Enhancing Basic Academic Skills with Audio-Recordings: A Review of the Literature

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Abstract

Because teacher-to-student ratios often make it difficult for teachers to work individually with students on skill-building activities, educators and researchers have developed and evaluated procedures in which audio-recordings are used to improve basic academic skills. In the current paper, we describe and analyze reading, math, and spelling interventions that use audio-recordings to prompt and pace rapid rates of accurate responding. In this review, we provide evidence of internal and external validity of easy-to-use, low-tech, recorded interventions across students (general education students and students with disabilities) and contexts (e.g., individually administered and class-wide). Discussion focuses on future theoretical research related to causal mechanisms and applied research on modifying recorded interventions to enhance learning rates.

Enhancing Basic Academic Skills with Audio-Recordings: A Review of the Literature

Educators have developed various models and systems designed to remedy basic academic skill deficits before they become significant enough to require intensive services (e.g., special education). Some remedial models include consultation, collaborative problem-solving teams, extended school year services, and more recently, response-to-

intervention (Curtis, Curtis, & Graden, 1988; Kratochwill, Elliott, & Callan-Stoiber, 2002; Shapiro, 2004). With most response-to-intervention (RtI) models, after skill deficits are identified, educators alter students' daily academic schedules to allow more time for remedying these deficits. During this additional instructional time, educators are encouraged to apply high-quality, evidence-based remedial procedures (Fletcher, Coulter, Reschly, & Vaughn, 2004; VanDerHeyden, Witt, & Barnett, 2005).

Judgments regarding the quality of remedial procedures may be influenced by researchers who develop, evaluate, and disseminate studies designed to assess the internal and external validity of behavior-change procedures (Detrich, Keyworth, & States, 2007). However, establishing that a procedure causes desired behavior change in a particular instance (internal validity) and may be effective if applied in other instances (external validity) does not mean that educators can apply the specific procedure. In many instances, contextual variables may influence educators' decisions to apply (or fail to apply) a specific remedial procedure (Fudge, Skinner, Williams, Clark, & Bliss, 2008; Ringeisen, Henderson, & Hoagwood, 2003; Skinner & Skinner, 2007). Some of these contextual variables include, (a) the amounts of training, time, and resources needed to apply the procedure (Detrich et al.), (b) the potential for a specific procedure to interfere with other instructional/remedial procedures (Ysseldyke, Thill, Pohl, & Bolt, 2005), (c) the effects of specific procedures on classmates (Skinner, Skinner, Skinner, & Cashwell, 1999), and (d) teacher, student, parent, or others' perceptions regarding a specific procedure (Elliott, 1986; Martens, Witt, Elliott, & Darveaux, 1985). Because these and other variables may hinder the application of procedures in some contexts but not in others, some have

referred to these as threats to contextual validity (Foster & Skinner, 2011; Skinner, 2013).

Educators and researchers have developed and evaluated remedial procedures that use audio recordings to prompt, model, and pace student responding to various academic stimuli (Freeman & McLaughlin, 1984). Additionally, audio recordings have been used to provide students with feedback regarding the accuracy of their responses (Lalli & Shapiro, 1990). Nearly all of the researchers evaluating such interventions have commented on the contextual validity of such procedures. In addition to saving teachers' time, audio-recorded procedures allow students to work individually, perhaps at learning centers, addressing their own idiosyncratic skill deficits at their own pace (Skinner & Smith, 1992). Working independently (e.g., without the aid of peer tutors and/or teachers) may enhance students sense of success when their skills improve. Additionally, receiving feedback from a recording may encourage responding from students who are hesitant or embarrassed to respond publicly in situations when others (e.g., classmates, teachers, parents, siblings) may evaluate their performance (Bliss, Skinner, & Adams, 2006). In addition to these individual applications, researchers have used audio recordings when conducting small-group and class-wide procedures designed to prevent and remedy skill deficits by occasioning high rates of active, accurate responding (McCallum, Skinner, Turner, & Saecker, 2006).

Researchers have designed and evaluated interventions that use audio recordings to enhance basic reading, mathematics, and spelling skills. Although recent attention has been focused on more advanced technologies (e.g., computers, electronic tablets), tape-recorded interventions are easy to develop, and studies evaluating tape-recording interventions can inform those using more advanced technologies. In the following sections, we will

describe and analyze these procedures and the research studies designed to validate them. We will focus on the applied and theoretical implications of these procedures and conclude with some directions for future researchers.

Reading

Prior to the early 1980s, the literature supporting the benefits of using tape recorders during interventions was primarily anecdotal (Freeman & McLaughlin, 1984; Haring & Bateman, 1977; Schubert, 1978). Since that time, numerous researchers have demonstrated how audio recordings can be used to assist students with reading skill deficits by prompting or modeling accurate and/or fluent reading (Freeman & McLaughlin; Shapiro & McCurdy, 1989). Other researchers have used audio recordings to provide feedback on sight-word reading accuracy (Lalli & Shapiro, 1990).

Taped-Words Intervention

Using a multiple-baseline across participants design, Freeman and McLaughlin (1984) evaluated the effects of a taped-words intervention on six male high-school students with learning disabilities. During the taped-words intervention, students were instructed to read a list of vocabulary words along with a tape player that delivered the words at a rapid rate (i.e., 80 words per min). The taped-words intervention was applied for 1 min each day over three to seven school days, depending upon each student's rate of improvement. The words targeted were selected because they were above the students' reading levels and came from the students' curricula materials.

The dependent variables were the number of words read correctly per minute (WCPM) and errors per minute (EPM) as students read aloud from a word list. Results showed that after the taped-words was applied, all six

students increased their average WCPM and decreased their average EPM. Although baseline trend data showed that all six students' WCPM was increasing, the researchers suggested that the findings may have been caused by a neurological impress process or modeling rates (Freeman & McLaughlin, 1984). Both the overall improvement following the application of the taped-words intervention and the increasing baseline trends influenced subsequent applied and theoretical researchers.

Taped interventions across students. Following Freeman and McLaughlin's (1984) study, some researchers examined the effects of taped-words interventions across different populations. In two studies, researchers demonstrated that the taped-words procedure could be used to enhance WCPM on word lists in high school students with emotional-behavioral disorders (EBD) and reading skill deficits (Shapiro & McCurdy, 1989; Skinner & Shapiro, 1989). Again, in both studies, students were instructed to read aloud along with a tape recording that presented words at a rapid rate (60-80 words per minute).

Later researchers manipulated word presentation rates. Sterling, Robinson, and Skinner (1997) compared the effects of two taped-words interventions on word-list reading in three students (ages 10, 11, 12) with mild to moderate intellectual disabilities (IQ scores of 48, 65, and 70 respectively). During this study, words were presented four times per session, with one condition presenting words every second and the other condition every 5 seconds. Results indicated that regardless of the rate of presentation, taped-words interventions enhanced students' WCPM on word-list reading. Other researchers working with elementary students with EBD and reading skill deficits found similar results as both rapid rate and slower rate presentations of words within taped-word interventions enhanced WCPM to a similar

degree (Skinner, Johnson, Larkin, Lessley, & Glowacki, 1995; Skinner, Smith, & McLean, 1994).

Bliss et al. (2006) evaluated the effects of taped-words interventions on an English language learning (ELL) elementary student. However, the student was not instructed to read along *with* the tape but rather, he was encouraged to try to read each word *before* hearing it on the tape. During sessions, the targeted word list was repeated three times with different response intervals (amounts of time for the student to read the word before it was played on the tape) each time the list was repeated (i.e., 1-s intervals, then 3-s intervals, and then 0-s intervals). Results indicated that taped-words procedures produced rapid increases in the student's WCPM on word lists. Informal parent and teacher reports suggested an increase in the student's confidence in his reading (he volunteered to read aloud in class more often) and speaking abilities (he was speaking in English more frequently in and outside of school).

Taped interventions over time. Most of the researchers who have conducted taped-words intervention studies did not collect maintenance data. However, two studies with elementary students with EBD and reading skills deficits suggested that 6 weeks after taped-words procedures were halted, students' gains in word list reading fluency were maintained (Skinner et al., 1994; Skinner, et al., 2005). When Bliss et al. (2006) evaluated the effects of taped-words interventions on sight-word reading in the ELL student, they found the student maintained the ability to read the target words accurately and rapidly 7 weeks following the removal of the intervention.

Requiring students to read words out of context (i.e., in word lists) has been the most commonly used procedure for evaluating effects of taped-words interventions.

Researchers investigating flash card sight word instruction have found that teaching words in isolation may enhance students' ability to read words in passages as well as their passage comprehension (Browder & D'Huyvetters, 1988; Fleisher & Jenkins, 1978). In addition to assessing the effects of taped-words interventions on word-list reading, Shapiro and McCurdy (1989) evaluated the effects of taped-words interventions on the WCPM of five students with EBD as they read passages that contained words targeted by taped-words procedures. Also, they assessed students' comprehension on these passages. Unfortunately, four of the five students showed only minimal increases in the percentage of list words read correctly when they were imbedded in passages as well as minimal increases in passage comprehension.

Taped Passages Interventions

Although Shapiro and McCurdy (1989) found little evidence that taped-words interventions enhanced passage reading fluency, in studies where taped interventions were designed so that the student listened to or read silently along with a taped audio presentation of passages, researchers found increases in reading performance. Rose and Beattie (1986) used a tape recorder to apply a listening-while-reading intervention to passage reading. Researchers recorded passages read at 130-160 WCPM. Four elementary school boys with learning disabilities were instructed to read the passages along with the tape. Results suggested that this taped-passage procedure enhanced students re-reading of the targeted passages. The researchers ran a similar procedure where the teacher read aloud, as opposed to the tape player, and found stronger results when the teacher read aloud.

Working with boys (8-11 years old) with learning disabilities, Daly and Martens (1994) compared taped-words interventions to listening passage previewing (LPP) and silent

passage previewing (SPP) and evaluated the effects on passage reading (taped-words intervention condition) or re-reading (SPP and LPP conditions) fluency. The LPP condition was identical to Rose and Beattie's (1986) procedure in which a tape delivered a listening-while-reading procedure. During SPP, students merely read the passage to themselves before reading them again. The words targeted in the taped-words intervention word list condition were included in the passages. Daly and Martens found that Rose and Beattie's LPP procedure caused the greatest increases in WCPM. Lionetti and Cole's (2004) participants included four students in either fourth- or fifth-grade who were reading one to two years below their current grade level. Two taped passage intervention were implemented. During one, passages were read 2.6-4.5% above the student's independent reading rate; during the other, passages were read 19.0-24.6% faster than the student's reading rate. Results showed some increases in WCPM across conditions after the students re-read the passages present just above their current reading rate.

Variables that Influence Effectiveness

Speed of recording.

Although numerous studies support the efficacy of taped interventions for enhancing oral reading performance, researchers have proposed several different processes that may account for these improvements. Freeman and McLaughlin (1984) suggested that improvements may have been caused by students modeling the rapid reading provided by the recordings. Another vague and untested causal model suggests that the recordings may have prompted rapid reading, which impressed upon the students' neurological systems a pattern of more rapid responding (Rivers, 1980;

Smith, 1979). Researchers investigated this proposed relationship between the speed of recorded reading during taped interventions and re-reading speed. Some have compared taped-words interventions with words presented at rapid rates (e.g., one word read immediately or 1 s after the other) and at slower rates (e.g., every 5 s) and found both rates of presentation to be equally effective in enhancing WCPM on word lists (Skinner et al., 1994; Skinner et al., 1995; Sterling et al., 1997). Lionetti and Cole (2004) varied recorded reading speed during taped passage interventions. Generally, their results suggested that recorded reading speed is not related to re-reading speed; however, there was some evidence suggesting that if the recorded reading speed was just slightly faster than the student's unassisted reading speed, increases in re-reading fluency occurred.

Opportunities to respond. Researcher found increasing baseline trends prior to applying taped-words interventions (Freeman & McLaughlin, 1984; Shapiro & McCurdy, 1989) which suggest that practice or the opportunities to read words provided during both assessment and taped-word procedures may have caused the increases in word-list reading fluency. To test this hypothesis, Skinner and Shapiro (1989) modified the adapted alternating treatments (MAAT) design (see Sindelar, Rosenberg, & Wilson, 1985) by adding a fourth series that was probed or assessed less frequently (see Cuvo, 1979). Using this MAAT design, they compared the effects of a taped-words intervention to the effects of a practice intervention during which secondary students were instructed to simply read word lists independently, without tapes. Across both interventions, students were given two opportunities to read the word lists: for taped-words interventions, once with the tape and once during assessment; for the practice condition, once independently before the assessment and once during the assessment. Results showed

equal improvements in WCPM on word lists assigned to the taped-words interventions and practice interventions. Additionally, students' performance on both a third list that was assessed once per session and a fourth list that was assessed intermittently, suggested that spill-over effects (perhaps caused by modeling or neurological impress) did not account for the increases in WCPM on the practice intervention word lists. These results led researchers to conclude that the opportunities to respond embedded within the taped-words intervention caused the improvements in word-list reading fluency. Although both conditions led to similar performance gains, researchers noted that the rapid paced taped-words intervention was much more time efficient than the practice intervention (Skinner & Shapiro).

Learning trials. Lalli and Shapiro (1990) trained students to use a tape to evaluate their own word-list reading. After they attempted to read words, students were trained to listen to tapes which played the word lists, self-evaluate and self-record their accuracy, and then reward themselves when they met criteria for enough words read correctly. When Skinner et al. (1994) manipulated the pace of word presentation during the taped-words procedure, they found that both immediate and 5-s intervals were equally effective. Furthermore, although researchers did not train the students to self-evaluate (the students were instructed to read with the tape), they observed the students read the words before hearing them on the tape and then sometimes reacted (e.g., said "all right") when they heard the tape confirm the accuracy of their independent reading. These studies differ from original taped-words interventions in that students used the tape to prompt stimulus-response-stimulus (S-R-S) learning trials, with the printed word being the first stimulus, the students reading the word before tape (as opposed to

with the tape) being the response, and the final stimulus being the recording of the word which was used to provide feedback.

As previous researchers have found that complete S-R-S learning trails may enhance learning more than merely providing opportunities to practice (Belfiore, Skinner, & Ferkis, 1995; Ferkis, Belfiore, & Skinner, 1997), when running their taped-words intervention with the ELL student previously mentioned, Bliss et al. (2006) treated each new word as a separate stimulus-response-stimulus (S-R-S) learning trial. Rather than instructing the student to read *with* the tape, the ELL student was instructed to attempt to read each word *before* it was presented aloud on the tape. Thus, "beating the tape" (McCallum, Skinner, & Hutchins, 2004, p. 138) was a goal and automatic (i.e., rapid and accurate) word reading was increased through the use of immediate feedback provided by the recording. Additionally, to increase correct response rates and the probability that for each S-R-S learning trial the student's last response was correct, the student was instructed to repeat the words after hearing them on the tape. Data showed that this student made rapid gains in reading accuracy and fluency after the intervention was applied and these increases were maintained over time.

Learning Rates

Despite evidence suggesting that improvements in word-list reading may be caused primarily by the practice opportunities that are embedded within taped-words interventions, researchers have suggested that this should not diminish the value of taped-words interventions (Shapiro & McCurdy, 1989; Skinner & Shapiro, 1989). One practical benefit of the taped-words procedure is that it is very efficient, especially when 80 words are read in 1 minute. However, a limitation of the intervention studies reviewed to this point is the

researchers' failure to precisely measure instructional time spent in each intervention condition.

For example, although Skinner et al. (1995) presented words at different rates (e.g., every 1 s or every 5 s), they displayed their WCPM data on time-series graphs by using an imprecise measure of cumulative instructional time, 'sessions' on the horizontal axis. Initial analyses of these data suggested no differences across the two interventions. When Skinner, Belfiore, and Watson (1995/2002) re-analyzed these data using a more precise measure of cumulative instructional time (instructional seconds), results showed that because the 1-s intervention took so much less time, that it resulted in far superior learning rates. Because students who need remedial services are rarely failing to learn, but rather, not learning rapidly enough (Skinner et al., 1995/2002), when attempting to select a remedial procedure, educators need to know which procedures result in the most rapid increases in learning or skill development (Skinner, 2008; Skinner, 2010). This research has heuristic value as it encouraged subsequent taped-intervention researchers to run comparative effectiveness studies using more precise measures of instructional time in order to identify the intervention that remedied skill deficits most rapidly (Carroll, Skinner, Turner, McCallum, & Woodland, 2006; Poncy, Skinner, & Jaspers, 2007; Poncy, Skinner, & McCallum, in press).

Math

The research on taped reading interventions had additional heuristic value because it encouraged others to develop and evaluate audio-recorded interventions that could be applied to basic mathematics skills. These procedures were developed based on researchers' observations during 5-s taped-word interventions that students appeared to try to read the word before the tape and then used the tape as feedback (Skinner

et al., 1995 and Skinner et al., 1994). Thus, rather than reading with the tape, when word were presented every 5 s, students independently began using the tape to prompt S-R-S trials.

Taped-Numbers Intervention

Krohn, Skinner, Fuller, and Greear, (in press) used a multiple-baseline across-participants design to evaluate the effects of a taped-numbers intervention on ELL elementary students. This intervention was similar to the Bliss et al. (2006) taped-words procedure with several exceptions. Most notably, instead of targeting sight-word reading, researchers targeted number identification or number reading. Participants included four kindergarten students, three of whom were receiving ESL services from a teacher who indicated each had limited English language skills. Five worksheets were used, each containing four columns of numbers. A corresponding tape was created for each worksheet. These recordings included a tone to prompt identification (the researcher pointed to the number at this point), followed by a 2-s delay, and then a recording of the word being read in English for each number on the list. The students were instructed to try to read each number before hearing it (i.e., try to beat the tape) and repeat it after hearing it. Intervention procedures were run with the students three days per week.

During assessment, Krohn et al. (in press) allowed students 5 s to read each number. All four students showed stable or decreasing baseline performance. After the taped-numbers (TN) intervention, was applied, number reading accuracy increased and all four students reached 100% accuracy in number identification over 3-4 weeks of intervention. Maintenance data showed 100% accuracy on 27 of 28 post-treatment assessments over a two to five week interval.

Taped-Problems Intervention

McCallum, et al. (2004) developed and evaluated the taped-problems intervention. This procedure was designed to enhance math fact fluency by occasioning high rates of math fact S-R-S learning trials using audio recordings to pace students through trials and provide prompts and/or feedback. In their first study, instead of providing answers to basic division facts (e.g., 20/4 = __) verbally, McCallum et al. encouraged the participant, a 10-year old African-American boy from a general education classroom to try to write answers to division-fact problems on paper *before* the recorded answer was played (i.e., try to beat the tape).

Rather than applying fixed intervals for responding, McCallum et al. (2004) repeated each set of problems five times and varied the response intervals or the time the student had to respond before the tape played the answer. The sequence of intervals for the five readings of the problem set was: no-delay, 3-s, 5-s, 2-s, and 1-s.The first time through the list, the response intervals were very brief to reduce the probability of inaccurate responding during the initial trial and discourage finger counting on all subsequent trials. Also, because the student was instruct to write correct answers after hearing them, his first response to each problem was typically correct. As lists were repeated, response intervals were then lengthened to give the student a chance to respond independently, before the tape, and then made briefer to encourage rapid or automatic responding. However, after the study began, the researchers re-made the tapes by removing the 5-s response intervals because the student complained that this interval was too long. The participant showed rapid increases in DCPM after the intervention was applied and appeared to reach a ceiling with over 100% improvements after only three brief (< 5 min) sessions. Also, researchers reported that after applying the

taped-problems intervention, the student no longer attempted to solve problems using finger-counting procedures.

Taped interventions across students and math facts. Following this initial study, researchers applied taped-problems interventions across populations, including students with mild and moderate intellectual disabilities. Carroll et al. (2006) implemented taped-problems procedures with a referred 12-year old girl with a mild intellectual disability. The student's teacher indicated that the student possessed basic computation skills, but often used finger-counting procedures to solve addition facts, which hindered her ability to work quickly and accurately. Researchers applied both taped-problems and another math-fact intervention known as Cover, Copy, and Compare (CCC). CCC is an intervention strategy, which, like taped-problems interventions, allows students to practice academic skills repeatedly while encouraging self-correction of errors and active responding (McLaughlin & Skinner, 1996). When using CCC, students are presented with a problem. The student covers the answer and attempts to solve the problem in a space provided beside the presented information. Upon completion, the answer is uncovered and the student determines if the information was copied correctly. If so, the student moves to the next problem. If the information is not copied correctly, the student performs a correction procedure, which often involves recopying the information up to three additional times (McLaughlin & Skinner, 1996). After several sessions, the Carroll et al. (2006) found that taped-problems interventions yielded the most rapid increases in math fact fluency. These finding were supported by Poncy et al., (2007) who conducted a similar study while working with a 10-year old girl with a moderate to severe intellectual disability on her addition-fact fluency. Using a 4-s delay procedure, Poncy et

al. found the taped-problems intervention to be highly effective after only 7 sessions, with 100% increases in single-digit addition problems.

Others have applied taped-problems procedures across general education elementary students. Because different grade-levels were targeted, different basic facts were also targeted. Thus, evidence suggest that taped-problems interventions are effective across addition (e.g., Windingstad, Skinner, Rowland, Cardin, & Fearrington, 2009), subtraction (e.g., McCallum, Schmitt, Schneider, Rezzetano, & Skinner, 2010), multiplication (e.g., McCallum et al., 2006), and division facts (e.g., McCallum et al., 2004).

Taped interventions across contexts: Class-wide intervention. Perhaps because enhancing math-fact fluency may enhance (1) students' perceptions of math, (2) students' ability to master more advanced math tasks, and (3) the probability of students' choosing to engage in math activities (Gagne, 1982; Pellegrino & Goldman, 1987; Skinner, 2002), the National Council of Teachers of Mathematics (2000) recommended that basic fact fluency be included as a general education curricula objective. Consequently, researchers adapted the taped-problems procedures they developed for remediation (for student with skill deficits) so that it could be applied class wide as a preventative or instructional strategy. McCallum et al. (2006) used a multiple-probes across-tasks design to evaluate the effects of class-wide taped-problem interventions on multiplication-fact fluency in a third-grade classroom that included 18 general-education students. As with the other class-wide studies, the students in the McCallum et al. study had varying levels of fluency development. Pre-treatment data showed that based on Deno and Mirkin's (1977) criteria, 3 of the students were at instructional level on multiplication-fact fluency and 15 were at frustrational level.

In the McCallum et al. (2006) study, DCPM were measured both individually and as a class average. Each day that baseline, intervention, and assessment procedures were run, sessions totaled about 20 min. After three weeks of taped-problems intervention trials, the class's average DCPM more than doubled, from 6.5 to 13.6, and was maintained over one week without intervention. Although the average increase in DCPM was 6.4, the range across students was 1 to 11.5 DCPM. These results suggested that the taped-problems intervention is effective not only as a remedial procedure, but as a class-wide instructional procedure. However, these results also showed that class-wide taped-problems was not effective for all students. Analogous results were obtained by Windingstad et al. (2009) in a study in which longer time delays (i.e. 4-s) were eliminated, creating even more efficient learning trials for a classroom of 19 second-grade students. In this study, addition problems were used. Comparing baseline to intervention phase class averages, DCPM increases ranged from 2.86 to 17.56 (median 9.06) and follow-up data suggested that most of these gains were maintained over a three weeks.

McCleary et al., (2011) applied taped-problems interventions to addition and multiplication facts in second- and fourth-grade classrooms. The second-grade class increased their DCPM by an average of 5.4 and maintained these gains over two to four weeks. After the fourth-grade class returned from winter break, they appeared to have lost motivation and showed little improvement in multiplication fact fluency. Consequently, researchers supplemented class-wide taped-problems interventions with an interdependent group-oriented reward. DCPM class means were 14.34 for baseline, 21.82 during intervention before rewards, 34.87 after rewards were added, and 28.79 during the two week to four month maintenance phase. Although the students did not maintain the levels of multiplication fact fluency that they

achieved when motivated by rewards (e.g., pencils, erasers) they maintained a DCPM two times higher than that with which they started. Again, across both classrooms some students benefited little from the procedures.

Aspiranti, Skinner, McCleary, and Cihak (2011) targeted first-grade students whose teacher indicated that she had never attempted to enhance their math fact fluency. Addition facts were targeted and the classroom teacher ran most of the intervention sessions, which lasted about 15 min each morning. Both individual rewards and a group contingency were applied. Results indicated that the class average DCPM nearly doubled and these gains were maintained. These findings demonstrated that a taped-problems intervention can be an effective procedure for general education students that are just developing the ability to respond automatically to basic facts.

Taped interventions across problems and time. Miller, Skinner, Gibby, Galyon, and Meadows-Allen (2011) also used a multiple-baseline design (across problem sets) to evaluate the effects of a class-wide taped-problems intervention on addition-fact fluency. These authors extended previous research by testing for generalized effects. Specifically, taped-problems intervention trials targeted addition problems with digits presented in one order (e.g., 7 + 5 = __) and researchers assessed student fluency on problems presented in the same order and on inverse problems (e.g., 5 + 7 = __). Results suggested that taped-problems interventions enhanced addition fact fluency on target problems and inverse problems.

Maintenance data on taped-problems interventions has been collected in several ways. Some researchers used a delayed assessment procedure, evaluating the intervention's effectiveness the next day, prior to beginning the subsequent

taped-problems intervention session (McCallum et al., 2006, McCallum et al., 2010; McCleary et al., 2011; Windingstad et al., 2009). As the primary dependent variable in these studies (DCPM) was collected at least 23 hours after receiving the taped-problems intervention, these data provide support for the maintenance of associated gains. Also, most researchers evaluating taped-problems interventions have used multiple-baseline or multiple-probe across-tasks designs, which involve the staggered application of taped-problems interventions across sets of problems. Consequently, when taped-problems interventions was removed from a set of problems and applied to another set of problems, data collected on student performance on the previously targeted problem set was used to assessment maintenance. Examination of these data showed that in almost all instances, students maintained most of their gains in fluency over their baseline performance levels (e.g., McCallum et al., 2004; McCleary et al.; Windingstad et al.).

Finally, some researchers have collected maintenance data days and weeks after all intervention procedures ceased. For example, McCallum et al. (2004) assessed fluency 7 and 12 days after all taped-problems procedures ceased and found clear evidence of maintenance. McCallum et al. (2006) found that most of the members of the fourth-grade student population maintained much of their gains in fluency 1 week after the final taped-problems intervention session. Poncy et al. (2006) found that a 10-year old with intellectual disabilities maintained gains in addition-fact fluency over a 2-week break from school. Windingstad et al. (2009) and McCallum et al. (2010) found that second-grade students generally maintained their gains 3 weeks after all taped-problems treatments ended.

Supplementing taped-problems with other procedures. Researchers have conducted studies designed to determine if supplementing taped-problems with other procedures

enhances the effectiveness of taped-problems interventions (Bliss et al., 2010; McCallum et al., 2010). One reason taped-problems interventions are thought to be effective is that they occasion high rates of active, accurate, academic responding (Greenwood, Delquadri, & Hall, 1984). Working in a small group format, Bliss et al. used an adapted alternating treatments design to compare the effects of taped-problems interventions with taped-problems procedures plus an additional immediate assessment on the multiplication-fact fluency of five fifth-grade students with math skill deficits. The two conditions were identical with respect to taped-problems procedures applied and the assessments used to evaluate taped-problems interventions being applied the following school day. However, in the treatment using additional assessment, immediately after the taped-problems intervention, a brief practice sprint (essentially a fluency assessment) was conducted in order to provide an additional opportunity for students to respond. Results suggested that adding this additional post-intervention practice procedure did little to enhance fluency.

When working with first grade students, Aspiranti et al. (2011) combined taped-problems interventions with individual and group contingencies, but did not use a procedure designed to evaluate these components. After fourth-grade students' fluency gains appeared to stall, McCleary et al. (2011) supplemented taped-problems interventions with a similar interdependent group-oriented reward program and found a dramatic increase in DCPM (average of 21.82 increased to 34.87). However, working with two second-grade classrooms, McCallum et al. (2010) compared the impact of taped-problems interventions alone with taped-problems procedures plus an interdependent group-oriented reward, in which the entire class earned a reward if their class average subtraction-fact fluency scores on

the delayed (next day) assessment improved over the previous day. All students were African-American and 39 of 40 students had subtraction fact fluency deficits. Both classes showed immediate and rapid fluency gains after the interventions were applied with no differences between the isolated taped-problems intervention and taped-problems plus reward classes. Also, post-test survey data did not support the hypothesis that students found the reward condition more acceptable. These two studies suggest that supplementing taped-problems with interdependent group-oriented rewards may enhance learning rates in some, but not all instances.

Comparative Effectiveness Studies: Taped-problems interventions versus Cover Copy Compare

Another intervention that has been used to occasions high rates of accurate responding and enhance math fact fluency is Cover, Copy, Compare (CCC). CCC was originally developed to increase spelling accuracy, but was adapted to address math facts (Skinner, Turco, Beatty, & Rasavage, 1989). Results of numerous studies and a recent meta-analysis provide strong support for the internal, external, and contextual validity of CCC (Joseph et al., 2012). When applied to math facts, CCC requires a student to look a math problem and answer, cover the problem and answer, write or state the problem and answer, and evaluate this response by uncovering the problem and answer and comparing the response to the original stimulus. Like taped-problems interventions, CCC incorporates immediate feedback regarding response accuracy and an immediate error correction procedure (i.e., following an error, students copy the problem and answer at least one time), ensuring the accuracy of the last response (McLaughlin & Skinner, 1996).

Working with a fifth-grade girl with mild intellectual disabilities, Carroll et al. (2006) compared CCC to taped-

problem interventions. The participant was given both CCC and taped-problems interventions three days per week. Session time was held constant across both procedures at 7.5 min, the time required to complete the taped-problems intervention. Thus, the student was encouraged to try to complete as many CCC trials as she could in 7.5 min. After 4 weeks of intervention procedures, the student's DCPM were higher on the problem set assigned to the taped-problems procedure, relative to the problem set assigned to CCC. Additionally, as the intervention phase progressed, the student's performance on the taped-problems showed an increasing trend, but her increases on problems assigned to CCC stopped increasing after only two sessions. These results suggested that the taped-problems intervention resulted in more rapid increases in math fact fluency than CCC.

Working with a 10-year old girl with intellectual disabilities (IQ = 44), Poncy et al. (2007) conducted a similar study by assigning one set of problems to taped-problems and the other to CCC. However, rather than holding instructional time constant for each procedure, they held learning trials constant. Thus, between both CCC and taped-problems intervention sessions, the student completed 24 trials. Results showed similar rapid increases in math-fact accuracy and fluency between conditions. However, because taped-problems interventions took 30% less time than CCC, learning rates were approximately 30% greater. Poncy et al. (in press) followed up these studies by comparing learning rates under class-wide taped-problems interventions to learning rates under class-wide CCC in a general education third-grade classroom. During this study, subtraction-fact fluency was targeted and learning time was held constant as both interventions were applied for 6 min each day. Average data across all 20 students revealed that taped-problems interventions resulted in a 13.5 DCPM increase; CCC resulted

in a 6.5 DCPM increase. Analysis of individual student data suggested that the taped-problems intervention was most effective for 16 of the 20 students.

Spelling

Recently, McCallum, Evans, Friedrich, and Long (2011) adapted the taped-problems procedures for use with spelling skills, creating the taped-spelling intervention. Audio recordings were presented in which each spelling word was followed by an 8-s delay, and then the correct spelling of the word was presented. Students were instructed to try to beat the tape by writing the correct spelling of each word before it was provided. Like taped-problems, taped-spelling interventions incorporate numerous practice opportunities, immediate accuracy feedback, and error correction procedures (students are instructed to correct any mistakes upon hearing the correct spellings on the recording). McCallum et al. implemented taped-spelling interventions with four middle-school students diagnosed with, or at risk for, reading and writing learning disabilities. During this study, mp3 players and headphones were used and self-monitored all procedures. Results demonstrated immediate and sustained increases in spelling performance (total words correct and letter sequences correct) in response to taped-spelling interventions.

Future Research

Although there is clear evidence that taped interventions can be effective, the causal mechanisms that may account for skill development are less clear. Early taped-words intervention researchers focused on modeling or a neurological impress mechanism, yet others found evidence that students do not model recorded reading speed. Rather, the opportunities to read words embedded within the taped-words intervention may account for much of the increases in word-list reading

fluency (Skinner & Shapiro, 1989). Additional research is needed to enhance our understanding of the mechanisms causing the word reading increases associated with taped-words.

In daily life, individuals rarely read word lists in isolation, and this skill has limited functionality; however, fluent passage reading may enhance reading comprehension levels and comprehension rates (Daly, Chafouleas, & Skinner, 2005; Skinner, Williams, et al., 2009). Thus, researchers may be more likely to find increases in reading fluency following taped-passages procedures, as opposed to taped-words. As Lionetti and Cole (2004) found some evidence that reading passages at a pace just slightly faster than students typically read may enhance passage re-reading fluency, future researchers should continue investigating the effects of taped-reading speed on passage re-reading. Perhaps with the correct rate and enough repetitions, researchers will find evidence of a functional relationship between taped-reading speed and passage re-reading fluency that supports these causal mechanisms.

Researchers have found that the opportunities to read words embedded within the taped-words interventions could account for much of the intervention's effectiveness by demonstrating that merely providing opportunities to read word lists (e.g., during assessments) increased word-list reading fluency (McCurdy & Shapiro, 1989; Skinner & Shapiro, 1989). Yet, when Bliss et al. (2010) provided an additional opportunity to complete math facts following taped-words intervention sessions, they found little or no increases in fluency. These conflicting results suggest the need for future investigations of opportunities to respond. Recent computer based research by Yaw (2012) suggests that ceiling effects may play a role. Bliss et al. had students complete each targeted problem three times during a taped-

problems intervention. However, Skinner and Shapiro had students read word lists only one time per taped-words intervention session. Thus, in the Bliss et al. study, the additional assessments increased students' opportunities to respond from three to four which may have caused a smaller increase in learning than the increase from one to two opportunities to respond that Skinner and Shapiro's participants received from the additional assessment.

Although providing opportunities to practice without feedback may enhance learning, when word presentation rates were slowed, students ignored experimenters' directions to read with the tape. Instead, students used the tape to prompt them through S-R-S trials, attempting to read before the tape and use the recording as feedback (Skinner et al., 1995; Skinner et al., 1994). These observations had heuristic value as they prompted researchers to conduct a series of studies using tapes to prompt S-R-S learning trials to enhance reading, math, and even spelling skills across students, target behaviors, and context (e.g., Bliss et al., 2006; McCallum et al., 2011; McCallum et al., 2004). Evidence that responding within complete S-R-S learning trials may cause more learning than mere practice (e.g., Ferkis et al., 1997) suggests that these students may have responded in a manner that enhanced their learning. Regardless, because S-R-S learning trials take more time, researchers should conduct additional studies in which they manipulate responding within and outside S-R-S learning trials. For example, students could attempt to beat the tape and then repeat the response immediately after they hear the tape. Thus, they would attempt to make one within S-R-S response and another response immediately following the S-R-S trial.

Class-wide investigations of taped-problems interventions showed that the procedure was effective for most students; however, some students showed little to no gains following the intervention (McCallum et al., 2006;

McCleary et al., in press, Windingstad et al., 2009). Few, if any, learning strategies are likely to be effective across all students and objectives. Future researchers should attempt to determine why taped interventions are effective in some instances and not others. For example, researchers may want to determine if skill development levels (see Codding et al., 2007) or aptitudes (e.g., processing speed, auditory processing deficits) influence the effectiveness of the procedures. Additionally, altering the number of items targeted during each intervention session may have different impact across students. Finally, researchers may want to conduct more studies designed to evaluate generalizable effects (see Miller et al., 2011). For example, research on listening-while-reading (when students listen to a person rather than a recording) suggest that taped passage may enhance passage comprehension (Hale, Skinner, Winn, Oliver, Allin, & Molloy, 2005; Ridge & Skinner, 2011).

When attempting to influence educators to apply a particular remedial procedure, providing evidence of internal, external, and contextual validity is only the first step. Next, researchers should conduct comparison studies designed to provide evidence regarding which procedures will remedy skill deficits most rapidly (Skinner, 2008; Skinner, 2010). When the data across all three studies comparing CCC and taped-problems interventions were aggregated (Carroll et al., 2006, Poncy et al., 2007; Poncy et al., in press), taped-problems procedures resulted in greater increase in learning rates (DCPM) across 18 of the 22 students. Similar comparison studies should also be conduct to determine how taped interventions can be altered to enhance learning rates. Skinner et al. (1995/2002) compared taped-words interventions in which words were presented every 1 s versus every 5 s and found that the 1 s intervention produced greater learning rates. Similar studies should be conducted with

taped-problems and taped-spelling interventions as researchers may find that applying briefer response intervals may allow for many more learning trials in a fixed amount of time, which translates into increases in learning rates. Researchers could also attempt to apply other procedures to enhance learning rates by reducing intervention time (Skinner, Fletcher, & Henington, 1996). For example, during taped-problems and/or taped-spelling interventions, students could attempt to state answers (aloud or sub-vocally), as opposed to writing their answers (Skinner, Belfiore, Mace, Williams, & Johns, 1997).

During taped interventions, researchers have manipulated response intervals, ranging from 1 s - 5 s. Some researchers indicated that students expressed dissatisfaction with longer (e.g., 4-5 s) intervals (McCallum et al., 2004; Windingstad, 2009). Future researchers who experimentally manipulated response interval may find that using very brief response intervals enhances students' perceptions of assignments and their learning by enhancing the pace of responding (Carnine, 1976; Hawkins, Skinner, & Oliver, 2005) and learning trial rates (Skinner et al., 1996). McCallum et al. used varying intervals, starting with very brief intervals to reduce error and discourage finger counting and then extending intervals to allow more time for independent responding. Experimental research is needed to determine if such procedures meet these goals and enhance learning.

Reinforcing performance improvements with individual and/or group-oriented rewards can enhance skill development without increasing time allocated to learning (Skinner, Skinner, & Burton, 2009). Although McCallum et al. (2010) found little evidence that supplementing class-wide taped-problems interventions with interdependent group-oriented rewards enhanced skill development; McCleary et al. (2011) found a large increase in fluency after adding an interdependent reward. Perhaps, reward quality may have

caused these disparate results. Regardless, more research is needed on supplementing taped interventions with rewards. Also, researchers should determine if adding self-monitoring components to taped interventions enhances learning. Student could record (tally) each time they beat the tape during the intervention, self-graph their fluency scores on assessments, and use these data to self-evaluate (Hilton, Hopkins, Skinner, & McCane-Bowling, 2011; Poncy, Skinner, & O'Mara, 2006).

Conclusion

Technological advances may cause some academicians to find taped-interventions anachronistic. However, relative to high-tech procedures, teachers may find the development of taped intervention materials easier, less time consuming, and less intimidating. For example, to prepare taped-words procedures, teachers can simply prepare a list of 80 words and record them aloud. To complete the taped-words intervention, students can use the same printed list and the teacher-made recordings by following simple instructions, "read the words along with the recording". Once prepared, material can be re-used or copied (McCallum et al., 2006). Although, educators and students may not have access to computers or appropriate computer programs, most have access to recording devices (even available on many cell phones). Additionally, the studies reviewed here suggest that students across ability levels can apply various taped intervention procedures. Thus, we believe that the data summarized here support the validity of taped-interventions.

We have described how previous taped-interventions research influenced subsequent theoretical and applied taped-interventions research. Conceptual findings from taped-intervention studies have had heuristic value as they have informed researchers investigating other interventions (e.g.,

Joseph & Nist, 2008; Orsega, Vander Zanden, & Skinner, 2011; Yaw, 2012). As researchers conduct additional studies designed to evaluate (a) modified taped interventions (e.g., altering response intervals), (b) supplemented taped interventions (e.g., adding a response following the tape recording), and/or (c) comparing taped interventions to other procedures (e.g., computer-assisted instruction) we urge a dual focus. First, we encourage theoretical research designed to specify causal mechanisms. Such studies may produce data to support the application of various strategies that can be applied across low-tech and high-tech interventions. For example, Yaw (2012), basing his research on taped intervention studies, demonstrated how reducing response intervals during computer-based flashcard instruction from 5 s to 1 s enhanced sight-word learning rates.

Finally, we encourage future researchers investigating taped interventions and other procedures to measure learning rates precisely so that educators can gain a better understanding of which strategies and procedures enhance target skills most rapidly (Skinner, 2008). For example, researchers investigating flashcard procedures and CCC have found that when procedures that appeared to enhance learning were assessed using precise measures of instructional time, results showed they actually reduced learning (e.g., Cates et al., 2003; Joseph & Nist, 2006; Nist & Joseph, 2008).

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