	SD	N	M	SD	N	M	SD
Week 1	14	10.04	.82	15	72.38	4.71	14	96.60	11.27
Week 2	14	11.26	.43	15	68.71	1.99	14	108.39	10.65
Week 3	14	11.29	.32	15	76.35	10.17	14	130.39	10.88
Week 4	14	11.14	.42	15	85.42	.29	14	134.86	4.74
Week 5	14	11.53	.27	15	90.02	6.94	14	140.16	1.51
Week 6	14	11.57	.15	15	89.74	1.84	14	137.57	2.71

Note. The Mean and SD are based on daily average data points collected for the intervention each week.

Table 2 *Pre-test and Post-test Data Across Treatment Groups*

		Pre-test	Post-test
Group	N	M	M
1 OTR	14	13.93	19.60
8 OTR	15	15.47	27.40
12 OTR	14	15.43	29.21

Multilevel Modeling

Three data points were missing across group progress monitoring. 93% of the sample completed all assessments. 100% of pretest and post-test measures were complete.

DCPM. The results for DCPM progress monitoring probes are as follows. First, the fixed effects for the unconditional means model illustrated a significant mean score of .728 DC for the average student at the end of the study (ICC = 0.673). Second, the unconditional growth model was fitted (ICC = 0.777). On average, students gained .728 DC from session to session. Within groups, average gains per session were .878 DC for 1 OTR, 1.928 DC for 8 OTR, and 2.528 DC for 12 OTR. Students in the 12 OTR group had average gains that were 1.650 DC more than students in the 1 OTR group, and .600 DC more than students in the 8 OTR group.

The fixed effects of the unconditional model demonstrated a significant mean score for student DCPM at the beginning of the study (ICC = 0.673). Second, the unconditional growth model was assessed (ICC = 0.777). The referent group for the OTR predictor was the 1 OTR group. On average, students gained nearly a digit (0.728) per session. This value in relation to the OTR group for each student was less than half a digit (0.150). Taken together, students in the 1 OTR group grew by 0.878 digits per session; students in the 8 OTR group grew by nearly 2 digits per session (1.928); and students in the 12 OTR group grew by nearly 3 digits per session (2.528). Third, the final model allowed for the slope of the OBS predictor to vary. Equations 1 and 2 model the Level 1 and Level 2 equations for this model, respectively. Equation 3 models the combined model for this data. The random effects were significant across all predictors. They decreased across the models with the addition of predictors and allowance for variability in the time (OBS) predictor.

$$\pi_o = \beta_{oo} + r_o \qquad \text{Equation 1}$$

$$\pi_1 = \beta_{1o} + \beta_{11}(OTR) + r_1 \qquad \text{Equation 2}$$

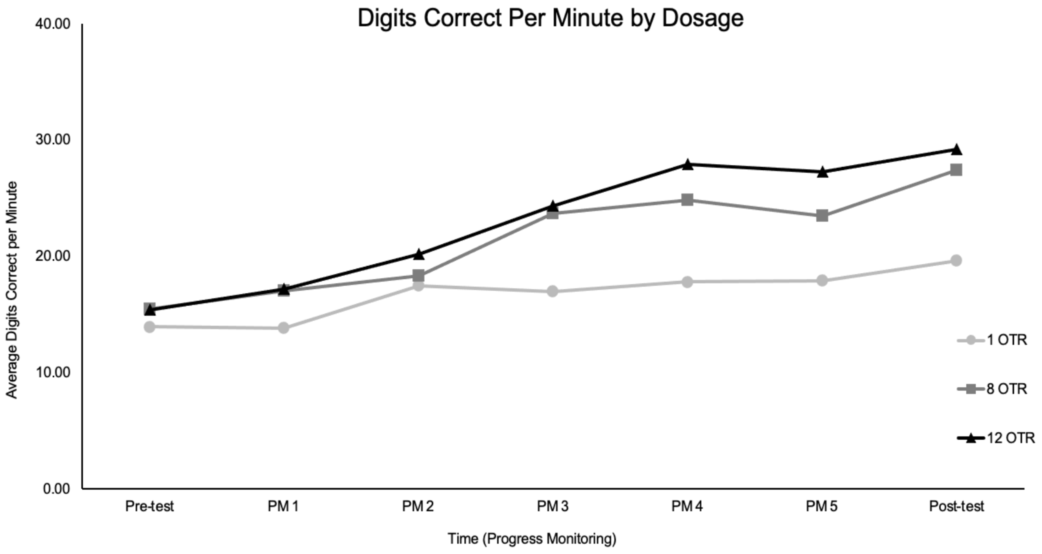
$$DCPM = \beta_{oo} + \beta_{1o}(OBS) + \beta_{11}(OTR)(OBS) + r_o + r_1(OBS) + e \qquad \text{Equation 3}$$

Table 3 *Model Summary*

Parameters	Unconditional	Unconditional Growth	Random Slopes
	Model		
Fixed Effects			
Intercept ($\square_{00}$)	19.994 (1.388)***	14.766 (1.071)***	14.752 (1.072) ***
OBS ($\square_{10}$)		0.728 (0.264)***	0.764 (0.248)***
OTR ($\square_{11}$)		0.150 (0.041)***	0.145 (0.039)***
Random Effects			
Intercept (r_o)	77.422 (8.799)***	74.407 (8.626)***	42.886 (6.549)***
OBS Slope (r_1)			1.106 (1.052) ***
Residual (e□	37.570 (6.129)	21.376 (4.623)	16.400 (4.050)
Model Summary			
Deviance Statistics	2046.630	1904.933	1861.029
Estimated Parameters	2	2	4

Note. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Figure 1 *Digits Correct per Minute Growth Plot by Treatment Dosage*



CHAPTER V

CONCLUSION

Summary

Research across the last thirty years has examined the complex interactions between intervention variables that can alter treatment outcomes (Yeaton & Sechrest, 1981; Dulak & Dupre, 2008). The goal of this research has been to provide guidance to schools on the delivery of evidence-based interventions that is the most appropriate, effective, and resource efficient (Codding & Lane, 2015). The current study aimed to add to the current literature base by further examining how much of an intervention is needed for adequate student growth. To do so, a dose-response approach modeled from medical treatment research was used to evaluate the effects of a computer-based, evidence-based math fluency intervention (explicit timing) when provided at different doses of opportunities to respond.

It was hypothesized that assignment to the treatment group would produce differential effects on student growth in math fact fluency, particularly between the 12 OTR group and 1 OTR group. Results illustrated that varying levels of opportunities to respond did significantly produce differential effects on student growth in math fact fluency. All students' digits correct per minute improved over time regardless of dosage, with each group increasing digits correct by .728 each session. Students in the 12 OTR group had a growth difference of 1.650 digits more than students in the 1 OTR group. Regarding the second research question, the digit correct rate of growth was .878 for the 1 OTR group, 1.928 for the 8 OTR group, and 2.528 for the 12 OTR group. Overall, students in each group demonstrated session-to-session growth throughout the course of the intervention.

Limitations of Study

The impact of this study should be considered within the context of its limitations. One limitation of the study was the sample size of 43 participants was small, considering there were three treatment groups. Violations of assumptions for normality and homogeneity of variance further demonstrated the impact of a small sample size on the study outcomes. With 43 participants, 14 students were assigned to the 1 OTR and 12 OTR groups and 15 were assigned to the 8 OTR group. Having a higher number of participants would allow for more students to be assigned to each group and possibly produce significant effects that this study was unable to measure. Additionally, only third-grade students were included in this study, which does not provide a representative sample of students engaging in math fluency practice. Further, due to COVID-19 and state-testing there were breaks in the schedule of implementation, so students did not receive the intervention across 26 consecutive school days.

Due to the study being conducted toward the end of the school year, a maintenance assessment was unable to be conducted. This measure would have allowed the researcher to assess whether student growth maintained after the intervention was discontinued. Lastly, additional variables that may have affected the results of this study include social validity and student motivation. This study did not include a reinforcement component to maintain student engagement throughout the intervention period. Students were directed to keep working and do their best when they were observed to be off-task, however, this may not have been adequate to maintain student motivation throughout the study.

Further, student and teacher perceptions of the intervention were not assessed. This may have provided additional information on if certain doses are actually feasible for daily classroom implementation. Including a social validity assessment in the study, may assist in establishing the most effective dose for intervention implementation.

Implications and Future Directions

Regarding the aforementioned limitations, there are practical implications and future directions that may increase validity of the study, impact within-subject results, and impact between-subject results. A future direction for the current study is conducting the experiment with a larger sample size to validate the current results and ensure all assumptions are met. With that, including other grade levels in the intervention can provide information on how math fluency is impacted across grade levels and increase overall generalizability of the results of the study.

Additionally, it is important for the study to assess other dose levels of OTRs to further understand the dose-response curve with this math intervention. The current study was only able to identify the therapeutic window in which effects are demonstrated. Future studies should aim on identifying the threshold and plateau points to provide a complete picture of the dose-response curve (Calabrese & Baldwin, 2003). With this information, practitioners can provide guidance to educators on how much of the intervention is necessary for desired results. Studying the dose-response curve with other academic interventions would also allow for more guidance on recommendations for intervention dosages. As social validity and reinforcement were not included in this study, it may be helpful for future research to include these components in relation to student performance. Teachers should complete a pre- and post-test measure that evaluates teacher perspective on the feasibility of the intervention to provide a social validity measure. Explicit timing interventions with a reward or reinforcement component was demonstrated to be significant for student growth in studies by Duhon et al. (2009) and Duhon et al. (2015).

An additional component not included in the current study that may be important to explore is the delivery of a maintenance assessment after the discontinuation of the intervention. This would provide a thorough picture on the impact of the intervention. Lastly, it will be pertinent for the study to examine whether students in the intervention are able to generalize the skills learned to paper-and-pencil methods. As demonstrated by Duhon, House, and Stinnett (2012), skills acquired through computer practice may not generalize to paper-and-pencil methods. While the present study assessed students on both modalities, it was beyond the scope of this study to examine the generalization of skills between the two. In general, the limitations of the current study may be mitigated through the inclusion of the aforementioned components, particularly a larger sample size. Overall, the outcomes of this study provide a starting point for further exploration of the dose-response curve among academic interventions, specifically with explicit timing. This information would address calls in research to identify a consistent definition of dosage and further examine the impact of dose-response within school settings (Skinner, 2008; Greenwood, 2009).

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Appendix A: Computer Training & Practice Sessions Protocol

Computer Training & Practice Sessions Protocol

1. Instruct all students to grab their assigned computer. Teachers should have a link to the math program in their online classroom platform where students can access easily.

   "We are going to practice using a math program online over the next few days so we can get familiar with it. For our practice session, we are going to work on addition problems. These problems will not be for a grade so just do your best"

2. Write login information on the board where all students can see.

   "*Everyone has their own login for the program, and it is very important you are on your account. I will help you with your login information"*

3. Ensure all students have logged in correctly and know their login information.
4. Once every student has logged on instruct them on how to use the program:

   "Once you are logged in, you will see a 'Start Game' button. When I say start, you will press that button and begin working on some math problems.

   "To complete the problems, you will type the answer on your keyboard when the problem shows up on your screen. Try to answer the problems as fast as you can without making any mistakes. When you type an answer to the problem, the program will give you a new problem. Some of these problems may repeat, but you must complete all of them. If you do not know the answer, give your best guess and move on to the next problem. You will know you are done when you have no more problems to complete."

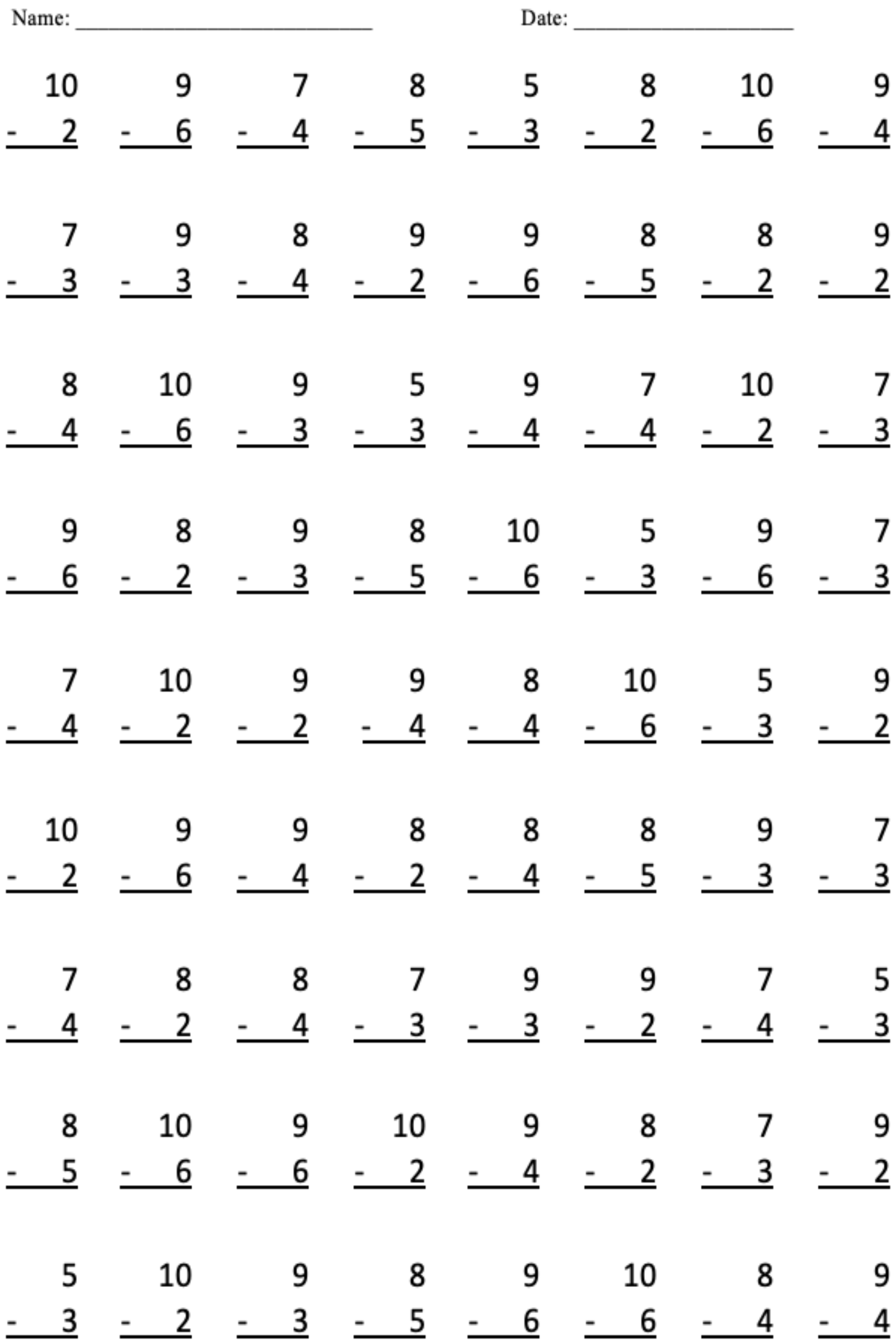
   "Once you have completed your problems for the day, raise your hand and someone will come over to you to tell you what to do next. Everyone should stay quiet and be respectful as everyone completes their problems for the day."

   "Are there any questions?"

   "Ready? Begin."

5. Run through several games with the students to model the appropriate behaviors over the course of three different sessions.

Appendix B.1: Subtraction Problems Paper Probe



Name: ____________________________ Date: ____________________

10 - 2	9 - 6	7 - 4	8 - 5	5 - 3	8 - 2	10 - 6	9 - 4
7 - 3	9 - 3	8 - 4	9 - 2	9 - 6	8 - 5	8 - 2	9 - 2
8 - 4	10 - 6	9 - 3	5 - 3	9 - 4	7 - 4	10 - 2	7 - 3
9 - 6	8 - 2	9 - 3	8 - 5	10 - 6	5 - 3	9 - 6	7 - 3
7 - 4	10 - 2	9 - 2	9 - 4	8 - 4	10 - 6	5 - 3	9 - 2
10 - 2	9 - 6	9 - 4	8 - 2	8 - 4	8 - 5	9 - 3	7 - 3
7 - 4	8 - 2	8 - 4	7 - 3	9 - 3	9 - 2	7 - 4	5 - 3
8 - 5	10 - 6	9 - 6	10 - 2	9 - 4	8 - 2	7 - 3	9 - 2
5 - 3	10 - 2	9 - 3	8 - 5	9 - 6	10 - 6	8 - 4	9 - 4

Appendix B.2: Subtraction Problem Set

10-2

9-6

7-4

8-5

5-3

8-2

10-6

9-4

7-3

9-3

8-4

9-2

Appendix C.1: Pre-Test, Progress Monitoring, and Post-Test Protocol

Pre-Test/Progress Monitoring/Post-Test Session Protocol

1. Pass out math probes to each student. Make sure each student has a pencil to write with before beginning the intervention.
2. Read the following directions:

   "Class today we are going to complete math worksheets. You are going to have one minute to complete as many problems as you can. When I say begin, start answering the problems on your worksheet. Start at the top and work across the page and then go to the next row. Try each problem, but if you come to a problem you do not know, you can skip it. Do your best to complete each problem as quickly as you can without making mistakes."

3. Continue, "*Are there any questions? Ready… Begin!" (Start timer for 1 minute)*
4. During the intervention, walk around the room and provide students with procedural feedback as needed and encourage students to do their best work.
5. After 1 minute, stop the timer and say, *"Stop! Put your pencils down."*
6. **For Progress Monitoring: Pick up math worksheets after one timing.**
7. **For Pre-Test & Post-Test:** Instruct students to flip to the next page and repeat two more timings to ensure all students complete a total of three math worksheets.
8. Once students have completed their session, collect all worksheets and thank them for their hard work.

Appendix C.2: Explicit Timing Intervention Protocol

Explicit Timing Intervention Protocol

1. Instruct students to grab their assigned computers and log in to the math program to complete their daily math problems.
2. Ensure all students are logged in correctly and provide any necessary assistance to students who may need it.
3. Instruct students on what task they are to work on when they finish their assigned problems.
4. Tell students to start their assigned problems.
5. During the intervention, walk around the room and provide students with procedural feedback as needed and encourage students to do their best work.
6. Check that all students have completed their assigned problems for the day and end session.

VITA

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