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A randomized, controlled study of computer-based intervention in middle school struggling readers

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Abstract

The current study was conducted to test the premise that computer-based intervention that targets auditory temporal processing combined with language exercises (Fast ForWord®) is effective in remediating children with disorders of language and reading. Sixty-five middle school struggling readers were randomly assigned to one of five groups and over a 12-week-period received one of the following interventions: (1) two phases of intervention with Fast ForWord® (FFW, experimental group), (2) two phases of intervention with SuccessMaker (SM, active control group), (3) FFW followed by SM, (4) SM followed by FFW, or (5) no intervention beyond the regular class curriculum (developmental control group). Changes in reading, phonemic awareness, spelling and language skills were assessed via a repeated measures MANOVA. Results indicated significant within-subjects effects (i.e., change for all participants over time), but no between-subject group differences, failing to show that Fast ForWord® resulted in any gains over and above those seen in the other groups.

Keywords: Reading; Oral language; Phonemic awareness; Spelling; Intervention; Randomized; Controlled; Dyslexia; Specific language impairment; Fast ForWord

1. Introduction

Reading disabilities affect up to 15% of all children and are the most prevalent of all learning disabilities (Lyon, Shaywitz, & Shaywitz, 2003). Developmental dyslexia is diagnosed by specific difficulties with reading that cannot be explained by intelligence or lack of educational opportunities (Lyon et al., 2003) and individuals with dyslexia typically lack the skills that facilitate grapheme-phoneme mapping required for word decoding (Shankweiler et al., 1999; Snowling, Goulandris, Bowlby, & Howell, 1986; Torgesen, Wagner, Simmons, & Laughon, 1990). On the other hand, individuals with specific language impairment (SLI) are characterized by unexpected difficulty in receptive and expressive oral language skills (Bishop & Snowling, 2004), and although it is not a diagnostic criteria, many of these children, 50% or more by some estimates, are also likely to experience difficulty in learning to read (Catts, 1993; Catts, Fey, Tomblin, & Zhang, 2002).

To date, success in identifying and treating language-based learning disabilities has been mixed due to the controversies surrounding the etiology of these conditions (Catts, 1993). In the English-speaking world a significant corpus of research has demonstrated that phonological awareness is fundamental to normal reading acquisition (Goswami, 2003; Liberman, Shanweiler, Fischer, & Carter, 1974; Wagner & Torgesen, 1987; Wagner, Torgesen, Laughon, Simmoms, & Rashotte, 1993; Wagner et al., 1997). Phonological awareness can best be defined as a "broad

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class of skills that involve attending to, thinking about, and intentionally manipulating the phonological aspects of spoken language" (Scarborough & Brady, 2002). Poor phonemic awareness has been attributed as the root cause for dyslexia (Bradley & Bryant, 1978) and its remediation the most promising avenue for reading intervention (Alexander & Slinger-Constant, 2004; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wagner & Torgesen, 1987; Wagner et al., 1993). While it is largely accepted that most children with dyslexia have poor phonemic awareness, it is also the case that some dyslexic readers do not have difficulties in such sublexical processes. This observation has given rise to several other explanations of children's reading problems, such as a difficulty with lexical procedures resulting in surface dyslexia (as opposed to phonological dyslexia; Castles & Coltheart, 2004). There are also other accounts that explain the multiple behavioral manifestations of dyslexia in the realm of magnocellular dysfunction, impaired automatization, cerebellar abnormalities, to name a few (for a review of these theories see Vellutino et al., 2004).

Historically, research into SLI has been separated from that of dyslexia, the former mostly being the focus of speech and language pathologists, while dyslexia fell into the domain of special education and psychology. Reading and phonological awareness problems are not unique to the dyslexic population, but are also observed in children with a diagnosis with SLI (for a thorough review see Bishop & Snowling, 2004). Recent co-examinations of these groups have found large overlaps amongst them, with half of the children with dyslexia exhibiting oral language problems and likewise, half of the SLI group showing poor reading performance (McArthur, Hogben, Edwards, Heath, & Mengler, 2000). As a result some researchers conceptualize these two learning disabilities as a continuum (Catts, 1993; Catts et al., 2002), whereas others view them as distinct disorders (Bishop & Snowling, 2004; Leonard, Eckert, Given, Berninger, & Eden, 2006).

Independent of these diagnostic controversies, it is widely agreed that, because of their reading problems, individuals with dyslexia and SLI are at high risk for poorer academic and occupational achievement than would be predicted based on their IQ and socio-economic status. Hence, there is an urgent need for a better understanding of effective remedial approaches which could ameliorate these children's reading impairments. One particular line of research that has led to a now widely pursued avenue of intervention suggests that children with SLI and/or dyslexia exhibit an impairment in the ability to discriminate rapidly presented auditory stimuli (Tallal, 2004; Tallal & Piercy, 1973; Tallal & Piercy, 1974; Tallal, Stark, & Mellits, 1985). Specifically, it has been proposed that a 'rapid auditory processing deficit' is not limited to verbal stimuli, but also manifests as impairment in the ability to discriminate rapidly presented nonverbal auditory stimuli such as tone sequences (Tallal & Piercy, 1973). Deficits in discriminating speech sounds and tone sequences have been shown to correlate with phonological processing impairment and reading problems (Klein, 2002). Thus, it could be argued that it is this mechanism, which via its impact on phonological processing, is effectively responsible for the failure of children with SLI or dyslexia to develop typical word decoding skills (De Martino, Espesser, Rey, & Habib, 2005; Farmer & Klein, 1995; Hari & Kiesla, 1996; Kraus et al., 1996; Nagarajan et al., 1999; Tallal, Miller, & Fitch, 1993. However see Bishop, Carlyon, Deeks, & Bishop, 1999; McAnally, Hansen, Cornelissen, & Stein, 1997; Nittrouer, 1999; Waber et al., 2001).

This theory was translated into practice by developing a remediation approach in which both non-linguistic auditory stimuli and speech stimuli are prolonged and presented repeatedly using a computer–based training procedure (Merzenich et al., 1996; Tallal et al., 1996). This procedure was intended to address the possibility that sensory stimuli (i.e., sound frequencies) entering the nervous system in rapid succession, are coded physiologically as a single unit of sound frequencies that fail to induce an appreciation of differentiation between them. The intervention protocols employed acoustically elongated tones and speech sounds that slowed the rate, increased the amplitude, and increased inter-stimulus-intervals. These adaptations enhanced non-speech and speech stimuli and brought about more salient processing of the individual stimuli. This type of learning has proven to be effective in psychophysical and physiological studies. For example, training of adult monkeys in specific auditory discrimination paradigms has been shown to lead to altered auditory cortical representational maps for those stimuli (Recanzone, Schreiner, & Merzenich, 1993). Similarly, perceptual improvement has also been demonstrated for the discrimination of formant transitions in rats; the amount of accompanying cortical change is usually related to the amount of training and behavioral improvement on the task (Orduna, Mercado, Guck, & Merzenich, 2001).

Based on this theoretical framework of learning induced plasticity, initial studies in children employing a precursor of what is now a commercial program called "Fast ForWord®" (FFW) revealed that targeted training of rapidly changing transitions in speech affected auditory processing thresholds and improved receptive language in language-learning impaired (LLI) children (Merzenich et al., 1996; Tallal et al., 1996). Tallal and colleagues (1996) involved 7 LLI participants ranging from 5–9 to 9–1 years of age, who participated in four weeks of training for 4 to 5 h a day, five days a week with an additional 1 to 2 h a day on weekends. Children worked one-on-one with a clinician, played each of the two acoustically modified computer games 20 min/day, listened to acoustically-modified recorded stories, and engaged in six other language exercises. The results revealed approximately 2 years language age gain for the seven children which prompted further investigation. Therefore, Merzenich and associates (1996) revised the computer exercises and added two other games. Twenty-two children from 5–2 to 10 years of age were divided into two groups, and each group followed the training program described above except that the comparison group received the same exercises and story telling with unmodified speech, thereby serving as a control. After the training, both groups displayed gains in speech discrimination, language processing and grammatical understanding; however, gains of the experimental group were significantly greater than those of the control group. The authors argued that the positive effects on language in children with SLI could be attributed to the amelioration of a fundamental temporal processing deficit by the acoustically modified approach.

These initial studies did not directly assess changes in reading and reading-related skills, although it was suggested that FFW intervention would have beneficial effects for individuals with dyslexia (Tallal et al., 1996). A more recent study by Tallal and colleagues (Temple et al., 2003) found reading improvement following FFW intervention in children with dyslexia. This study employed behavioral assessment and brain imaging technology of 20 children with dyslexia and 12 non-impaired readers (ages 8 through 12 years). All children underwent functional magnetic resonance imaging (fMRI) and behavioral testing prior to and following eight weeks of FFW intervention, while only those with dyslexia received the intervention. Behaviorally, significant pre-intervention versus post-intervention gains were demonstrated for the children with dyslexia on Word Identification, Word Attack (phonetically regular pseudoword reading), and Passage Comprehension on the Woodcock–Johnson Psychoeducational Battery (Woodcock & Johnson, 1989, 1990) and the dyslexic group moved from the below average range into an average range on these tests. As a group, the dyslexic readers also made significant gains in receptive language, expressive language and rapid naming. However, these gains were not reflective of the entire group: 50% of the sample made no significant gains in oral language skills and 45% showed no gains in reading. While the dyslexic children scored significantly lower on all language measures than the control group, the authors failed to report if individual children with dyslexia who showed no or minimal improvement on the language measures were the same children who failed to improve on the reading measures. As expected, the normal readers (who did not receive intervention) exhibited no significant changes in their performance between the two testing sessions. A drawback of the study is that there was no dyslexic comparison group against which to evaluate these intervention results.

Tallal and colleagues followed these reports with studies designed to replicate their earlier findings on a larger scale with populations of a variety of disabilities (Tallal 2000a; Tallal 2000b). For example, a national field study with over 500 children in clinics and classrooms experiencing SLI, attention deficit disorder (ADD), pervasive developmental disability (PDD), autism, central auditory processing disorder (CAPD), or dyslexia resulted in "approximately 90% of the children who complied with the study protocol" improving in language skills by at least one standard deviation (Tallal 2000a, p. 29). Unfortunately, the number of children "who complied with the study protocol" was not reported; therefore, the overall success rate cannot be determined. Further, there was no control group against which to compare the gains.

These reports raise the important possibility that environmental enrichment with carefully designed auditory stimuli may effectively remediate learning disabilities that are widespread and have been difficult to treat. However, despite the enthusiasm for training-induced plasticity, the efficacy of such approaches has been challenged. Some investigations have questioned the fundamental theory of an auditory temporal processing deficit in developmental dyslexia and specific language impairment due to failure in demonstrating a relationship between phoneme discrimination and auditory perceptual skills (Mody, 2003; Mody, Studdert-Kennedy, & Brady, 1997; Studdert-Kennedy, 2002; Studdert-Kennedy & Mody, 1995). A fragile or non-existent association between phonological processing and the processing of rapidly changing acoustic stimuli weakens the premise that language skills can be modified through low-level interception of auditory perceptual processes (McArthur & Bishop, 2001). However, despite these criticisms the authors of FFW continue to advance their product with the view that discrimination difficulties of rapidly changing successive acoustic events play a primary role in phonological development and disorders that can be addressed through acoustically modified speech (Tallal, 2004). At the same time, the composition of FFW has changed in that more recent versions of the programs also contain numerous games and exercises that place an emphasis on skills other than auditory perception; hence current FFW iterations differ from those initially reported (for a detailed review of these differences see Gillam, 1999).

Most studies that support a favorable outcome of FFW interventions have been conducted by or in conjunction with developers of the FFW programs. Consequently, independent studies are necessary for the purpose of replication, especially when a conflict of interest needs to be ruled out as pointed out in recent editorials ("A cure for dyslexia?," 2007; "Bringing neuroscience to the classroom," 2005). To date pilot and exploratory case studies of FFW, as well as a few group studies can be found in the peer-reviewed literature and these are reviewed next in chronological order and by study type. As will become apparent, these studies recruited children with a variety of language impairments and used one of a number of programs that are commercially available under the FFW rubric (e.g., Fast ForWord® to Language (FFW-L) and Fast ForWord Language to Reading (FFW-LR)), all of which emerged from, but are not identical to the 1996 precursors of the current FFW programs.

In 1999 Turner and Pearson examined the benefit of FFW-L with four children (ages 6–3 to 13–3 years) who exhibited language-based learning disabilities. In their series of case studies, all four children improved in some language functions. For example, Child #1 made significant improvement on the CELF-3 Total Language Score while Child #2 and Child #3 made little improvement. Child #1 demonstrated improved communicative skills at home, but syntax and pragmatic difficulties were unchanged. On the CELF-3 Expressive Language Score, Child #2 produced substantial gains, while Child #4 moved from below normal to high average on the Peabody Picture Vocabulary Test-III and on two subtests of the CELF-3. Also, his ability to pay attention was noticeably improved. The authors concluded that Fast ForWord Language aids children with language difficulties in different ways that create great improvement in some and minimal improvement for others.

Similarly, Loeb, Stoke, and Fey (2001) implemented FFW-L in a home-based case study of four speech and language impaired boys ages 5–6 to 8–1. Although improvements were generally small, pre-, post, and 3-month follow-up of standardized language measures revealed that all four youngsters made gains on some of the same measures that Tallal et al. (1996) used in their initial study. Overall, nearly 10% (58 items) of the 595 items tested revealed gains at post-testing with 61% of the gains (35 items) sustained at the three month follow-up. It is important to note that with only four cases, the study lacks adequate power to compare gains on 595 individual items that could occur by chance alone. Loeb and colleagues concluded that "although FFW-L delivered at home by parents may lead to some important changes in children's performance on structured tasks, broad, dramatic gains in spontaneous language use are less likely and may not be long-lasting" (p. 216).

Gillam, Crofford, Gale, and Hoffman (2001) compared two children receiving Fast ForWord in a laboratory setting to two children receiving a variety of computer-driven intervention programs using normal speech published by Laureate Learning Systems. The purpose of the study was to evaluate spontaneous language; reading was not assessed. The effects were similarly positive in both groups. This was surprising not only because the Laureate Learning Systems exercises targeted word and sentence skills (while only 3 of the 7 FFW games did), but also because Laureate Learning Systems' exercises do not involve training in low-level auditory processing. Hence the low-level auditory processing training aspect of FFW may not be as critical for language outcomes as Tallal's theory suggests.

In another independent study, Friel-Patti, DesBarres, and Thibodeau (2001) conducted case studies of five private school children with language learning difficulties (ages 5–10 to 9–2 years) enrolled in FFW training. They found modest language changes for the children as a group; however, "no clinically significant changes" were found for three of the five children on standardized language sample measures (p. 203). Turning to another single-subject study, Deppeler, Taranto, and Bench (2004) used an ABA design (baseline, intervention, and maintenance at 12-month follow-up) to investigate benefits of FFW with eight primary-aged Australian children with a range of receptive and expressive language impairments. The authors report that three participants increased their expressive language scores; one of the three reached significance. Two others had significantly decreased scores. Six of the eight children (75%) increased their receptive language scores with one making a significant gain. The researchers concluded that their results provided "limited support" for the FFW intervention.

Some studies focused on paradigms that assess auditory temporal processing skills before and after FFW intervention. For example, Marler, Champin, and Gillam (2005) used a masking design to evaluate changes in auditory temporal processing of four boys diagnosed with LLI. Two received FFW intervention and two received the Laureate Learning Systems computer activities as described in the study above. Their performance was compared to that of three boys with typical language development who received no intervention (all seven boys ranged in age from 6–10 to 9–3 years). Prior to the intervention the three boys with typical language development and one of the LLI boys demonstrated "normal" temporal processing as measured by lower thresholds in the backward masking condition than those in the simultaneous masking condition. Following the interventions, masking threshold improvements were observed for both intervention programs. Similar improvements led the authors to conclude that FFW did not show program-specific improvement of temporal processing over benefits realized by the Learning Systems approach.

Another auditory temporal processing backward masking study produced different results. Valentine, Hedrick, and Swanson (2006) found that in a group of 26 low and low-average readers (7 to 10 years old) backward masking thresholds improved immediately following 6 weeks of FFW-L intervention, as did language skills and phoneme awareness (but not reading). At six months follow-up, there were continued improvements in the thresholds for backward masking, but no improvements in language or reading skills. The researchers conclude that their "results do not support the assumption that by improving temporal processing (as measured by backward masking), reading and language skills would also improve" (p. 193). They also state that their study "calls into question the efficacy of an intensive auditory training program to improve reading skills" (p. 183).

Another study examined FFW's efficacy on auditory temporal processing, language skills and reading in a clinical setting. Agnew, Dorn, and Eden (2004) assessed the ability of seven children to accurately judge relative durations of auditory stimuli before and after participation in FFW, and to ascertain the effects on non-word reading and phonologic awareness. Following the four to six week daily intervention, children showed improved accuracy on a computer-based test of auditory duration judgment, but no analogous improvements in the visual domain, which supports the theory that training with modified speech improves auditory temporal discrimination. These gains in auditory processing, however, failed to generalize to reading or phonological awareness skills.

The first independent, larger group-based comparison study of FFW on reading and language measures was published by Hook, Macaruso, and Jones (2001) who compared children receiving FFW ($n = 11$) with those involved in a non-computerized Orton-Gillingham phonics program ($n = 9$), and with matched longitudinal controls ($n = 11$). All children were 7 to 12 years of age and were poor readers. Neither experimental group made significant gains on the Woodcock–Johnson Word Identification subtest, while only those working with Orton-Gillingham made significant gains in Word Attack which is a phonically structured, pseudoword reading task. Both programs led to similar immediate gains in phonemic awareness (indicating that gains in phonemic awareness training may fail to generalize to reading improvement). Consistent with the reports by Tallal and colleagues (Tallal et al., 1996), the FFW group made gains in spoken language and syntax immediately after intervention; however, comparison with the control group at the end of the study revealed that the gains failed to maintain at the two-year follow-up, demonstrating no long term benefits of FFW.

Troia and Whitney (2003) reported on a study involving 25 children assigned to FFW-L intervention drawn from a field study involving 89 children enrolled in either Title I (i.e., identified as low achieving) or a local academic support initiative; all children were referred due to their poor academic performance. Approximately one-third of the total group had a diagnosed learning disability or speech-language impairment and attended grades 1 through 6 (mean age = 9 years, 7 months). The FFW-L group ($n = 25$) was matched with a control group of 12 students on four domains: oral language competency, phonological processing abilities, basic reading skills, and classroom behavior. Pre- and post-test scores after a 4 to 8 week FFW-L intervention were equivalent for the two groups except that the FFW-L group gained significantly more on expressive oral language. An additional analysis of students with the most severe language impairments revealed that the FFW-L group made greater gains than the control group in expressive oral language, as well as syllable and sound blending.

Pokorni, Worthington, and Lamison (2004) explored the effectiveness of three programs: Fast ForWord ($n = 20$), Earobics (Cognitive Concepts, 1998) ($n = 16$), and Lindamood Phoneme Sequence Program (LIPS; Lindamood & Lindamood, 1998) ($n = 18$). The 54 students (7–5 to 9 years of age), nominated by speech and language pathologists, were receiving school-based speech/language services due to language and reading deficits. All 54 students were reading at least one year below grade level, were from English-speaking families, and had no known hearing deficits. Students were randomly assigned to one of the three interventions for one hour sessions, three times a day for 20-days within a public school summer program. FFW and Earobic students worked in groups of 5–6 in a computer lab while the LIPS students worked in groups of four with a teacher for direct instruction. Only the Earobics and LiPS programs were associated with gains in some measures of phonological awareness six weeks after the summer intervention, but the three groups did not differ substantially on segmenting phonemes, language subtests, or reading-related subtests.

In another randomized investigation in a large urban school system, Rouse and Krueger (2004) studied FFW effectiveness on reading skills of third, fourth, fifth and sixth grade students who scored in the bottom 20% or significantly below grade level on a statewide standardized test. Students were randomly assigned by grade and school to a FFW treatment group (overall $n = 272$) or to a control group that did not receive FFW training (overall $n = 240$). Dependent upon the availability of measures at individual schools attended, students were evaluated on a measure of reading and in some cases also on language ability. From the entire sample, equal numbers of treatment and control subjects were administered the following measures prior to and following the intervention: the CELF-3 (a standardized test of receptive and expressive language) administered to 89 students; *Success for All* (a measure of reading skills) administered to 374 students; the *National Assessment of Educational Progress* (a state-mandated standardized reading assessment) administered to 454 students; and *Reading Edge* (a measure of language and reading sold by Scientific Learning Corporation) given to 485 students. From derived data on these reading and language measures, the authors concluded that FFW may improve some language skills, but the gains tend not to translate to measures of language acquisition or actual reading skills.

More recently, Cohen and colleagues (Cohen et al., 2005) conducted a study with 77 children ages 6 to 10 years who experienced severe receptive-expressive language impairment. In their randomized controlled trail, children were assigned to one of three groups: Group A received FFW intervention as a home-based therapy; Group B, received a variety of commercially available computer programs at home designed to teach phonics, spelling, rhyme, analogies, and problem-solving skills; and Group C received no intervention beyond their language therapy and educational support which the other groups also received. There were no significant differences across groups (A, B, C) at pre-intervention on any of the expressive or receptive language measures, IQ, phonological processing, vocabulary or grammar measures. While all three groups demonstrated significant changes across measures at 9-week post intervention and 6-month follow-up, the researchers reported that children assigned to the FFW group showed no significant additional benefit of intervention on their primary measures beyond that found for the control children or those assigned to the generic computer games.

A set of pilot studies investigating a training regime that contained the same components as FFW (artificial slowing of natural speech and speech amplification) was applied by Habib and colleagues (Habib et al., 2002; see also Habib et al., 1999) to six children and contrasted to another six children who received the exercises without speech modification; all were 10 to 12 years of age. Phonemic awareness performance was determined by three batteries of odd-one-out phonological tasks normalized on a group of 80 age and reading matched peers with normal reading skills. These tasks, similar to those used during the intervention, revealed >20% improvement for the experimental group compared to no change in the control group. These changes, however, did not generalize to measures of reading. Within the same report, the authors describe a study involving 29 children with dyslexia who received similar training, but in lesser quantity delivered at home or in a clinic. Gains were observed in 21 of the children on a global measure of phonological performance, but in the absence of a dyslexic control group these results are difficult to interpret.

In summary, both the auditory temporal processing theory and the ensuing commercially distributed programs marketed under Fast ForWord®, have received some support, some failure of replication, as well as criticism. For example, Gillam (1999) argues that assessed gains reported by Tallal and colleagues in the original 1996 studies may have been the result of activities with a clinician rather than the exercises using modified speech. Another criticism has been that age equivalent scores used in Tallal's original 1996 papers, when compared to results based on standard scores, provide an incorrect impression of successful clinical changes (Friel-Patti et al., 2001). Another concern is that gains reported in reading or language skills following the intervention might be explained by other contributing factors, such as attention to the task. It is known that attention can be modulated significantly following the engagement of computer-driven games (Green & Bavelier, 2003), raising the possibility that reading gains are in fact mediated by general effects in attention, but mistakenly interpreted as specific, perceptual or language-based changes (Eden & Moats, 2002; Gillam, 1999). The absence of control groups in many studies reported since 1996 prevents the possibility of drawing strong conclusions about the efficacy of FFW, as any observed changes may be due to factors other than the training *per se*. Using the criteria articulated by the Institute of Educational Sciences (IES), Department of Education (Whitehurst, 2003), the comparisons of pre- and post-intervention data, which is the preferred format of Scientific Learning when presenting results of FFW intervention on their website, lack "possible evidence" for efficacy. That is, IES insists that randomized group assignment and the inclusion of a non-intervention control group are crucial in determining treatment efficacy. To date, these have not been widely employed for examining intervention programs such as Fast ForWord®. Importantly, it is necessary to address the question of intervention efficacy with respect to both reading and oral language gains, as improvement in both domains would provide support for the hypothesis put forward by Tallal and colleagues describing a connection between low-level auditory perception with higher-level oral and written language and a strengthening of these via FFW training (Tallal, 2004).

Using a randomized, controlled study in the schools, we examined the efficacy of FFW training in bringing about gains in both language and reading skills in 65 children with a range of language and reading problems. Language and reading gains were contrasted between this group and children participating in a reading and language-arts program, "SuccessMaker," (Computer Curriculum Corporation, 1995) that was also delivered via computers for the same amount of time. SuccessMaker (SM) provided an active control group (Group 2) that focused on the use of linguistic skills for language arts improvement, while FFW focused on improvement of auditory processing and linguistic skills and their impact on reading improvement. Both groups allowed us to determine whether expected gains were specific to participation in the FFW programs rather than to other reasons (e.g., a more general cognitive strategy such as attention resulting from intensive interaction with the computer).

1.1. Study design

The study contained two six-week intervention phases interwoven with three behavioral testing sessions (see below). This design allowed data acquisition at three time points: (1) prior to any intervention, (2) after the first intervention Phase I (i.e., 6 week after initial testing), and (3) after the completion of intervention Phase II. Group 1 received "Fast ForWord® to Language" (FFW-L) during the first 6 weeks (Phase I) followed by "Fast ForWord® Language to Reading" (FFW-LR) during Phase II. We anticipated significant gains by this experimental group in reading and language. To determine whether any of these expected gains were specific to participation in the FFW programs rather than to other reasons (e.g., a more general cognitive strategy such as attention resulting from intensive interaction with the computer), this experimental group was compared to an active control group (Group 2). Group 2 received "SuccessMaker" at the same intensity and over the same time periods (Phases I and II) as Group 1. To control for developmental changes that would occur over the time period of the study, we also included a developmental control group (Group 5) whose members participated in their regular curriculum. Finally, the study included two groups that allowed examination of the effects of FFW via a cross-over design: In Group 3, participants first received FFW-L (Phase I) followed by SuccessMaker (Phase II); Group 4 received these two programs in reverse order. Group 5 again served as a control to these two groups, controlling for development while receiving the standard curriculum.

We had several predictions:

(1) Reading and language gains would be greatest during phases that involved FFW intervention rather than SuccessMaker or the standard curriculum, because modified speech contained in FFW has shown to be more effective than training without modified speech.
(2) Gains for Group 1 would be more substantial then those measured in all other Groups, as students in Group 1 received twice the amount of FFW intervention compared to those in Groups 3 and 4, and more than those in Groups 2 and 5 (who received no FFW intervention at all).
(3) Within Groups 3 and 4, greater gains would be observed by the end of the study in Group 3, because these students could use skills gained from FFW-L in Phase I as a foundation upon which to build language arts skills during Phase II.

2. Methods

2.1. Participants

Personnel from three middle schools in three mid-Atlantic school divisions referred students for this study. Children were identified based on their limited progress in the area of reading. After learning about the study, 88 parents or legal guardians submitted consent forms (signed parental approval) and their children returned assent forms (signed student approval) thereby indicating their willingness to participate. The children's cumulative academic and behavioral records were reviewed for date of birth, IQ equivalent scores, reading scores (based on standardized group achievement tests), and special education eligibility. Students with autism or emotional disturbance were eliminated from the study. Remaining students were screened by the school nurse for auditory and visual acuity; those with normal auditory acuity and normal or corrected vision remained in the participant pool. Following this screening, 12 of the 88 students became ineligible for the study or withdrew.

Students were then assigned to one of five groups (described below) in two phases. First, following an invitation to all students, we randomly assigned a subset of 25 students who opted and qualified for participation in a protocol using brain imaging technology (Leonard et al., 2006) into one of the five groups. Then the remaining 51 participants were randomly assigned to one of the five groups. During the course of the project eleven students were lost due to family moves ($n = 6$), school suspension ($n = 3$), or withdrawal from the project ($n = 2$). At the completion of the study, Groups 1 to 5 contained 12, 14, 15, 11 and 13 subjects, respectively (see Table 1).

2.2. Interventions

All interventions (Groups 1 to 4) occurred five days a week, for 88 minutes a day during two 47 minute class periods, minus the necessary transition time. The two sessions were separated by lunch or another class. This time is consistent with various recommendations made by the Scientific Learning Corporation for FFW usage of either program (75 min a day for 5 days per week over six to ten weeks for FFW-L; 90 min day over 4–8 weeks for FFW-LR). Further, compliance for the FFW programs was established after 32 h of engagement with the FFW activities as recommended (http://www.scilearn.com/prod2/). This intensive time schedule exceeded the 20-min daily sessions recommended for SuccessMaker (SM) use (Computer Curriculum Corporation, 1995). Although, this may have resulted in diminishing returns for those subjects assigned to SM due to fatigue with the tasks, our primary goal was to use SM as an active control for FFW, and therefore equal time of administration was necessary. For both types of interventions, a token system of food, games, video rental certificates, and toys was used to reinforce attendance, attention to task, and completion of the exercises.

2.3.1. Fast ForWord®, Scientific Learning Corporation (SLC)

Software for both Fast ForWord® to Language (FFW-L) and Fast ForWord® Language to Reading (FFW-LR) consists of a series of "games" (For game descriptions, see Agnew et al., 2004; Gillam, 1999; Hook et al., 2001; Merzenich et al., 1996; Tallal et al., 1996). For each game, the software adjusts content delivery to individual responses in an effort to foster 80% accuracy or better per game. The producers of FFW state that both FFW-L and FFW-LR are expected to increase memory, attention, processing, and sequencing skills through exercises in listening accuracy, phonological awareness and language. Although the same skills are addressed in each program, graphics used in FFW-LR reflect a more mature audience. In addition, FFW-LR focuses on sound-printed letter correspondence, printed word recognition, and printed word order in addition to multi-step instructions, and English language conventions through the use of orally presented words, sentences, and stories intended to promote comprehension skills. Both the FFW-L and FFW-LR software include train-

Table 1
Research design

	Group 1	Group 2	Group 3	Group 4	Group 5
Phase I (6 weeks)	FFWL	SM	FFWL	SM	Regular curriculum
Phase 2 (6 weeks)	FFWLR	SM	SM	FFWL	Regular curriculum
No. of participants	$n = 12$	$n = 14$	$n = 15$	$n = 11$	$n = 13$

ing of auditory discrimination using non-verbal and verbal stimuli, as consistent with the theoretical framework of the temporal processing hypothesis which motivated the inception of these programs (Tallal, 2004).

All Fast ForWord® (FFW) exercises were delivered through headphones, and students used a computer mouse to respond. As part of the administration of FFW, subject performance data (with identifying information removed) were regularly uploaded to Scientific Learning Corporation for tracking individual student progress and adjusting program content. All three schools reserved computer lab time during school hours for this project, and providers were trained by representatives of SLC, who frequently observed to ensure accurate implementation of the two FFW programs. Even with dedicated lab time, providers were often challenged by students who tended to avoid the tasks and/or disrupt other students. The providers included full-time school employees (teachers and assistants) plus two individuals who were hired and trained specifically to monitor FFW implementation.

2.3.2. SuccessMaker (Pearson Digital Learning, formerly Computer Curriculum Corporation)

The SuccessMaker (SM) academic program was originally developed as part of a research-based, computer-assisted intervention project at Stanford University (Suppes, 1988) to teach standards-based skills using national academic curricula. SM individualizes instruction to student needs by adjusting instruction, content, and learning strategies to a level commensurate with the student's level of comfortable challenge (Computer Curriculum Corporation, 1995). The reading portion of this program uses literature-based activities that involve comprehension, vocabulary, phonics and writing that encourage students to apply knowledge they have gained from literature, subject-matter reading and topical areas of study (see http://www.pearsondigital.com/successmaker/). Importantly, while FFW targets individual tones, phonemes, discrimination of single syllable words heard and seen, listening to stories, and language skills, SuccessMaker focuses on vocabulary development, contextual reading, spelling, and writing skill development.

In a "white paper" on its website, Pearson Digital Learning provides one-page reports from several school divisions stating significant results in reading and mathematics after implementation of SuccessMaker. In 1994, Kulik conducted a meta-analysis of 96 studies; of these, only one reading study was published in a refereed journal, reporting an effect size of 0.79. Kulik's overall conclusion was that students who used SuccessMaker achieved significantly higher standardized scores on reading and mathematics measures than did students without use of the SM system.

2.3.3. Regular class instructions

The content of the school curriculum for Group 5 varied throughout the 12-week period, as students received instruction from a number of different teachers. Students were invited to receive the FFW training after data collection had been completed. Five students elected to do so.

2.4. Neuropsychological and psycho-educational testing

Student full scale IQ scores were based on extant school records of the *Cognitive Abilities Test* (Thorndike & Hagen, 1993) or the *Wechsler Intelligence Scale for Children* (Wechsler, 1991). When no ability records were available, students were administered the *Otis–Lennon School Ability Test* (Otis & Lennon, 1997) within our research protocol.

2.5. Psycho-educational assessment

Experienced psychometricians, who were blind to the students' group assignments conducted pre- and post- individual assessments during the school day using the test battery described below. Reading, spelling, and language skills were examined before and after the interventions. Measures included: (1) phonological skills known to be supportive of reading development (Torgesen et al., 1990); (2) language skills (receptive language and oral expression), and (3) reading (single real word reading, non-word decoding, and reading comprehension) and spelling. Each of these is described below.

(1) Phonological skills
  (a) *Phonological Awareness:* The Auditory Processing subtests on the *Woodcock–Johnson Psycho-Educational Battery, Revised* (WJ-R; McGrew, Werder, & Woodcock, 1991; Woodcock & Johnson, 1989/1990) were used to evaluate phonological skills. This composite is a measure of the ability to appreciate patterns among speech-based auditory stimuli. The score is derived from scores on Incomplete Words and Sound Blending (synthesizing/blending phonemes from syllables and phonemes heard).
  (b) *Phonological Retrieval: Rapid Automatized Naming* (RAN; Denckla & Rudel, 1974; Denckla & Rudel, 1976; Wolf & Denckla, 2005) was used to measure letter and number naming speed. Raw scores for the letter and number charts were separately normalized to provide z scores that were averaged.

(2) Language
  (a) *Receptive Language:* A composite score from the *Clinical Evaluation of Language Fundamentals, 3rd Edition* (CELF-3: Semel, Wiig, & Secord, 1995) was derived from standard scores from three subtests: Concepts and Directions, Word Classes and Semantic Relationships.
  (b) *Expressive Language:* A composite score from CELF-3 was derived from standard scores on three subtests: Formulated Sentences, Recalling Sentences, and Sentence Assembly (Semel et al., 2003).

(3) Reading and spelling
  (a) *Real word reading:* The WJ-R Letter-Word Identification subtest was used to measure aloud naming of letters and words presented in print.
  (b) *Non-word reading:* The WJ-R Word Attack subtest was employed to measure application of phonics and structural analysis to decode unfamiliar, phonically consistent non-words (pseudowords).
  (c) *Comprehension:* Passage Comprehension from the WJ-R was used to measure the students' comprehension of context-embedded information using a cloze procedure.
  (d) *Spelling:* The *Wide Range Achievement Test, 3rd Edition* (WRAT-3; Wilkinson, 1993a; Wilkinson, 1993b) spelling subtest was used to test the children's ability to write their names as well as write letters and words from dictation.

3. Results

3.1. Subject characteristics of entire study sample

The subject characteristics of the 65 participants who completed the protocol and whose data were submitted to data analysis are summarized in Table 2. The mean age of the entire sample was 12.53 years ($SD = 1.17$) with a mean grade of 6.65 ($SD = 1.01$). The majority of the 65 students (64.6%) were enrolled in grade 6. The overall mean IQ equivalent score of the sample was 92.55 ($SD = 14.41$). The sample consisted of 43.1% females, 29.2% White, 26.2% Black/African American, 18.5% Hispanic/Latino, and 4.6% Asian/Pacific Islander. About one-fifth of the parents (21.5%) declined to identify their children's ethnicity.

3.2. Demographic characteristics, IQ, reading and language skills prior to-intervention: Between-group comparisons

Theoretically, the randomization of participants to intervention groups should result in similar distribution of age and ethnicity across the five groups. Likewise, scores for full scale IQ and measures of phonological, reading and language skills before intervention should show little difference between groups. To assess whether the compositions and characteristics of the five groups were indeed comparable, we performed one-way ANOVAs and Chi-squared analyses on demographic and psycho-educational measures (standard scores) obtained prior to intervention. An ANOVA yielded no statistically significant findings for age [$F(4,60) = 0.73$, $p = .58$] or grade [$F(4,60) = .87$, $p = .49$]. Also, the relative composition of groups was found to be similar for sex [$\chi^2(4, N = 65) = 1.97$, $p = .74$ two-sided] and race/ethnicity [$\chi^2(16, N = 65) = 8.86$, $p = .92$ two-sided]. Next, we examined whether full scale IQ, phonological processing, reading, spelling and language measures were comparable across groups using a series of one-way ANOVAs. These revealed no statistically significant differences in intellectual ability [$F(4,60) = 1.77$, $p = .15$], or phonological skills of WJ-R Auditory Processing [$F(4,60) = .06$, $p = .99$] and Rapid Automatized Naming Test [$F(4,60) = .09$, $p = .99$]. Reading and spelling measures were also equivalent across the five groups (WJ-R Word Attack [$F(4,60) = 1.42$, $p = .24$], WJ-R Reading Comprehension [$F(4,60) = 1.80$, $p = .14$] and WRAT-3 Spelling [$F(4,60) = .71$, $p = .59$], except for WJ-R Letter–Word Identification [$F(4,60) = 2.752$, $p = .04$]. Here, Group 3 demonstrated the lowest mean score and Group 2 the highest. However, no statistically significant Letter–Word Identification differences were evident across groups in post-hoc analyses using Scheffé's method. Finally, language ability was equivalent across groups, with no statistically significant differences observed for CELF-3 Receptive Language [$F(4,60) = .25$, $p = .91$] or Expressive Language [$F(4,60) = .88$, $p = .48$]. These pre-intervention scores for each of the five groups are reported in Table 3 and indicate that the randomization had been effective in yielding comparable samples prior to initiating the intervention. We now turn to examining the outcomes of the children's phonological, reading and language measures during the 12-week duration of the study (1) as a whole (within-subjects analysis)

Table 2
Demographic characteristics (mean (SD) and frequency) of participants

	Group 1 FFWL&FFLR ($n = 12$)	Group 2 SM&SM ($n = 14$)	Group 3 FFWL&SM ($n = 15$)	Group 4 SM&FFWL ($n = 11$)	Group 5 reg. education ($n = 13$)	All groups ($n = 65$)
Age (years)	12.50 (1.20)	12.29 (0.90)	12.84 (1.49)	12.77 (1.20)	12.24 (0.97)	12.53 (1.17)
Grade	6.75 (0.87)	6.43 (0.85)	7.00 (1.20)	6.64 (1.29)	6.38 (0.77)	6.65 (1.01)
Sex						
Females	7	6	5	4	6	28
Males	5	8	10	7	7	37
Race/Ethnicity[a]						
White	4	2	5	4	4	19
Black/African American	3	4	3	2	5	17
Hispanic/Latino	2	4	2	2	2	12
Asian/Pacific Islander	1	0	0	1	1	3

[a] Numbers may not agree with reported totals when participants' parents declined to identify their race/ethnicity.

Table 3
Mean (*SD*) achievement, phonological, reading and language characteristics of participants at outset of the study

	Group 1 FFW ($n = 12$)	Group 2 SM ($n = 14$)	Group 3 FFW–SM ($n = 15$)	Group 4 SM–FFW ($n = 11$)	Group 5 reg. education ($n = 13$)	All groups combined ($n = 65$)
Full scale intelligence Quotient	87.83 (10.41)	94.57 (9.40)	88.00 (14.98)	100.91 (16.65)	92.92 (17.40)	92.55 (14.41)
Phonological skills						
WJ-R Auditory Processing	81.58 (12.99)	82.36 (10.31)	82.47 (10.79)	80.36 (12.36)	81.77 (12.64)	81.78 (11.42)
RAN-phonological Retrieval	−0.01 (0.89)	0.00 (0.77)	0.18 (0.94)	0.01 (0.73)	−0.01 (1.58)	0.04 (1.00)
Reading & spelling skills						
WJ-R Letter–Word Identification	83.33 (17.50)	94.57 (10.08)	78.87 (14.03)	86.09 (14.50)	89.77 (11.58)	86.48 (14.36)
WJ-R word Attack	78.58 (16.96)	88.71 (14.16)	78.33 (13.00)	86.82 (15.45)	84.54 (13.38)	83.29 (14.73)
WJ-R Passage Comprehension	85.42 (14.57)	93.86 (8.20)	86.20 (18.61)	87.09 (20.00)	94.77 (10.44)	89.57 (15.01)
WRAT-3 Spelling	83.17 (16.83)	85.86 (12.01)	77.80 (12.42)	84.55 (18.45)	85.08 (13.53)	83.12 (14.44)
Language Skills						
CELF-3 Receptive Language	78.58 (17.92)	82.07 (11.84)	80.00 (18.36)	81.18 (13.94)	84.77 (20.04)	81.34 (16.35)
CELF-3 Expressive Language	74.25 (17.18)	81.14 (13.67)	74.67 (21.19)	82.73 (18.33)	84.00 (16.59)	79.22 (17.55)

WJ-R, Woodcock–Johnson Psycho-Educational Battery, Revised.
WRAT-3, Wide Range Achievement Test, 3rd Ed.
RAN, Rapid Automatized Naming.
CELF-3, Clinical Evaluation of Language Fundamentals, 3rd Ed.

and (2) specific to the interventions (between-subjects analysis).

3.3. Change over time: Within-subjects analysis for all participants

We examined the changes in phonological, reading and language skills in the entire sample ($n = 65$) over the duration of the study (including both Phases I and II) using a Repeated Measures MANOVA. Across the 12-week time interval, within-subjects effects yielded a statistically significant Wilks's λ (lambda) of .351, estimated with the F statistic [$F(8, 53) = 12.239$, $p < .001$]. The proportion of partial population variance explained by the within-subjects main effect is large, as designated by the partial *Eta* squared, $\hat{\eta}^2 = .649$ (Levine & Hullett, 2002). Partial *Eta* Squared is an index of effect size describing the observed proportion of explained variance in which .01 may be considered small, .06 may be considered medium, and .16 may be considered large (Snyder & Lawson, 1993).

Turning to our specific measures, we found that tests of within-subjects contrasts for the entire sample of 65 students yielded statistically significant change and medium to large effect sizes for the domain of phonological skills (WJ-R Auditory Processing; $p < .001$, $\hat{\eta}^2 = .333$), reading (WJ-R Letter–Word Identification; $p < .001$, $\hat{\eta}^2 = .220$: WJ-R Word Attack; $p = .003$, $\hat{\eta}^2 = .135$: WJ-R Passage Comprehension; $p = .004$, $\hat{\eta}^2 = .128$) and language (CELF-3 Receptive Language; $p < .001$, $\hat{\eta}^2 = .228$, and CELF-3 Expressive Language; $p < .001$, $\hat{\eta}^2 = .329$). Non-significant changes were observed for a measure of phonological retrieval (RAN Naming; $p = .417$, $\hat{\eta}^2 = .011$) and spelling (WRAT-3 Spelling; $p = .105$, $\hat{\eta}^2 = .043$). Overall, these results indicate that the group of 65 students made significant gains in domains of reading and language throughout the duration of the study. To examine if these changes were preferentially driven by the experimental intervention we conducted between-groups analyses, as described next.

3.4. Change over time: Between-subjects analysis (intervention differential effectiveness)

The extent to which the interventions produced between-subject differences amongst the groups on measurements of phonological, language, reading and spelling skills was examined with a Repeated Measures MANOVA: A Single Repeated Measures MANOVA was performed with the eight variables simultaneously for both pre- and post-test scores. The results demonstrated that Group differences as a function of intervention (i.e., Group membership) over a 12-week period did not approach statistical significance [$F(32, 197) = .708$, $p = .877$].

These results were contrary to our expectations since we had predicted that reading and language gains would be greater for Group 1 than Group 2 (prediction 1), greater for Group 1 than Groups 3–5 (prediction 2), and greater for Group 3 compared to Group 4. We do not attribute this negative result to insufficient power, as the observed power computed using a relaxed *alpha* of .10 is adequate at 0.745, with between subjects change accounting for less than 10% of the partial population variance. To further test for the robustness of our findings we conducted a further analysis in which we collapsed the measures across Groups 1 and 3 (FFW) and Groups 2 and 4 (SM) for Phase I of the study and tested for significant differential changes over this six-week time period. Despite the doubling of the num-

Table 4
Mean (*SD*) standard scores changes in achievement, reading, phonological and language across intervention groups

	Group 1 FFW ($n = 12$)	Group 2 SM ($n = 14$)	Group 3 FFW–SM ($n = 15$)	Group 4 SM–FFW ($n = 11$)	Group 5 reg. education ($n = 13$)	All groups combined ($n = 65$)
Phonological skills						
WJ-R Auditory Processing	3.42 (11.52)	7.00 (8.94)	7.53 (10.66)	10.00 (5.74)	5.69 10.86)	6.71 (9.77)
RAN-phonological Retrieval	−0.06 (0.26)	−0.08 (0.62)	0.04 (0.37)	−0.10 (0.42)	−0.02 (0.38)	−0.04 (0.42)
Reading & spelling skills						
WJ-R Letter–Word Identification	1.58 (7.56)	0.78 (5.58)	4.53 (2.72)	2.45 (3.14)	3.08 (3.80)	2.54 (4.88)
WJ-R Word Attack	3.42 (9.72)	3.00 (7.26)	4.27 (6.82)	2.91 (5.79)	1.31 (8.80)	3.02 (7.61)
WJ-R Passage Comprehension	2.17 (6.18)	4.50 (6.76)	2.73 (8.26)	6.27 (9.49)	−0.92 (8.86)	2.88 (8.07)
WRAT-3 Spelling	−2.58 (7.33)	4.50 (5.05)	−0.80 (4.30)	2.36 (5.30)	2.31 (6.07)	1.17 (6.02)
Language skills						
CELF-3 Receptive Language	3.42 (9.69)	9.07 (11.91)	5.73 (9.89)	5.64 (10.41)	4.15 (11.19)	5.69 (10.52)
CELF-3 Expressive Language	5.25 (10.60)	9.64 (10.82)	3.53 (10.70)	6.27 (10.07)	9.15 (7.29)	6.75 (9.99)

WJ-R, Woodcock–Johnson Psycho-Educational Battery, Revised.
WRAT-3, Wide Range Achievement Test, 3rd Ed.
RAN, Rapid Automatized Naming.
CELF-3, Clinical Evaluation of Language Fundamentals, 3rd Ed.
Standard score differences are presented for each measure (based on test scores with a mean = 100, $SD = 15$) with the exception of RAN, which is based on z-score changes in rank (mean = 0, $SD = 1$).

ber of subjects in the FFW and SM groups, this analysis also failed to show a significant between-group effect over the 6-week time period [$F(4,47) = 2.162$, $p = .088$].

The effects of intervention were measured with changes in age-based standard scores, as difference scores provide a norm-referenced and easily understood way to quantify change. It is noted, however, that standard score differences can obfuscate genuine improvement in times of rapid development, if changes due to intervention do not keep up with changes due to normative maturation.

Finally, although students were assigned to work with FFW for specific time durations each school day, we examined the possibility that our negative findings resulted from relatively less exposure to the FFW intervention due to other factors (e.g., student non-compliance). However statistical testing on the overall hours of direct participation in the computer-administered interventions across Groups 1–4 over the duration of the study revealed no between-group differences that could account for the lack of intervention-driven gains [$F(3,48) = 1.996$, $p = .13$].

3.5. Summary of results

Together these results demonstrate that although all groups made gains on all measures of language and reading over the duration of the study, the experimental treatment group (Group 1, made up of two interventions of Fast ForWord®) failed to result in any greater changes when compared to the other groups, including the active control group (Group 2) or developmental control group (Group 5) as seen in Table 4. Likewise, the crossover intervention groups (Groups 3 and 4) yielded no statistically significant differences in comparison to the regular education group (Group 5) or to one another. The lack of a positive finding in favor of Fast ForWord® could not be explained by a difference in the amount of time spent receiving the intervention.

4. Discussion

The purpose of this study was to evaluate the efficacy of FFW in bringing about gains in language and reading and to replicate laboratory-based findings in a middle school setting with a demographically diverse sample of children. Our experimental design allowed us to assess progress made by the children receiving FFW in comparison to those made by children engaged in another, non-temporally modified computer-driven program, thereby providing an active control group. In addition, our experimental design included children participating in the regular education curriculum for middle school poor readers, allowing us to control for developmental changes and for test–retest effects on the pre- and post-intervention measures. Our results fail to support claims that FFW has a specific beneficial effect on language skills (Merzenich et al., 1996; Tallal et al., 1996) and reading performance (Temple et al., 2003). Rather, we found that all children made gains over time and that those made by groups who received FFW were no greater than the gains made by children who participated in the other computer program, or those who received nothing other than the school's curriculum. These results are important as they suggest that beneficial outcomes observed in children engaged in the use of FFW or SM, may not be the results of the intervention at all, but in fact are just as likely to occur during regular school instruction without these programs.

These findings are inconsistent with earlier reports on the prototype of FFW published by Tallal and colleagues (Merzenich et al., 1996; Tallal et al., 1996), but consistent with some of the more recent findings that have emerged since the commercial version of FFW became available for independent research (Agnew et al., 2004; Cohen et al., 2005; Friel-Patti et al., 2001; Gillam et al., 2001; Hook et al., 2001). Initially, strong positive results were reported by Tallal, Merzenich and colleagues based on laboratory studies involving young children (Merzenich et al., 1996; Tallal et al., 1996). These initial studies did not directly assess changes in reading and reading-related skills, although it was suggested that FFW would have beneficial effects for individuals with dyslexia. Indeed, Temple and colleagues (2003) subsequently found that following FFW intervention, children made significant gains in reading (for example, on measures of Word Identification and Word Attack). The same studies also demonstrated changes in brain activity (using functional MRI) associated with the intervention during a phonological processing task, but a dyslexic control group was not included in the study design.

Due to the claim that FFW has remedial effects on both written and oral language, the present study included measures of both domains. Further, the sample was heterogeneous with regard to performance across these measures; although the children were identified by their teachers based on their poor reading performance, many of these children also had low performance on measures of oral language. The sample is therefore highly representative of children who would typically be considered suitable candidates for FFW intervention in the public school system or in private clinics and FFW is marketed to this type of population of adolescents. Our results, however, showed that even when provided with a double trial of FFW, these children failed to make gains in reading or language skills that were greater than the other groups in this study. Our sample of 65 children is larger than most peer-reviewed research published on FFW, and it is consistent with results recently reported in a similarly-sized, randomized, controlled study of FFW, investigating language outcome in a group of children younger than those in the current study (Cohen et al., 2005).

Our results compel us to consider explanations for why our findings were not more positive. One obvious explanation is that the scientific framework under which FFW was developed is flawed and that the underlying model of how the brain processes acoustic properties of speech in typical and impaired individuals may be in error. This issue has been widely debated (Marshall, Snowling, & Bailey, 2001; Rosen, 2003; Snowling et al., 1986; Studdert-Kennedy, 2002; Studdert-Kennedy & Mody, 1995) and will not be discussed further here. However, there have been numerous suggestions of why the intervention results reported by Tallal, Merzenich and colleagues may not be reproducible. For example, it has been suggested that in the original studies, the activities conducted with a clinician rather than activities with modified speech sounds might be the source of the gains (Gillam, 1999). Commercial use of FFW does not involve the employment of a clinician as an extension of the computer work. Also, there have been concerns as to whether gains in rapid auditory processing actually generalize to skills of reading and language, or if the FFW games effectively "trained to the task;" hence improvement on measures similar to the games should be expected. Finally, experimental designs showing significant gains may lack a format of rigorous treatment trials, possibly leading to false positives. For example Temple et al. (2003), reported gains in reading, but did not include a dyslexic control group and therefore did not control for the "treatment" effect (Temple et al., 2003). Instead, the analysis was based on pre- versus post-test data, and the limitations of this approach have been discussed elsewhere (Gillam, 1999). Taken together, it seems that the early scientific conclusions were drawn prematurely from studies with a small number of participants, without the necessary control groups and without the appropriate outcome measures.

It is worthwhile to take other factors into consideration which could account for why our results did not concur with those obtained by Tallal, Merzenich and colleagues. Our study focused on a group of children slightly older than those reported in the original behavioral studies. An age difference raises the possibility that our failure to replicate gains could be attributed to age-related issues. However, the possibility that the FFW theoretical framework is inappropriate for adolescent readers is unlikely. First, there is no evidence to suggest that Tallal's auditory temporal processing theory does not generalized to a population of children entering puberty, even though they might be undergoing developmental cortical maturation (Giedd et al., 1999). Second, the work by Temple and colleagues (2003) did include some children above 10 years of age. Thirdly, the same authors report on an absence of the left prefrontal activity (measured with functional MRI) in response to rapidly changing (relative to slowly changing) nonlinguistic acoustic stimuli in dyslexic adults. Importantly, two of the adults with dyslexia who underwent FFW training showed associate changes in brain activity (Temple et al., 2000). On the other hand, in an adolescent population, motivational and self-efficacy factors may play a significant role in limiting the effectiveness of intensive, solo, computer-driven interventions (see Alvermann & Phelps, 2004; Mathewson, 1994), as the population in our study frequently requested peer-interaction. It is also noteworthy that in younger children reading acquisition tends to be constrained by phonological processing demands of word recognition and decoding, whereas different skills and processes, such as vocabulary development and comprehension skills, may account for poor reading skills in middle school students, adolescents, and adults (McCardle, Scarborough, & Catts, 2001). Although these developmental issues need to be taken into consideration when interpreting the results from the current study, previous work has shown adult gains in response to FFW (Temple et al., 2000) and in response to phonological based training approaches (Eden et al., 2004). Finally, our results demonstrate that struggling readers can make gains. Indeed the effect sizes for the entire sample ($n = 65$) were surprisingly large (e.g., 0.33 for WJ-R Auditory Processing and CELF-3 Expressive Language), but this change was not driven only by the FFW intervention. Rather, the fact that all groups made equally large changes over time suggests that these gains were due to other factors, such as a general developmental spurt, test-retest effects, or because circumstantial influences led to increased effort (e.g., Hawthorn Effect, whereby people's behavior or performance temporarily changes as a result of being observed in a study). While the exact cause or causes for these gains cannot be determined with certainty, we can rule out the possibility that they were driven by the experimental FFW or SM intervention. This finding emphasizes the importance of the inclusion of control groups, without which our observations could have been misinterpreted as treatment-driven gains.

In summary, this randomized, controlled, investigation revealed no differential gains on measures of language and reading following the administration of a computer-administered intervention program, Fast ForWord®, in middle school students with low reading achievement. Although children made gains following the intervention, the increases were no greater than those made in response to either a standard regular education reading curriculum or another computer-based program without acoustic manipulation of the stimuli presented. These findings suggest that Fast ForWord® should not be considered appropriate for all students with language and/or reading deficits (and the same is true for SM). Future studies are needed to reveal the characteristics of students for whom Fast ForWord® is beneficial.

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