Journal of School Psychology 55 (2016) 71–78

Contents lists available at ScienceDirect

Journal of School Psychology

journal homepage: www.elsevier.com/locate/jschpsyc

Comparison of opportunities to respond and generation effect as potential causal mechanisms for incremental rehearsal with multiplication combinations

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ARTICLE INFO

Article history:
Received 23 January 2013
Received in revised form 13 May 2015
Accepted 7 January 2016
Available online 3 February 2016

Keywords:
Generation effect
Opportunities to respond
Intervention
Mathematics

ABSTRACT

Incremental rehearsal (IR) is an intervention with demonstrated effectiveness in increasing retention of information, yet little is known about how specific intervention components contribute to the intervention's effectiveness. The purpose of this study was to further the theoretical understanding of the intervention by comparing the effects of opportunities to respond (OTR) and generation demand on retention of multiplication combinations. Using a between subject 2×2 factorial design, 103 4th and 5th grade students were taught seven multiplication combinations using one of four versions of IR that orthogonally varied OTR (high versus low) and generation demands (high versus low). A two-way ANOVA revealed main effects for OTR, generation demands, and an interaction of the two factors. The effect of generation demands was large ($d = 1.31$), whereas the overall effect of OTR was moderate ($d = 0.66$). Critically, the two factors interacted, with the largest learning gains observed when OTR and generation demands were both high. The results of this study suggest that generation demand is an important factor in the effectiveness of rehearsal interventions.

1. Introduction

Mathematical proficiency is closely linked to desired student outcomes such as the ability to solve complex problems and college graduation (Kilpatrick, Swafford, & Findell, 2001; National Mathematics Advisory Panel [NMAP], 2008). Students who can quickly recall basic mathematical combinations (e.g., 3×4, $8 + 5$, $12 \div 3$) are more likely to develop skills necessary for (a) solving a wide variety of complex problems, (b) interpreting abstract mathematical principles, and (c) independent living in adulthood (Patton, Cronin, Bassett, & Koppel, 1997; Shapiro, 2010; Tolar, Lederberg, & Fletcher, 2009). There appears to be a fundamental role for computational fluency in the development of mathematical proficiency (Kilpatrick et al., 2001; NMAP, 2008), which is why students need to obtain proficiency in multiplication and division combinations by late elementary (i.e., 4th and 5th grade, NMAP, 2008). However, students with mathematical difficulties often struggle to recall the basic mathematic combinations rapidly enough to apply the information and often rely on inefficient strategies such as counting on their fingers (Geary, 1993; Rivera, 1997; Woodward, 2006). Thus, students with mathematical disabilities tend to benefit from mathematics instruction that emphasizes repeated practice over discussion (Gersten & Chard, 1999).

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Action Editor: Craig Albers

http://dx.doi.org/10.1016/j.jsp.2016.01.001

Given the importance of mathematical fact proficiency and repeated practice, numerous interventions have been introduced to improve computational fluency (Burns, 2005; McCallum, Skinner, & Hutchins, 2004; Skinner, Turco, Beatty, & Rasavage, 1989). Among these interventions, incremental rehearsal (IR; Tucker, 1988) has garnered a large amount of empirical support. IR is a flashcard intervention that involves presenting a new item to be learned with a high percentage of review (or known) items. For example, one unknown item is often rehearsed with seven (87.5% known), eight (88.9% known), or nine (90% known) known items in a manner in which the item to be learned is presented the same number of times as the number of known items (e.g., 7 times for 7 known items) during the initial practice and in decreasing numbers of repetitions in subsequent practice sets. Early and ongoing research using IR has produced promising results when targeting students' reading and vocabulary skills (Burns, Dean, & Foley, 2004; MacQuarrie, Tucker, Burns, & Hartman, 2002; Nist & Joseph, 2008).

Although less research exists concerning the effects of IR on mathematical performance, the study by Burns (2005) and the later replication by Codding, Archer, and Connell (2010) provided a promising basis for using IR as a computational fluency intervention. Moreover, mathematical fluency seems more consistent with the purpose of IR than reading. From a learning perspective, multiplication combinations are considered simple facts, which are defined as memorized correct responses to visual stimuli (Kame'enui & Simmons, 1990). For example, when students who are proficient at mathematics see 3×3, they recall the number 9 without counting three sets of three or using another strategy. The research regarding IR for reading created simple facts within reading such as sight words (Burns et al., 2004), vocabulary words (MacQuarrie et al., 2002), and letter sounds (Volpe, Burns, Dubois, & Zaslofsky, 2011). Certainly there are aspects of mathematics that are not simple facts (e.g., word problem-solving), but multiplication combinations are clear examples of simple facts, which aligns well with IR's focus on enhancing retention of single items. Thus, previous IR research in mathematics taught multiplication combinations to increase computational fluency (Burns, 2005, 2011; Codding et al., 2010).

It is important to identifying causal mechanisms within an intervention in order to understand it better so that the important core components can be protected as modifications are studied (Burns, 2011). The best way to identify potential causal mechanisms is to closely examine the theory from which the intervention was developed (Ellis, 2005), which also provides a heuristic to study and advance interventions (Hughes, 2000; Tharinger, 2000). Moreover, theory can be used to identify common causal mechanisms across interventions, which can help practitioners examine new interventions from a theoretical perspective to determine about which ones they should be particularly optimistic or skeptical (Kazdin, 2000). Unfortunately, school psychology research does not frequently consider theoretical implications of intervention research (Mercer, Idler, & Bartfai, 2013).

IR is an intervention around which theoretical implications have been studied. The first attempt to better understand the theoretical underpinnings of IR was a study conducted by Szadokierski and Burns (2008) that examined the influence of opportunities to respond (OTR; Greenwood, Delquadri, & Hall, 1984). OTR is perhaps best conceptualized as a completed sequence in which a tutor presents the stimulus to be learned to a student, the student provides a response, and the tutor provides feedback about the accuracy of the response (Belfiore, Skinner, & Ferkas, 1995). OTR is theorized to be important in the development of associative memory. Students' repeated exposure to correct (and incorrect) answers shapes the strength of the association between the item and the correct answer, as well as the efficiency for which those items are later retrieved (Siegler, 1988).

Szadokierski and Burns (2008) compared the effect of OTR and the percentage of known words within IR because behavioral theories propose that increasing OTR led to improved student outcomes (Greenwood et al., 1984; Kern & Clemens, 2007; Sutherland, Adler, & Gunter, 2003). They used a two-by-two factorial design with IR that varied the percentage of known words (90% vs. 50%) and the number of OTR (high vs. low) with 4th grade students. A main effect was observed for OTR but not for the percentage of known items. The effect size between high and low OTR was quite large ($d = 2.46$), but increasing the percentage of known material from 50% to 90% yielded a small negative effect ($d = -0.16$). Previous single-case design research also found that the number of OTR was more closely related to student retention than the number of known items within the task (Burns, 2007).

OTR appeared to be closely linked to the effectiveness of IR, but there are additional potential hypothetical explanations. Varma and Schleisman (2013) recommended that IR be studied with theory from cognitive psychology so that school psychology researchers can demonstrate the principles of learning and cognition that are apparent in IR and capitalize on them in future intervention research. One potential causal mechanism proposed by cognitive psychology is the generation effect, which refers to the finding that material is better retained when a self-generated response is elicited rather than read (Slamecka & Graf, 1978). Although most studies of the generation effect have used verbal items such as words, a handful have used mathematical items (Gardiner & Rowley, 1984; McNamara, 1995). In a representative study, McNamara and Healy (2000) had adults either generate or read the answers to complex multiplication problems, where a two-digit number was multiplied by a one-digit number to yield a three-digit number. Retention was much better for generated products than for the read-only products. McNamara (1995) compared second grade students' retention of multiplication combinations when taught using a read-only condition or a generate condition. The results indicated that retention of multiplication combinations was greater for students in the generate condition when they also had lower prior knowledge. Students who demonstrated higher prior knowledge at pretest did not benefit from the condition in which they generated the response. In a replication, Rittle-Johnson and Kmicikewycz (2008) found that as prior knowledge increased, the benefits of a generation component decreased. This finding may be particularly relevant in the context of learners who struggle to retain new information.

There are competing theoretical explanations for why generation improves memory. Generation strengthens the association between problems and answers, but it also strengthens the relationship between problems and the best procedures for solving them (McNamara & Healy, 1995; Rittle-Johnson & Kmicikewycz, 2008). Regardless of the explanation, it is clear that generation is effective. A meta-analysis of 86 studies found a moderate effect (0.40) of generation versus reading, and a large effect (0.87) when focusing on conditions that used mathematical items (Bertsch, Pesta, Wiscott, & McDaniel, 2007).