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ARTICLE

An investigation of moderators of a precision teaching and frequency building intervention

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ABSTRACT

Research examining behavioural fluency to date has demonstrated positive outcomes in relation to the efficacy of such interventions to increase the rate of correct responding with targeted mathematics skills. Equally as important is the necessity to investigate potential moderators of behavioural fluency so that the most effective instructional approaches can be implemented. The current study investigated the ability of individual differences and implementation variables to moderate outcomes of a frequency building intervention targeting mathematics skills with 71 participants. Participant age, grade, gender, standardised measures of mathematical ability, pre-intervention rates of correct responding with instructional materials, and intervention intensity were investigated as moderating variables. Participant age, pre-test rates of correct responding, and intervention intensity demonstrated the greatest ability to moderate intervention outcomes. The findings are discussed in relation to the importance of matching frequency building interventions to individual students' needs.

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Mathematics; frequency building; precision teaching; behavioural fluency; intensity; moderators

Mathematics is a pivotal academic domain which is necessary for future performances across many academic and applied skills. Proficiency within this domain is purported to be more likely attainable once component mathematics skills are fluent (Binder, 1996; Chiesa & Robertson, 2000; Johnson & Street, 2013; Stocker et al. 2019). Furthermore, a link between fluency with single-digit arithmetic problems and overall mathematical ability and growth have been demonstrated in the literature (Carr & Alexeev, 2011; Carr et al., 2008). Given the benefits of achieving fluency with component mathematics skills, it follows that effective and empirically validated practise approaches emphasizing frequency building should be incorporated into education. Research investigating practice approaches with mathematics skills has demonstrated positive outcomes to date (Gross et al., 2013; Hartnedy et al., 2005; Poncy et al., 2010, 2013). A meta-analysis conducted by Codding et al. (2009) demonstrated moderate to large effect sizes for nine practice type interventions implemented to increase the rate of correct responding with mathematics skills. Additionally, Stocker et al. (2019) showed that frequency building

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directly leads to several critical learning outcomes (e.g., long-term retention) associated with the attainment of fluency aims or goals.

However, developing automaticity with mathematics skills can be challenging (Miller et al., 2011). While research investigating practice approaches has demonstrated predominantly positive outcomes, a number of studies in the literature report that some interventions were not effective for *all* participants to attain fluency with target skills (Bliss et al., 2010; Miller et al., 2011). Such findings imply that certain variables may impact the delivery or operationalization of frequency building or practice approaches to achieve best outcomes. Codding et al. (2009) noted that although their analysis of practice type interventions demonstrated effectiveness in improving performance, individual differences and implementation variables (e.g., intensity of intervention) can affect the outcomes of such interventions.

It may be argued that equally as important as empirically validated procedures for increasing fluency, is the identification of the individual characteristics of students for whom they are most effective. Matching intervention to individual students' needs is recognised as an important component of effective instruction (Burns et al., 2010; Johnson & Street, 2013; Mong & Mong, 2012); however, a lack of research to date exist regarding how this should be addressed. Individual differences and implementation variables and their impact on intervention effectiveness should be examined prior to intervention implementation. Subsequent research investigating such variables will inform best practice within applied experimental research and the implementation of interventions in educational settings.

Investigations of moderation effects can determine when or for whom an independent variable most strongly or weakly affects a dependent variable (Baron & Kenny, 1986; Frazier et al., 2004; Kraemer et al., 2002; Wu & Zumbo, 2008). Such analyses can be conducted when investigating whether an instructional method is equally effective for students who present with varying levels of potentially moderating variables and can explain the strength of the causal relationship between the intervention and outcomes (Wu & Zumbo, 2008). Using targeted analyses, in-depth investigations of the ability of individual differences (e.g., students' age and pre-intervention ability) and implementation variables (e.g., intervention intensity) to moderate the effectiveness of interventions can be conducted.

Analyses of moderating variables can be difficult to evaluate in smaller sample sizes associated with single-case experimental design (SCED) which is the predominant method by which practice type and frequency building interventions leading to behavioural fluency are evaluated (Codding et al., 2009). A limited number of studies investigating variables in terms of their ability to moderate the effectiveness of practice type interventions have been conducted using meta-analyses (Burns et al., 2010; Morgan & Sideridis, 2006; Scholin & Burns, 2012). Methe et al. (2012) conducted a meta-analysis of interventions for basic mathematics computation (e.g., contingent reinforcement, goal setting, cover copy compare, peer-tutoring) and found that student age, time spent in intervention, and intervention type appeared to moderate intervention effects. Continued research is necessary to better understand how individual differences and implementation variables can impact individual performances specifically within the context of practice type and frequency building interventions in order to yield optimal outcomes for each individual. Research to date has implicated a number of variables which are in need of further investigation.

Previous research has indicated that intensity of an intervention can impact outcomes of interventions (Codding et al., 2011; Duhon et al., 2009; Mellard et al., 2010). Duhon et al. (2009) evaluated the impact of increased intensities of a frequency building intervention with mathematic skills. Intensity was quantified as the frequency of sessions implemented per day. Results demonstrated that increased frequencies of sessions impacted outcome measures. Hale (2009) further demonstrated the ability of a higher frequency of sessions to increase fluency with mathematics skills to a greater extent than a lower frequency of sessions. Considering the implications for both research and applied practice, such findings highlight the importance of evaluating intervention intensity further in terms of its ability to moderate outcomes of frequency building and practice type interventions. When designing and implementing interventions, it is important that students receive instruction at an intensity that will result in best outcomes. However, to date, it is an area that has had limited empirical consideration (Duhon et al., 2009).

A number of studies indicate that student age should be considered when developing interventions with the goal of increasing fluent performances. Participant age has been shown in previous research to impact performance on fluency tasks. Kave (2006) conducted word fluency tests (a three-letter phonemic fluency task and a three-category semantic fluency task) with 150 children to examine performances related to participant age. Five age groups were examined (8–9, 10–11, 12–13, 14–15, and 16–17 years) with 30 participants in each group. Analysis of outcomes demonstrated an incremental increase in performance according to increased age indicating that age plays an important role in individuals' ability to perform fluently with specific tasks. However, in a meta-analysis evaluating the effectiveness of differing reading fluency interventions for students with learning disabilities, Morgan and Sideridis (2006) found that participant age did not moderate interventions' effectiveness. This may indicate that, despite an incremental performance associated with increasing age, certain interventions can increase the fluency with which all learners perform during reading tasks. However, such questions should be explored further in future research.

Sak and Maker (2006) investigated mathematical ability in relation to participant age and school grade with 841 first to fourth-grade students. Their findings demonstrated the contribution of age to fluent performances was low at all grade levels but that there was a statistically significant difference among grades for fluency with mathematics skills. Given the paucity of research investigating such variables and some inconsistencies in findings across studies, further investigation is warranted to inform interventionists on how practice type and frequency building interventions could potentially be modified to suit students of differing ages. Further research is also necessary to investigate the ability of student age to moderate the effects of frequency building and practice type interventions with mathematics skills specifically.

Previous research has indicated the potential for gender differences in mathematics fluency (Carr et al., 2008; Royer et al., 1999). Specifically, Carr et al. (2008) found that in a sample of 241 second-grade students, girls had lower fluency with mathematics skills than boys and reported that this likely contributed to boys' faster acquisition of mathematical skills during early elementary school years. However, Morgan and Sideridis (2006) demonstrated that participant gender accounted for significant variability in an intervention's effectiveness meaning that gender moderated the outcomes of interventions. The majority of interventions evaluated in their meta-analysis were more effective when used with female participants. Inconsistencies in such findings to date indicate a necessity for further investigations of gender as a potentially moderating variable.

In addition to participant age and gender, performance on assessments of mathematical ability prior to receiving practice type and frequency building interventions warrants further investigation, in terms of how scores on such assessments may predict outcomes and best inform intervention design. A number of studies have found that students with lower scores on mathematics assessments prior to intervention require more repetitions to achieve automaticity with math facts than more skilled learners (Burns et al., 2015; Stickney et al., 2012) and achieved automaticity later (Stickney et al., 2012). Miller et al. (2011) evaluated the effects of a Taped-Problems procedure to increase fluency with addition math facts with 19 participants. They found it to be effective for 15 participants; however, four showed few gains as a result. The authors suggest that from their observations, the intervention was more effective for those who had higher levels of skills prior to beginning the intervention, and that further research is needed to determine if the effectiveness of the approach can be enhanced by making adaptations to meet specific students' needs. It follows that the identification of students who would benefit from such adaptations prior to intervention could be identified through pre-intervention assessment of skill level which would inform on how best to match interventions to each individual's needs. Research is necessary to identify assessments which may inform interventions best.

Burns et al. (2010) purport that sampling students' levels of correct responding with instructional materials can inform instructional planning. Pre-test levels of accuracy and fluency with such materials should inform the appropriateness of practice type and frequency building interventions for individual students. Results of their meta-analytic review of mathematics interventions (targeting both acquisition and fluency) demonstrated that acquisition interventions resulted in larger effect sizes among children with lower pre-test rates of correct responding but produced moderate effects for children with higher pre-test rates of correct responding. Similarly, practice type and frequency building interventions had only a small to moderate effect with students who had lower pre-test rates of correct responding with targeted skills. The findings indicate that practice type and frequency building interventions are not as effective for students who present with lower rates of correct responding prior to intervention and as such this had an impact on the effectiveness of each intervention. Sampling students' rate of correct responding prior to intervention may inform intervention design and facilitate in matching instruction to students' needs. However, to date, few studies have examined the consistency with which fluency scores on computational tasks can be used to guide instructional programming (Burns et al., 2006) or can moderate the effectiveness of interventions.

Standardised norm-referenced assessments are often used to evaluate students' level of ability in an academic repertoire, and to make recommendations about future academic instruction. Standardised norm-referenced assessments are typically administered annually and provide the basis for determining whether students are making adequate yearly progress (Johnson & Street, 2013). The tests provide scores on a broad range of skills within each academic domain measuring aspects of learning which are targeted in general education settings. Students' scores across subtests of specific mathematical abilities can identify individual strengths and weaknesses which are used to inform and facilitate intervention planning. Research investigating the ability of pre-test scores on norm-referenced assessments to moderate the effectiveness of practice type and frequency building interventions with mathematics would be beneficial so that their ability to inform such instruction can be evaluated.

The current study provided an investigation of moderators which impact the effectiveness of a frequency building intervention in order to facilitate the development of the most effective evidence-based interventions which can be matched to individual students' needs. The study implemented frequency building and Precision Teaching (PT) using the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) with 71 students between the ages of six and 12 years. Moderators were investigated in relation to their ability to moderate the outcomes of the current frequency building intervention. The primary outcome indicating successful performance was the number of fluency aims (i.e., quantitative goals as measured by frequency or rate) achieved by each participant demonstrating their ability to progress through the curriculum and frequency building intervention. Participant age, grade, gender, pre-test scores on mathematics assessments, and intervention intensity were investigated to evaluate their ability to moderate intervention outcomes.

Method

Participants and setting

Participants were 71 typically developing students between the ages of 6 years and 3 months and 12 years and 10 months (M = 8 years and 9 months). Sixty-two percent (N = 44) were female and 38% (N = 27) were male. Scores on the Mathematics Fluency subtest of the Woodcock Johnson, Third Edition (WJIII; Woodcock et al., 2001b) prior to intervention ranged from 65 to 145 (M = 97.8, SD = 14.9). Parental consent was obtained for all participants included in the study.

Participants were all at primary school level ranging between first and sixth grade across three intervention settings. Two mainstream schools (Setting 1 and 2) were located in disadvantaged communities qualifying for participation in a School Support Programme (Delivering Equality of Opportunity in Schools; DEIS) by the Department of Education and Skills Ireland (DES, 2005). Participants in Settings 1 and 2 consisted of 78.8% of the sample (45% in setting 1 and 33.8% in setting 2). The remaining 21.2% of the sample (15 participants) were in Setting 3, which was an after-school homework club developed by a community development project in a disadvantaged community. The 15 participants attended the homework club once per week. Participants were recruited by contacting a number of schools and homework clubs and presenting the study details to the principal and staff. Once the principal agreed to participate in the study, parental consent forms were sent home through the school and those students who returned consent forms participated in the study.

Moderators

Potential moderating variables included in the analyses were participant age, gender, pre-intervention standardised scores of mathematical ability using a norm-referenced assessment (WJIII; Woodcock et al., 2001b), rate of correct responding with instructional materials, and intervention intensity. Table 1 shows the mean values of moderator variables across school grades.

Woodcock-Johnson III

Three mathematics subtests of the WJIII (Applied Problems, Calculation, and Mathematics Fluency) were conducted at pre-testing with each participant prior to implementing fluency-based instruction. Applied Problems assesses quantitative reasoning, mathematics achievement, and knowledge. Word problems are presented orally in conjunction with a stimulus booklet which presents problems using pictures and, at more advanced levels, words. As the problems increase in difficulty, participants are provided with a paper and pencil to solve. Calculation measures mathematics achievement in relation to the ability to access and apply knowledge of numbers and calculation procedures. It is a paper and pencil test involving arithmetic and computation. Participants were presented with problems on a worksheet and recorded their answers on the sheet next to each problem. The Mathematics Fluency subtest measures the ability to solve simple addition, subtraction and multiplication facts quickly. Participants were presented with a sheet of single-digit calculations and asked to answer as many as they could correctly in 3 min. There were two sheets in total with 80 problems on each.

Rate of correct responding with instructional materials

Pre-tests were conducted to assess rate of correct responding with instructional materials for each participant. This was conducted using a review worksheet from the Morningside Math Facts: Addition and Subtraction curriculum (Johnson, 2008). The review worksheet consists of 100 addition and subtraction problems presented in random order. Multiple exemplars of problems pertaining to the first 12 fact families in the Morningside curriculum were presented. Participants were asked to complete as many problems as they could during a 1-min timing. Rate of correct responding per minute was calculated by the experimenter. All problems required one or two-digit answers. A correct response was recorded if all digits in the answer to the problem were correctly written. Responses

Table 1. Mean values of moderator variables across participant grades.

				Mean scores of mathematical ability			
					Woodcock-Johnson III		
Grade *(% sample)*	% Male	% Female	Mean age	Rate of correct responding with instructional materials *(range)*	Applied Problems *(range)*	Calculation *(range)*	Math Fluency *(range)*
1 *(25.4%)*	38.9	61.1	6.96	7 *(1–12)*	103.7 *(69–120)*	99.8 *(69–127)*	103.7 *(75–118)*
2 *(32.4%)*	39.1	60.9	8.03	10.3 *(4–23)*	102.2 *(71–116)*	93.2 *(53–116)*	102.2 *(73–145)*
3 *(14%)*	40	60	9.05	11.3 *(2–27)*	93.1 *(77–110)*	81 *(50–96)*	93.1 *(65–117)*
4 *(8.5%)*	33.3	66.7	9.98	12.8 *(5–26)*	85 *(60–104)*	93.5 *(79–101)*	85 *(73–94)*
5 *(7%)*	80	20	11.3	19.8 *(16–23)*	95 *(80–111)*	96.2 *(81–114)*	95 *(89–103)*
6 *(12.7%)*	11.1	88.9	12	18 *(14–21)*	88.1 *(85–108)*	99.1 *(80–126)*	88.1 *(81–96)*

were scored as incorrect if any digit in the answer to a problem were incorrect or if digits were omitted or placed in the incorrect order. Number of correct responses per minute was calculated to represent rate of correct responding on the test of fluency.

Intervention intensity

Varying intensities of intervention were implemented with the sample meaning that intensity of intervention could also be analysed as a potential moderator of outcomes. A mean of 19 frequency-building sessions, ranging from nine to 26 were conducted. The intervention was implemented non-concurrently across the three settings over a full school year (September to June) with participants receiving a mean of 13.5 weeks of intervention ranging from 10 to 26 weeks. The mean number of minutes each participant was exposed to intervention was 459 ranging from 85 to 780 minutes in total. Intensity of intervention was analysed in terms of the number of minutes of intervention received.

Outcome measures

Moderating variables were analysed to evaluate their ability to impact scores on outcome measures. The outcome measure used was the number of fluency aims that participants achieved during the intervention. Each slice of the Morningside curriculum has an associated fluency aim (e.g., 50–60 correct responses per minute) which should be achieved before moving onto the next slice. Students progressed through each slice of the curriculum at their own pace. The number of fluency aims achieved during intervention was calculated by adding the total number of aims each participant had achieved by the end of the intervention.

Intervention

Intervention sessions to increase mathematics fluency using the Morningside Math Facts: Addition and Subtraction curriculum (Johnson, 2008) were conducted with each participant. Fluency aims (i.e., target number of correct responses per minute) were predetermined by the curriculum. Participants were exposed to a mean of 19 sessions, ranging from nine to 26. The mean number of minutes each participant was exposed to intervention was 459 ranging from 85 to 780 minutes in total. The intervention was implemented non-concurrently across the three settings over a school year (September to June) with participants receiving a mean of 13.5 weeks of intervention ranging from 10 to 26 weeks. Intervention sessions consisted of four to six participants in each group and two to four instructors per group.

Materials

Each participant was allocated a folder containing materials for frequency building and PT (i.e., data display and monitoring on a Standard Celeration Chart). Participants were provided with data collection sheets to record the number of correct and incorrect responses they had achieved after each timing. The data collection sheet included the fluency aim for each worksheet, the date, space to input correct and incorrect responses, and a prompt for each participant to request a raffle ticket once they achieved their aim.

Worksheets currently being practised and Standard Celeration Charts (SCC) were also located in each participant's folder. Digital timers were used to conduct timings.

Curriculum

The Morningside Math Facts: Addition and Subtraction curriculum (Johnson, 2008) was used with addition and subtraction computation. The curriculum uses fact families to build fluency with addition and subtraction using single digits. A worksheet containing target fact families is provided so that each fact family can be recited both accurately and fluently. The curriculum includes a fluency aim of accurately reciting each fact family within 4–6 seconds before progressing to pencil and paper worksheets. Pencil and paper worksheets each consist of 100 problems presented in random order pertaining to 36 fact families. The fluency aim for number of correct responses per minute for each worksheet is 50–60 per minute. The curriculum also includes cumulative and review worksheets which consist of problems pertaining to fact families learned in previous sessions. The aims set by the curriculum are 60–70 correct responses per minute for cumulative worksheets and 70–80 correct responses per minute for review worksheets. There are a total of 84 fluency aims to achieve throughout the complete curriculum.

Curriculum start point allocation

Prior to implementing the intervention, one-minute timed assessments were conducted with each participant with worksheets from different levels of the curriculum. This was to ensure that no participant would start at a point in the curriculum at which they were already fluent. Participants were placed at the point at which they did not achieve the fluency aims outlined by the curriculum. As no participant attained fluency aims on either the addition or subtraction levels, all were allocated start points at the beginning of the instructional material.

Frequency building sessions

During the first session, folders were allocated and the general procedure was explained. Participants were shown how and where to record correct and incorrect responses after timings, how to identify which worksheet from the curriculum that they should be working on, and the corresponding fluency aim. It was explained to each participant that they would receive positive feedback in the form of "checks" (entered as √ onto a chart) based on four target behaviours. The first target behaviour was "working well" and checks were delivered contingent on correct responding and working independently. The second target behaviour was "working fast" and checks were received in this category if participants beat their score on their previous timing. The third target behaviour was "getting your goal" and participants received a check in this category for achieving a fluency aim. Finally, participants received checks for "good listening" whereby checks were awarded when participants listened to, and followed instructions, throughout the session.

Each participant had a chart on the desk beside their folder with pictures and words representing each category. The instructor reinforced target behaviours throughout the session by simply placing a check on the relevant category. Once five checks were accumulated, a raffle ticket was awarded. If 10 checks were achieved within one session, two raffle tickets were awarded. One check on the "getting your goal" category was immediately reinforced with a raffle ticket ensuring that achieving a fluency aim received a higher magnitude of reinforcement. At the end of each week, the raffle was conducted and one participant chose an item from the "prize box".

Before participants began timings with each pencil and paper worksheet, they were required to learn each fact family orally. It was explained that they should practice reciting each as fast as they could and they were informed of their fluency aim (4–-6 seconds). An instructor would return to the participant after a period of time and verify that each family could be recited in 4–6 seconds. The participants recorded their correct and incorrect responses on the data collection sheet following each timing.

When participants were completing pencil and paper worksheets, they marked an X on the worksheet to indicate how many problems they would need to complete to "beat their score" from their previous timing. The instructors circulated amongst the participants to ensure everyone in the group was working on the correct target and had identified the correct fluency aim. When the group was ready the timed practice session began. Each participant was asked to place their pencil on the paper at their start point. They were reminded that they needed to answer as many problems as they could correctly in 1 min and should try to beat their score from the last timing. They were also made aware of the fluency aim allocated to the worksheet which they would need to achieve in order to obtain a raffle ticket and to move on to the next worksheet. The instructor set the timer for 1 min, said, "Let's begin", and started the timer.

Corrective feedback

No corrective feedback was delivered during timings; however, participants received praise throughout timings contingent only on active engagement in the task. When a timing was complete, the group was instructed to "drop their pencils", count the number of problems they had completed and to signify any incorrect responses by drawing a circle around it. The instructors circulated amongst the group to verify number of correct and incorrect responses and to provide corrective feedback on errors with participants individually. The instructor identified incorrect responses and presented the relevant problems orally. Least-to-most prompts were used until the participant could emit the correct response.

If a fluency aim was not achieved but faster rates of responding were obtained, the participant received a check for "working fast". When participants had increased correct responding they also received a check for "working well". When a fluency aim was not attained, additional timings were implemented until the fluency aim was achieved.

Decision analysis

Decisions about each participant's progress were made by visually inspecting the data on SCCs. Timings Charts, a variant of an SCC, were completed during the session facilitating decisions on progress within each session. Daily Per Minute Charts (i.e., SCCs) were also completed in order to make decisions based on progress across daily sessions. Each participant's visualized pattern of progress or "learning picture" was assessed on both the Timings and Daily chart in order to decide how to progress with instruction. When participants demonstrated a steady increase in rate of correct responding, they continued with timings and corrective feedback until the fluency aim for each worksheet was achieved.

Aspects of teaching were adapted based on learning problems demonstrated on the SCCs. The adaptations always matched the difficulty each participant presented with. If a participant's performance was accurate but low in frequency, adaptations were made in order to build frequency (e.g., the number of opportunities for timings was increased and less time given to corrective feedback). If participants' learning pictures demonstrated a high rate of errors, adaptations to teaching were made to ensure the skill was performed accurately (e.g., skills on which errors were made consistently were isolated, untimed practice with corrective feedback was provided after each response and rate of correct responding increased with the isolated set before returning to the original worksheet). When rate of correct responding was variable and compliance was observed to be a problem within a session, participants were reminded that reinforcement was contingent on the four previously named target behaviours. Instructions were increased to provide greater opportunity to reinforce "good listening" and participants observed to work throughout timings without distraction received checks for "working well".

Intervention agents and training

Instructors included the experimenter (first author) and six Masters level students completing university postgraduate training in Applied Behaviour Analysis. Group training sessions in frequency-building, PT, and use of the curriculum were provided by the experimenter to instructors prior to and throughout the course of the school year. The experimenter was also on-site, allocating time across the three settings, and provided individual on-site training and feedback on instructors' implementation of the intervention.

Inter-rater reliability

Thirty percent of the worksheets completed to measure pre-test fluency with instructional materials were independently scored by two individuals to examine inter-rater reliability. Inter-rater agreement was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplied by one (Codding et al., 2010). Percentage agreement for number of correct responses on worksheets was 100%. Achievement of fluency aims by participants was verified by the experimenter during onsite visits to each setting.

Data analysis

Pearson's product moment and Spearman's rho (for categorical variables) correlations were first conducted to investigate if there were statistically significant correlations between each moderator and outcome measure (number of fluency aims achieved). Correlation results were used to inform the structure of a multiple regression model. Only moderators that demonstrated a significant correlation in this preliminary analysis were included in the regression model. A Hierarchical Multiple Regression (HMR) was conducted to assess the ability of the model to predict the number of fluency aims achieved. The number of minutes of intervention received by participants was entered in the first block of the regression, while the remaining predictors in the final were entered in the second block. Significant predictors are discussed in relation to their ability to moderate participants' scores on outcome measures. Preliminary checks were conducted with each variable to ensure there were no violations of assumptions. Outliers identified on boxplots were recoded to the nearest value in the distribution.

Results

The mean number of fluency aims achieved by the sample was 5.06 (*SD = 4.49*). Four participants achieved zero aims while the highest number achieved was 26 (n = 1).

Regression analysis

Based on significant correlations found using Pearson product-moment and Spearman's rho correlation coefficients (see Table 2), a Hierarchical Multiple Regression was used to investigate how well three specific variables predicted the number of fluency aims achieved during intervention. Preliminary analyses demonstrated that standardised measures of mathematical ability (WJIII; Woodcock et al., 2001b) were not significantly correlated with the number of aims achieved and as a result were excluded from the model. Participant age, gender, pre-test rate of correct responding with instructional materials, and number of minutes of intervention all demonstrated significant correlations with the number of fluency aims achieved; therefore, they were included in the model.

The number of minutes of intervention was entered at step 1 and explained 15% (R^2 =.154) of the variance in the number of fluency aims achieved. Participant age, gender, and pre-test rate of correct responding were entered at step 2. Total variance explained by the model as a whole was 55%, F (4, 37) = 11.7, p < .001 (R^2 = .558). Participant age, gender, and pre-test rate of correct responding explained an additional 40% of the variance in the number of aims achieved, after controlling for intensity variables, *F* change (3, 37) = 11.2, p < .001, ΔR^2 = .404). In the final model, pre-test rate of correct responding, participant age, and number of minutes of intervention were statistically significant as unique predictors with pre-test rate recording a higher beta value. Higher rate of correct responding at pre-test, a higher participant age, and a higher number of minutes in intervention predicted a higher number of aims achieved. Table 3 shows the beta values for each variable. Figure 1 depicts the multiple regression model R-value. Predicted values from the regression equation were created to develop the

Table 2. Pearson product-moment and Spearman's rho correlation coefficients for moderators and outcome measures.

Moderators	No. aims achieved
Participant age	.569**
Pre-test rate with instructional materials	.678**
Participant gender	.273*
WJIII Applied Problems	.084
WJIII Calculation	.146
WJIII Mathematics Fluency	.120
Intervention Intensity	.392**

*p <.05. **p <.01.

Table 3. Summary of hierarchical multiple regression analysis assessing the impact of moderators on the number of fluency aims achieved.

Step	Variable	B	Standard error	B	R2	R2 change
1.	Number of Minutes	.016	.006	.392*	.154	
2.	Participant Age	.784	.325	.307*		.404
	Participant Gender	.387	1.06	.042		
	Pre-test rate	.292	.087	.452**		

*p <.05. **p <.01.

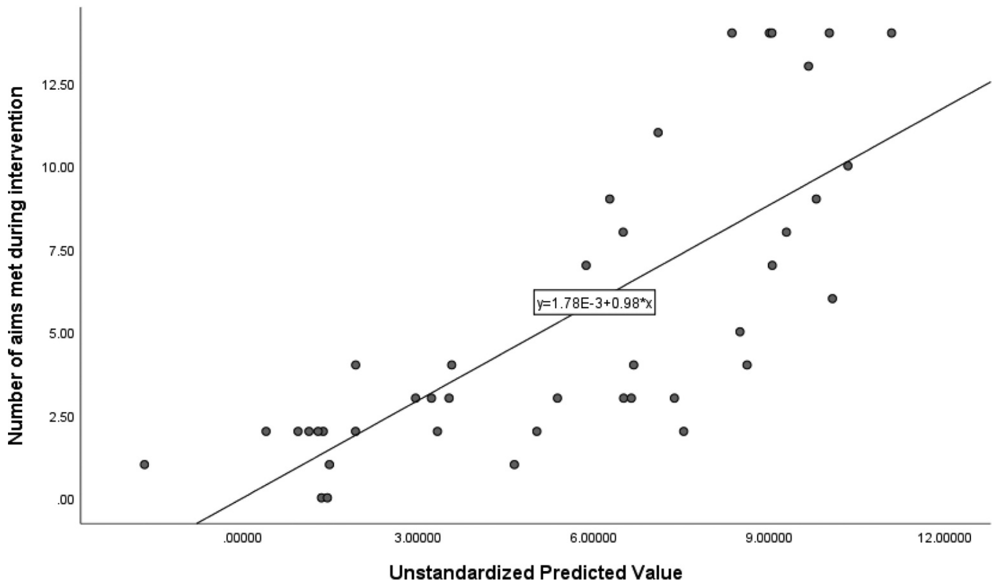

Figure 1. Scatterplot depicting the relationship between the dependent variable and predicted values derived from regression equation.

scatterplot depicting the relationship between the dependent variable and predicted values.

Discussion

The empirical evaluation of frequency building interventions and corresponding curricula to increase mathematics skills is paramount, to ensure evidence-based methods of instruction can be implemented within educational settings (Poncy et al., 2013). Equally as important is the examination of factors which moderate the effects of such interventions and the identification of students for whom frequency building is appropriate. The current investigation of potential moderators of a frequency building intervention yielded significant and notable results, with participant age, pre-test rates of correct responding, and intervention intensity demonstrating the greatest ability to moderate intervention outcomes. The number of fluency aims achieved during intervention was the outcome measure used to demonstrate participants' ability to progress through the frequency building intervention. Pre-test rate of correct responding best predicted this ability with those who had higher rates of responding at pre-test achieving more aims.

The finding supports Burns et al. (2010) suggestion that sampling students' levels of correct responding with instructional materials can inform instructional planning in terms of the appropriateness of practice type and frequency building interventions for individual students.

Burns et al. (2006) asserted that students can be confronted with academic difficulties when a mismatch is made between a student's skill level and instructional material. It is essential that instructional material is challenging enough and yet not too easy. The authors note that students who show the strongest growth in performance are students for whom the task represents an appropriate instructional match. The current findings support this assertion. Participants who had lower pre-test rates of correct responding required more untimed practice and corrective feedback between frequency building timings and did not achieve as many fluency aims. Acquisition interventions would perhaps be more beneficial for such students before frequency building and practice type interventions are implemented. Alternatively, frequency building in conjunction with other instructional approaches (e.g., Detect, Practice, and Repair; Poncy et al., 2013) could be evaluated for appropriateness with such students.

Pre-test scores on the WJIII (Woodcock et al., 2001b) were not significantly associated with the number of fluency aims achieved. Standardised norm-referenced assessments of academic achievement are valuable methods of assessment to determine if students are performing at levels similar to their same-age peers, for allocation of resource and learning support hours and to identify individual strengths and weaknesses. However, with respect to ability to inform intervention, the current study found that there was no relationship between a standardised measure of mathematical ability and participants' response to a frequency building intervention.

Burns et al. (2010) allude to problems with norm-referenced measures of academic achievement and their ability to inform intervention. Such measures may lack instructional relevance and there is as of yet no clear link between aptitudes and intervention effectiveness. Torgesen (2000) identifies another issue with normative approaches to assessment outlining that there will always be students who fall in the lowest quartile and so will appear to be at risk regardless of their performance. Such issues with norm-referenced assessments indicate a necessity for additional assessments of instructional needs to inform best practice for mathematics instruction.

Meta-level assessments measure performance on a subset of skills that best predict mastery of related skills. They typically measure mastery of element or component skills which are pre-requisites to mastery of compound or composite repertoires that norm-referenced assessments measure (Johnson & Street, 2013). The results described herein indicate that it may be beneficial to incorporate meta-level assessments of rates of correct responding for specific skills in educational settings to inform instructional methods appropriate for each individual student. Specifically, when implementing frequency-building with the Morningside Math Facts: Addition and Subtraction curriculum (Johnson, 2008), pre-test rates of correct responding may be investigated prior to implementing frequency building instruction. Further research is necessary to investigate the exact rate(s) necessary in order to achieve optimal outcomes with participants.

Participant age was also a unique predictor of participants' ability to achieve fluency aims. This finding suggests that student age should be considered when designing interventions to increase mathematics fluency. Specifically, such factors are important when considering the appropriateness of frequency building for individual students and when determining fluency aims. The Instructional Hierarchy (Haring & Eaton, 1978) provides an approach to instruction which allows acquisition of skills, followed by a focus on building fluency. Once acquisition mastery criteria are met, fluency is targeted. Pre-test rates of correct responding were also lower for younger participants (see Table 1) indicating that they may equally have benefited from acquisition interventions prior to exposure to frequency building.

In addition to considering such variables when determining the appropriateness of frequency-based interventions, the current findings may have further implications for the selection of appropriate fluency aims and counting times. Fluency aims were the same for all participants, regardless of age or grade, within the current study. Kave (2006) found that age plays an important role in individuals' ability to perform tasks fluently with performances increasing incrementally as age increases. Further, Heikkilä et al. (2013) describe the process of "automatization", or fluency, with reading skills as gradual and developmental rather than being an "on/off" skill. This suggests that student age plays a role in developing fluency with academic skills.

Within the current research, a number of younger participants demonstrated accurate responding with mathematics skills targeted in the Morningside Math Facts: Addition and Subtraction (Johnson, 2008) curriculum; however, they did not achieve the same number of aims as older participants within the sample. Younger participants would likely have achieved more aims had those aims been set at a lower level. However, that is not to say that lower fluency aims would lead to the same outcomes associated with fluency (e.g., retention, endurance). It may also be the case, that younger students would have achieved more fluency aims had counting times been shortened (e.g., from one minute timings to thirty second timings). Binder et al. (1990) suggest that counting times may be varied in order to deal more effectively with individual difference in attention span. Further research is necessary to investigate optimal fluency aims and counting times as differentiated by age.

Gender was not found to be a unique predictor in the final model and demonstrated only a weak correlation with the number of fluency aims achieved. Carr et al. (2008) found that females demonstrated lower fluency scores with mathematics skills than males; however, results of the current study suggest that gender does not affect ability to achieve fluency with mathematics skills given appropriate instruction. Frequency building is a focused, systematic manner for practising and developing fluency (Kubina, 2019). It would appear theoretically peculiar that practice works differentially based on gender.

The concept of intervention intensity has received limited empirical consideration to date (Barnett et al., 2004; Duhon et al., 2009; Hale, 2009; Mellard et al., 2010) despite agreement among researchers that intervention dose should be a critical variable for consideration, with implications for applied experimental research and for applying interventions in educational settings (Codding et al., 2011). The current study found that intervention intensity (defined as the number of minutes of intervention received) was a unique predictor in the final model. Higher intensity interventions were correlated with a higher number of fluency aims achieved. These findings are in line with Duhon et al. (2009) and Hale (2009) who found that a higher frequency of sessions impacted fluency outcomes to a greater extent than lower frequency sessions. Since intensity has the potential to moderate intervention outcomes, it is important that future studies evaluating frequency building ensure to specify and quantify intensity in terms of the number of sessions and minutes each participant received. This allows for comparisons across intervention studies and facilitates the application of effective frequency building interventions in applied settings.

With regards to the concept of intervention intensity, it should be noted that there are several variables other than intervention dose that increase instructional intensity. Mellard et al. (2010) suggest that there are at least 10 variables that influence instructional intensity including dose (minutes, frequency, and duration), instructional group size, immediacy of corrective feedback, mastery requirements of content, number of response opportunities number of transitions between classes and tasks, specificity of curricular goals, and instructor expertise and skills. The finding that intervention dose (number of minutes of intervention received) is significant and noteworthy for research and practice; however, other elements that contribute to intervention intensity are of the utmost importance and should be evaluated as moderators of intervention outcomes in future research. Considering our finding that age was a moderator of intervention outcomes, it may also be worth noting that changes to intensity of intervention over and above intervention dose (e.g., instructional group size, immediacy of corrective feedback, mastery requirements of content, number of response opportunities) may have been of benefit to younger participants in particular.

Limitations and future directions

Larger sample sizes would be beneficial to increase the external validity of such findings, in particular, because measures of pre-intervention rate of correct responding with instructional materials was not attainable for all 71 participants. Further, 62% of the sample were female. Despite the sample size, significant findings were demonstrated with important implications for practice. Further investigations of moderators of frequency building interventions are warranted, using larger and more homogeneous samples. Researchers should also consider employing comparison control groups and random assignment to strengthen the methodology of future studies.

The intervention agents received training and a significant amount of oversight and supervision in implementing the current intervention. However, treatment fidelity data were not collected to obtain data on the accuracy of implementation across intervention agents. Inter-rater reliability data were collected for some but not all measures. This is a significant limitation of the current study and should be addressed in future studies investigating similar research questions.

A number of additional possible moderating variables were not assessed in the current research as they were outside the scope of the current research. Torgesen (2000) for example, investigated cognitive, language, behavioural, and demographic characteristics in relation to reading ability. They found that children who showed the poorest growth in reading ability came from homes in which parents had the lowest levels of education and income and were related by their teachers as showing the broadest range and highest frequency of behaviour problems in the classroom. Cognitive abilities (e.g., working memory) and behaviour problems have been linked with fluent performances by behavioural fluency theorists (Binder et al., 2002; Bliss et al. 2010; Miller et al., 2011). Such links should be investigated and evaluated experimentally and research on moderators of frequency building interventions expanded.

Conclusion

Competency in mathematics is pivotal for engaging in many academic and applied skills and is essential to everyday life. Equally as important as providing an evidence-base for frequency building interventions, is the necessity to identify additional variables which may impact or moderate their effectiveness. Matching of instruction to individual students' needs is considered an essential element of intervention design (Mong & Mong, 2012). Identification of moderating variables will inform on how best to plan and design interventions in order to achieve the best outcomes for each individual student. The current findings may contribute to the design of frequency building interventions for primary school level students indicating that the age, pre-test rate of correct responding, and intensity of intervention are vital to consider prior to intervention. Further research evaluating the effects of frequency building and PT, using the Morningside Math Facts curriculum to increase fluency with mathematics skills could be conducted using larger sample sizes and a more rigorous experimental design. However, the current findings have significant applied implications for the design and delivery of curricula to promote long-lasting positive outcomes in mathematics performance in children.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Ethical approval

The study was conducted in full compliance with relevant ethical codes. The study received formal approval from the university research ethics committee prior to implementation.

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