Effects of Computer-Based Intervention Through Acoustically Modified Speech (Fast ForWord) in Severe Mixed Receptive–Expressive Language Impairment: Outcomes From a Randomized Controlled Trial

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Seventy-seven children between the ages of 6 and 10 years, with severe mixed receptive–expressive specific language impairment (SLI), participated in a randomized controlled trial (RCT) of Fast ForWord (FFW; Scientific Learning Corporation, 1997, 2001). FFW is a computer-based intervention for treating SLI using acoustically enhanced speech stimuli. These stimuli are modified to exaggerate their time and intensity properties as part of an adaptive training process. All children who participated in the RCT maintained their regular speech and language therapy and school regime throughout the trial. Standardized measures of receptive and expressive language were used to assess performance at baseline and to measure outcome from treatment at 9 weeks and 6 months. Children were allocated to 1 of 3 groups. Group A ($n = 23$) received the FFW intervention as a home-based therapy for 6 weeks. Group B ($n = 27$) received commercially available computer-based activities designed to promote language as a control for computer games exposure. Group C ($n = 27$) received no additional study intervention. Each group made significant gains in language scores, but there was no additional effect for either computer intervention. Thus, the findings from this RCT do not support the efficacy of FFW as an intervention for children with severe mixed receptive–expressive SLI.

KEY WORDS: computer applications, Fast ForWord, language disorders, randomized controlled trial

Specific language impairment (SLI)—language delay that cannot be accounted for in terms of nonverbal ability, hearing impairment, behavior or emotional problems, or neurological impairments (Plante, 1998; Stark & Tallal, 1981)—affects some 6% of children of school age (Law, Boyle, Harris, Harkness, & Nye, 2000). The problems tend to persist and be associated with adverse outcome, not only for language development (e.g., Conti-Ramsden, Botting, Simkin, & Knox, 2001; Johnson et al., 1999) but also for literacy and academic progress (e.g., Bishop & Adams, 1990; Catts, 1993; Catts, Fey, Tomblin, & Zhang, 2002; Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998); self-esteem; and behavior (e.g., Baker & Cantwell, 1987).

SLI with a receptive language component in particular appears to be more refractory to treatment than specific expressive or phonological delays (e.g., Law et al., 2000). A recent meta-analysis conducted by Law, Garrett, and Nye (2003) confirmed that although the reviewed evidence from randomized controlled trials showed a positive effect for speech and language therapy for children with expressive language, phonological, and vocabulary difficulties, there is insufficient evidence to claim that intervention has positive effects for children with receptive language difficulties.

An understanding of the underlying mechanisms that give rise to SLI is likely to be informative in designing an effective intervention, and researchers have reported evidence for a number of possible causes reflecting the broad spectrum of clinical features that the term describes (Conti-Ramsden, 2000). These include examples of specific deficits in grammatical structure (e.g., Rice, 2000; Van der Lely, 1996; Van der Lely & Stollwerck, 1997); in phonological working memory (Bishop, North, & Donlan, 1996; Gathercole & Baddeley, 1990; Montgomery, 1995; Snowling, Chiat, & Hulme, 1991); and in perceptual processing (e.g., Ahmed, Lombardino, & Leonard, 2001; Friel-Patti, Frome Loeb, & Gillam, 2001; Leonard, McGregor, & Allen, 1992; Stark & Tallal, 1981; Tallal, 1976, 2000; Tallal & Piercy, 1973a, 1973b; Tallal, Stark, & Curtiss, 1976; Wright et al., 1997).

Tallal and coworkers have termed these perceptual processing difficulties *temporal* processing difficulties, reflecting their hypothesis that basic temporal integration processes play a fundamental role in establishing neural representations for units of speech and processing nonverbal tones. Within this account, children with SLI are held to process auditory information at a slower rate than their typically developing peers. They therefore are disadvantaged when discriminating dynamic temporally cued components such as formant transitions that are brief in duration or rapid in succession (e.g., separated by short interstimulus intervals, usually in the range of tens of milliseconds). In support of the temporal processing theory, they have reported that SLI children require longer processing times to discriminate, sequence, and remember brief stimuli when followed by another stimulus (Tallal, 1976; Tallal & Piercy, 1973a, 1973b). This deficit, which is independent of sensory modality, included deficits in the perception of intrasyllabic acoustic stimuli that are characterized by a variety of brief or rapidly changing acoustic cues (Tallal, 2000).

Following the perceptual processing account of SLI, a speech-modification algorithm was used by Tallal and colleagues to amplify and temporally extend brief dynamic events in speech on the premise that this might alleviate the difficulty that such children have when processing these elements embedded in ongoing speech (Nagarajan et al., 1998). This algorithm was used to modify speech acoustically in both a range of materials for listening exercises (Tallal et al., 1996) and adaptive computer games (Scientific Learning Corporation [SLC], 1997, 2001). Impressive gains in temporal processing ability, phonological processing, and language comprehension were reported for language-learning-impaired children exposed to these games (Merzenich et al., 1996; Tallal et al., 1996). The researchers attributed these improvements to acoustic modifications of the stimuli. This conclusion was based on their gains relative to the gains of a control group, which took part in exactly the same games and listening exercises but without stimulus modifications. The control group, while making significant gains in performance, did so to a significantly lesser degree than did the experimental group. The adaptive computer games used in these studies were the prototypes for a series of four packages that use acoustically modified speech. These are commercially available from Scientific Learning Corporation (SLC; 1997, 2001) and are marketed as Fast ForWord.

The efficacy of one of the four packages, Fast ForWord—Language (FFW), designed to develop "oral language comprehension and listening skills" (SLC, 2003a), has been subsequently examined in both single-case and small-series studies where the outcomes have been variable (Friel-Patti, Frome Loeb, & Gillam, 2001). Tallal's research group also has conducted further nonexperimental studies on the effect of exposure to these adaptive games in large clinically hetereogeneous populations of over 500 children. They report very substantial improvements in receptive and expressive language scores, with some 90% of the participants achieving gains equivalent to standardized effect sizes of > 1.0 based on pre- versus posttraining performance on standardized tests of speech, language, or auditory processing (Tallal, 2000).

More recently, there has been considerable interest in the effects of FFW training on reading achievement. Research reveals that students with dyslexia, age 8–12 years, made sizable gains in phonological processing skills related to reading after FFW training (Habib et al., 2002; Temple et al., 2003). Interestingly, Temple et al. reported that these gains were mirrored by posttraining increases in the levels of brain activation in the left temporal–parietal cortex, left inferior frontal gyrus, right hemisphere frontal and temporal areas, and anterior cingulate gyrus. Field studies in some 18 school districts from across the United States reported by SLC (2003b, 2004b), including at-risk participants in urban areas, also revealed gains in phonological awareness, phonological memory, rapid naming, vocabulary, and reading comprehension in response to FFW. SLC now promotes FFW training as being of value also to children with reading difficulties.

Notwithstanding this evidence for positive treatment effects, FFW has been a source of great and continual controversy, especially as a treatment for a temporal processing deficit (Studdert-Kennedy & Mody, 1995). With regard to the underlying theory of the program, some researchers have been unable to replicate key findings that serve as the basis for FFW (e.g., differential adverse effects of backward masking on children with SLI relative to controls, as reported by Wright et al., 1997). They argue that the difficulty in distinguishing contrasting stimuli such as /ba/ and /da/ arises from their phonetic similarity rather than a general difficulty in processing acoustic cues such as transitional formants (Bishop, Carlyon, Deeks, & Bishop, 1999; Mody, 2003; Mody, Studdert-Kennedy, & Brady, 1997). Recent reviews of the evidence in regard to dyslexia and SLI by Rosen (2003) and Troia and Whitney (2003) also cast doubt on the rapid auditory temporal processing account, arguing that auditory deficits are correlated with language disorders but are not necessarily causal of them. Further, Wright, Bowen, and Zecker (2000) highlight the degree of individual variation in perceptual tasks and the multidimensional nature of reading and language disorders.

The strength of the evidence regarding the efficacy of FFW has been a further source of debate, with Gillam (1999) identifying a series of methodological problems with the study reported by Tallal et al. (1996). In addition, while improvements in auditory processing and phonological tasks are generally reported, other studies have failed to find statistically significant levels of generalization to standardized measures of reading or to tasks such as reading of nonwords (Agnew, Dorn, & Eden, 2004; Beattie, 2000; Hook, Macaruso, & Jones, 2001; Troia & Whitney, 2003). The complexity of FFW also is problematic in terms of which components of the program actually contribute to positive outcomes. Nonetheless, reported gains in oral language scores for children enrolled in the FFW program appear to be a significant advance over those seen with other types of interventions. For this reason, it is important to study the effect of exposure to FFW games through the design of a randomized controlled trial with blind assessment of outcome, in line with recommendations on levels of evidence (Sackett, Straus, Scott-Richardson, Rosenberg, & Haynes, 2000). In this article, we report the findings of such a trial, which focuses on children with mixed receptive–expressive SLI.

Method

Project Design

This study used a multicenter randomized controlled trial (RCT). It was implemented with blind assessment of outcome by qualified speech-language pathologists (SLPs), who were not otherwise involved in the project. To avoid the effects of bias arising from dropout and withdrawal, children entered the study on an intention-to-treat basis. Here, outcomes from all of the children originally allocated to each condition are compared, regardless of whether they participated in their allocated treatment or completed their postbaseline assessments. Randomization by center was conducted by personnel who were not otherwise involved in the research project. Children were randomized to one of three groups: Group A, a home-based intervention with FFW; Group B, a home-based intervention with computer-based activities using unmodified speech stimuli; and Group C, acting as a control. All children continued with their regular speech-language therapy and school regime throughout the study.

Sample size was determined on the basis of a large standardized effect size of 0.80. This is a more conservative effect size than that reported by Tallal et al. (1996), who obtained a standardized effect size of 0.95 while using a precursor to FFW. With three groups, three time points, $\alpha = .05$, $\beta = .80$, and a two-tailed test of significance (Cohen, 1988), the required sample was estimated at 79 participants.

Ethical Approval

Ethical approval for the study was granted by the Multi-Center Research Ethics Committee for Scotland and the appropriate education authorities.

Participants

Potential participants were referred by SLPs and pediatricians. Participants had to be 6–10 years of age, monolingual English speakers, and have a diagnosis of receptive SLI to be eligible for the study. Other inclusion criteria included absence of neurological deficits or pervasive developmental disorders, documented normal hearing sensitivity, a Nonverbal IQ score of greater than 80 on the British Ability Scales: Second Edition (BAS II; Elliot, 1996) or Raven's Coloured Progressive Matrices (Raven, Court, & Raven, 1995), and a Receptive Language score of less than –1.30 standard deviations on the Clinical Evaluation of Language Fundamentals—Third Edition UK (CELF–3^{UK}; Semel, Wiig, & Secord, 2000). *Z* scores were used to convert percentile scores on the Coloured Progressive Matrices (Raven et al., 1995) to a scale with a mean of 100 and a standard deviation of 15. An additional prerequisite for all participants was access to a landline telephone service at home for Internet linkup with FFW. Parents were not required to have any computer experience or computer hardware; technical support

Table 1. Participants by group, gender, and age.

Group	Male *n*	Female *n*	Age range (months)	*M*	*SD*
Group A (Fast ForWord)	16	7	72–119	88.13	15.43
Group B (computer software)	22	5	72–117	89.19	14.52
Group C (control)	17	10	72–117	89.33	12.90
Total	55	22	72–119	88.92	14.08

and the necessary equipment were provided at no expense to each participant.

In evaluating participants for eligibility, 194 children were referred to the project. Among this group, 106 children failed to meet the eligibility criteria, and the parents of 9 suitable children declined to allow their child to participate. Thus, 77 children met the eligibility criteria for this study (2 below the target sample size of 79) and were randomized to one of the three treatment groups. Details of the gender and age of the participants in each group are shown in Table 1.

Instrumentation

Details of the language assessment battery used are shown in Table 2, with a rationale for their inclusion in the study.

Computer Arms of the Study

FFW is not currently licensed for commercial use in the United Kingdom; however, SLC permitted its use for this research study. The research SLPs were trained and certified as FFW providers using the normal commercial procedures. Parents of children randomized to Group A or B were supplied with an Apple I-Book laptop computer (with relevant software installed) for the duration of the intervention. FFW enrollment fees and Internet access were paid for by the project. Parents received face-to-face training from research SLPs on the use of the computers in their homes. Children were instructed to play the assigned computer games for approximately 90 min, 5 days a week, for 6 weeks, under parental supervision. This is the time scale suggested by SLC for FFW. Miller, Linn, Tallal, Merzenich, and Jenkins (1999) have reported that the outcome of treatment, as measured by formal tests, can be predicted reliably after 20 days of FFW intervention. Regular contact was maintained between the researchers and the parents through home visits and telephone support. Parents contacted a research SLP throughout the project when difficulties arose.

SLC has advised the use of an extrinsic reward system to maintain motivation for children playing FFW, and rewards were used for both Group A and Group B. The amount of time spent playing the games was recorded for both of the intervention groups.

Details of the Groups

Group A: FFW. FFW is an interactive, computer-based program for which the type of game and the game level are controlled by SLC in response to the child's daily performance (www.scilearn.com). As part of this study, parents were trained to upload FFW data to the SLC Web site through an Internet connection. Integral to the collection of these data are measures of each child's exposure to the games, including duration played (minutes per day) and days played. Progress on the exercises was monitored by the research SLPs on a daily basis and copied to parents at regular intervals.

SLC (2000) also attributed a compliance score, measured on a scale of 1 to 10, to each child, with a higher score indicating better compliance. This "schedule score" is defined in the following way:

> The schedule score is calculated by comparing the participant's actual training schedule with the established training schedule. (SLC, 2002, p. 105)

The approved training, or exercise, schedule provided by SLC for use in this study, which also formed the basis for calculating schedule scores, was as follows:[1]

> On days one through three, participants train on three exercises (a total of 60 minutes of training). On the fourth and fifth days, participants train on four exercises (a total of 80 minutes of training). Starting with the sixth day, participants train on five exercises (a total of 100 minutes of training). (SLC, 2000, p. 95)

SLC also provides the following additional information about the interpretation of the schedule score:

> Research conducted by Scientific Learning shows that benefits from the training program are related to the established training schedule.

[1]Although SLC has more recently updated and extended the number of approved training protocols for FFW to four (see SLC, 2004a, for further details), the protocol that they provided for users during the period of the present study continues as one of the recommended options.

Table 2. Measures used in the language assessment battery.

Assessment	Rationale for inclusion	Measures used in analysis
CELF–3[UK] (Semel, Wiig, & Secord, 2000).	The Clinical Evaluation of Language Fundamentals—Third Edition UK is used as a clinical tool for the assessment and evaluation of language skills in children, adolescents, and young adults. For children age 6–8 years, 3 subtests (i.e., Sentence Structure, Concepts and Directions, and Word Classes) combine to give a Receptive composite score, while for the Expressive composite score, Word Structure, Formulated Sentences, and Recalling Sentences form the core subtests. Children older than 9 years take the Concepts and Directions, Word Classes, and Semantic Relations scales to give a Receptive composite score and Formulated Sentences, Recalling Sentences, and Sentence Assembly for an Expressive composite score. Thus, for each child, a number of different language skills are assessed in the core CELF–3[UK] components. The test was standardized in the U.K. and included a sample of Scottish children.	Receptive Language standard score Expressive Language standard score Total Language standard score
TOLD–P:3 (Newcomer & Hammill, 1997)	The Test of Language Development—Primary, Third Edition, comprises 6 core and 3 supplemental tests. To minimize testing, we selected two core subtests as outcome measures: Picture Vocabulary, which measures the extent to which a child understands the meanings associated with spoken English words, and Grammatic Understanding, which assesses the child's ability to comprehend the meaning of sentences, with the primary emphasis on grammatical aspects of the sentence. These two subtests provided additional single-word and connected-speech information about the child's comprehension skills.	Difference between chronological age and age equivalent in the Picture Vocabulary and Grammatic Understanding tasks.
PhAB (Frederickson,Frith, & Reason, 1997)	The Phonological Assessment Battery is designed to assess phonological processing. For our purposes, phonological-awareness skills were derived from performance on the Alliteration test, the Rhyme test, and the Spoonerisms test. While the test manual includes Non-word Reading in its phonological-awareness grouping, many of our SLI children did not reach the minimum raw score, and thus, we were unable to derive an actual standard score on their performances.	Standard scores for Alliteration, Rhyme, and Spoonerisms
BAS II Word Reading Scale (Elliot, 1996)	The British Ability Scales: Second Edition Word Reading Scale was one of the achievement scales. They assess decoding of printed words.	Standard score
Bus Story Test (Renfrew, 1997)	The Bus Story Test is widely used in clinics in the U.K. Its primary aim is to assess the ability to give a coherent description of a continuous series of events; it is a screening test of verbal expression skills and narrative.	Difference between chronological age and age equivalent for Information, Sentence Length, and Number of Subordinate Clauses

The schedule score numbers are defined as follows:

- 8.5-10.0 greater than the national median
- 8.0-8.5 from the national mean to the national median
- 0-8.0 less than the national mean

The national mean and median are based on the schedule scores of participants in Scientific Learning's database (based on approximately 44,000 participants). The national mean reflects the national average (currently 8.0). The national median reflects the number below which 50 percent of the participants score (currently 8.5). Note: A low schedule score may be due to sick or vacation days (SLC, 2002, p. 105).

Group B: Computer software. Intervention B comprised six commercially available, age-appropriate educational software packages designed to encourage aspects of language development, as outlined in Table 3.

These packages were chosen following advice from a national educational advisory center. Children were given three packages per week and were encouraged to play each for 30 min a day, 5 days a week. The packages were rotated on a prearranged schedule. The minutes played on each day were logged on the computer using a customized program. The parents also recorded the days on which the games were played and minutes played.

Table 3. CD-ROM titles used by children in Group B.

Title	Publisher	Description
Tomorrow's Promise: Phonics and Spelling 1	Longmans	Open-exploration format. From word lists containing 16 words, several listening- and spelling-based activities in a farm-game setting with within-game rewards. Ranges from single word to sentence level.
Rhyme & Analogy A	Sherston Software/ Oxford University Press	This structured format has 12 story books with three tasks in each. Activities cover phonological awareness, reading, writing, and vocabulary.
Darby the Dragon	Broderbund	Open-exploration format. A narrative game with opportunities to develop phonetic, visual, and problem-solving skills in a language-rich environment.
Rhyme & Analogy B	Sherston Software/ Oxford University Press	Same format as Rhyme & Analogy A, with different stories.
Tomorrow's Promise: Phonics and Spelling 2	Longmans	Same format as Tomorrow's Promise: Phonics and Spelling 1 with different word lists.
Matti Mole	Sherston Software/ Oxford University Press	A structured disk with opportunities for some open exploration. Story narrative incorporating 16 different activities, mainly in areas of grammar and morphology.

Group C: Control. The control group received no intervention from the study. The children were given similar extrinsic rewards during reassessments.

Group Equivalence at Baseline

Baseline measures for each group are shown in Table 4. One-way analyses of variance (ANOVAs) were carried out on these baseline measures to evaluate and compare the group scores.

The results confirmed that there were no significant differences among the three groups in regard to age, Nonverbal IQ, the CELF–3^{UK} Receptive Language score, CELF–3^{UK} Expressive Language score, CELF–3^{UK} Total Language score, Phonological Assessment Battery (PhAB; Frederickson, Frith, & Reason, 1997) Alliteration standard score, PhAB Rhyming standard score, PhAB Spoonerisms standard score, BAS II Word Reading standard score, Bus Story Test Information score, Bus Story Test Sentence Length score, Bus Story Test Subordinate Clauses score, Test of Language Development—Primary, Third Edition (TOLD–P:3; Newcomer & Hammill, 1997) Vocabulary score, or TOLD–P:3 Grammar score, all Fs(2, 74) < 2.58, all ps > .08. The randomization procedure thus achieved equivalence across the three groups with regard to pretreatment scores, which also reveal that the participants in all three groups had severe mixed receptive–expressive SLI, with CELF–3^{UK} scores for both receptive and expressive language on average –2 *SD*s below the mean.

Outcomes

Outcomes were measured at 9 weeks post-baseline assessment and at 6 months follow-up by qualified SLPs who had no other involvement in the project. The primary outcome measures were the Receptive, Expressive, and Total Language scores of the CELF–3^{UK}. Secondary outcome measures were the TOLD–P:3 Picture Vocabulary and Grammatic Understanding components (Newcomer & Hammill, 1997), the PhAB (Frederickson, Frith, & Reason, 1997), the BAS II Word Reading standard score (Elliot, 1996), and the Bus Story Test (Renfrew, 1997).

Results

Computer Games Exposure

Shown in Tables 5 and 6 are the details of exposure to computer games for children in Groups A and B, respectively. Considerable variability in the time spent on FFW and computer games is evident in these data. One-way ANOVAs revealed no significant differences between the two groups in regard to the number of days played, $F(1, 48) = 1.73$, $p = .195$; total number of minutes played, $F(1, 48) = 3.38$, $p = .072$; or average number of minutes played per day, $F(1, 48) = 3.01$, $p = .089$.

Outcome Measures

Shown in Table 7 is a summary of mean baseline, 9-week, and 6-month follow-up data. Details of missing data are summarized in Table 8.

Intention-to-treat analyses (Chalmers, 1998) were carried out to minimize the bias that can arise from withdrawal or dropout. The procedures used to deal with missing data, for which the child was unwilling or unable to complete the assessment task, were as follows:

(1) Four missing pretest scores for secondary outcome measures for 3 children (all from Group B) were imputed by means of Expectation Maximization (SPSS for Windows, Release 11.5.0).

Table 4. Summary of baseline measures for each treatment group.

Measure	Mean pretreatment score		
	Group A Fast ForWord–Language (n = 23)	Group B Computer (n = 27)	Group C Control (n = 27)
Nonverbal IQ/IQ equivalent[a]	100.26	98.11	95.96
SD	13.60	11.85	13.40
CELF–3[UK] Receptive Language[b]	68.74	69.19	68.59
SD	3.72	4.91	5.22
CELF–3[UK] Expressive Language[b]	67.74	68.22	68.19
SD	3.93	5.44	4.81
CELF 3[UK] Total Language[b]	66.43	67.15	66.41
SD	3.33	3.90	3.37
PhAB Alliteration[b]	81.13	80.63	79.78
SD	10.86	10.19	9.32
PhAB Rhyming[b]	80.74	80.81	82.78
SD	11.30	11.26	10.37
PhAB Spoonerisms[b]	83.96	84.41	80.33
SD	6.77	8.03	6.58
BAS II Word Reading[b]	87.70	84.22	79.52
SD	15.57	10.10	12.40
Bus Story Test Information[a]	−33.43	−34.93	−31.30
SD	14.12	13.77	14.34
Bus Story Test Sentence Length[a]	−23.43	−31.26	−24.37
SD	13.95	15.11	17.38
Bus Story Test Subordinate Clauses[a]	−36.91	−41.30	−41.00
SD	14.45	12.05	11.97
TOLD–P:3 Vocabulary[a]	−29.70	−19.33	−23.00
SD	16.97	18.64	17.63
TOLD–P:3 Grammar[a]	−17.65	−23.78	−17.11
SD	14.60	18.66	15.51

Note. Three children did not complete the full pretreatment assessment battery: 1 child in Group B failed to provide scores for PhAB Rhyming and Spoonerisms, and there were missing scores for BAS II Word Reading for 2 other children, both in Group B. Missing value analysis (SPSS for Windows, Release 11.5.0) was used to generate imputed values for these three missing data points by means of Expectation Maximization.

[a]score. [b]standard score.

(2) Missing data from the 9-week collection point were replaced by the individual's baseline score for the appropriate measure (for 26 scores from 9 children, 2 in Group A, 3 in Group B, and 4 in Group B).

(3) Missing data from the 6-month follow-up were replaced by data from the 9-week collection point where available (for 22 scores for 7 children: 1 in Group A, 4 in Group B, and 2 in Group C) and by all 12 baseline scores in the case of 1 child in Group B, who participated only in the first assessment stage (see Table 8).

A series of 3 × 3 mixed-design ANOVAs were used to analyze the data, with group (FFW vs. computer software vs. control) as the between-group variable and data-collection point (baseline vs. 9 weeks vs. 6 months) as the within-group variable. Because of the equivalence of the pretreatment scores, the Group × Data-Collection Point interaction provides a measure of any postbaseline between-group differences resulting from intervention (Zhang & Tomblin, 2003). Separate ANOVAs were carried out for each outcome measure in view of the relatively small number of participants in each group and multivariate tests used for within-group effects.

Consider first the effectiveness of FFW. The crucial Group × Data-Collection Point interaction shown in Table 9 failed to reach significance for any of the primary outcome measures from the CELF–3[UK], all Fs(2, 74) < 1.85, ps > .12, indicating that there were no between-group differences in postbaseline scores. Only one significant Group × Data-Collection Point interaction was observed, that for the PhAB Rhyming subtest score (p = .007). The source of this interaction was explored using an analysis of simple effects and t tests. The results revealed that Group A, those children

Table 5. Group A exposure to Fast ForWord computer games.

Case ID	Days played	Minutes played	Minutes played per day		Schedule score
			M	*SD*	
FF003	32	2,912	91.00	17.49	10.0
FF004	16	1,349	84.31	15.64	8.6
FF005	24	2,071	86.29	39.73	7.9
FF009	21	1,878	89.43	14.76	9.6
FF012	30	2,739	91.30	17.97	10.0
FF018	25	1,954	78.16	32.75	4.8
FF020	42	3,654	87.00	34.62	9.9
FF022	31	2,990	96.45	22.54	10.0
FF024	32	2,917	91.16	19.02	9.1
FF027	23	1,910	83.04	27.61	6.3
FF028	26	2,117	81.42	13.35	7.8
FF032	7	365	52.14	47.66	8.6
FF034	32	2,527	78.97	31.28	4.5
FF035	25	2,260	90.40	13.63	7.2
FF041	30	3,318	110.60	71.57	6.4
FF047	22	2,103	95.59	17.78	7.2
FF058	31	2,898	93.48	13.76	6.5
FF062	9	380	42.22	21.21	3.2
FF063	29	2,723	93.90	11.50	8.0
FF064	12	680	56.67	17.60	3.2
FF066	17	1,476	86.82	16.76	7.2
FF067	25	2,446	97.84	24.70	7.2
FF076	18	1,562	86.78	27.42	7.3
M	24.30	2,140.38	84.56		7.41
SD	8.36	881.03	15.37		2.04

Note. Unless stated otherwise, values are totals.

receiving FFW, had significantly higher scores for Rhyming at 6 months than did either Group B (p = .022) or Group C (p = .02). There were no significant differences between Groups B and C at 6 months ($p >$ .96) and no significant differences among the three groups at either baseline or 9 weeks ($p > .50$). Note, however, that one of the baseline Rhyming scores for Group B was imputed and that there were four missing scores for Rhyming at the 6-month follow-up: one from Group A, two from Group B, and one from Group C. Nonetheless, an analysis of complete test–retest Rhyming data from all three data-collection points (i.e., with no missing scores) also revealed higher scores for Group A at 6 months than for Group B (p = .034) or Group C (p = .027), with no differences among the three groups at earlier stages.

There also were no significant main effects of group for the primary outcome measures of Receptive Language scores, Expressive Language scores, or Total Language scores on the CELF–3^{UK}, all Fs(2, 74) < 1.00, all ps > .83. Similarly, there were no significant main effects of group for the other secondary outcome measures (all ps > .13). However, there were significant main effects of data-collection point, indicating that the participants made significant gains in scores over the baseline versus 9-week versus 6-month follow-up period. The results from the three groups combined revealed that significant improvements in scores were made by all three groups in the primary outcome measures of Receptive Language, Wilks's Λ = .588, $F(2, 73) = 25.57$, p = .0001; Expressive Language, Wilks's Λ = .876, $F(2, 73) = 5.17$, p = .008; and Total Language, Wilks's Λ = .784, $F(2, 73) = 10.07$, p = .0001, on the CELF–3^{UK}.

Progress on all other outcome measures was significant (ps < .05), with the exceptions of the BAS II Word Reading Scale, Wilks's Λ = .954, $F(2, 73) = 1.77$, p = .178; Bus Story Test Sentence Length, Wilks's Λ = .982, $F(2, 73) = 0.656$, p = .522; Bus Story Test Subordinate Clauses, Wilks's Λ = .994, $F(2, 73) = 0.236$, p = .790; and the TOLD–P:3 Vocabulary score, Wilks's Λ = .990, $F(2, 73) = 0.373$, p = .690.

Analyses of trend revealed significant gains in scores ($p < .05$) between the baseline, 9-week, and 6-month assessments and a leveling off of these gains in scores between the 9-week and 6-month assessments for

Table 6. Group B exposure to educational computer activities.

Case ID	Days played	Minutes played	Minutes played per day *M*	Minutes played per day *SD*
FF002	33	3,202	97.03	26.66
FF010	20	1,867	93.37	36.99
FF013	16	1,564	97.75	95.83
FF014	34	2,512	73.88	35.62
FF015	28	1,990	71.07	18.69
FF019	30	2,236	74.53	67.63
FF023	21	1,480	70.48	33.43
FF029	24	1,136	47.33	24.34
FF031	27	1,996	73.93	35.51
FF037	7	782	111.71	97.72
FF038	14	1,332	95.14	49.14
FF042	8	277	34.63	16.26
FF043	10	688	68.80	57.56
FF044	14	118	79.86	44.51
FF045	7	329	47.00	62.67
FF049	17	692	40.71	34.52
FF050	4	234	58.50	22.35
FF055	26	888	34.15	23.29
FF057	25	2,828	113.12	67.13
FF059	30	2,803	93.43	40.56
FF065	30	2,596	86.53	23.95
FF068	40	4,901	122.53	132.10
FF069	41	2,526	61.61	27.66
FF071	8	746	93.25	86.96
FF072	14	500	35.71	19.06
FF073	26	2,070	79.62	25.11
FF078	3	131	43.67	15.63
M	20.63	1,608.31	74.05	
SD	10.97	1,123.19	25.35	

Note. Unless stated otherwise, values are totals.

the Receptive Language ($p > .17$) and Total Language ($p > .13$) scores on the CELF–3[UK], the Alliteration and Rhyming scores on the PhAB, the Bus Story Test Information score, and the TOLD–P:3 Grammar score. In the case of Expressive Language, the baseline versus 9 weeks comparison just failed to reach statistical significance, $F(1, 76) = 3.80$, $p = .055$, although there was significant change in scores made between the baseline and 6-month assessment scores, $F(1, 76) = 10.60$, $p = .002$. Scores on the PhAB Spoonerisms subtest also showed significant change in scores between baseline and 9-week ($p < .0001$) and 9-week and 6-month assessments ($p = .018$). However, there was no evidence of significant improvement in scores in the case of Reading, Bus Story Sentence Length, Bus Story Subordinate Clauses, and the TOLD–P:3 Vocabulary scores (all p values > .068).

In the case of the primary outcome measures, mean postintervention scores from baseline to the 9-week and from baseline to the 6-month data-collection points for the Receptive Language scale exceeded the upper bound of the 95% confidence interval for mean preintervention scores for all three groups. This finding indicates that the improvement in the children's scores was unlikely to be due to test–retest error. Overall improvement in Expressive Language scores was more variable. For Groups A and C, only the mean postintervention scores for Expressive Language from baseline to 6-month follow-up were outside of the 95% confidence interval for mean preintervention scores, while the mean postintervention scores for Group B both from baseline to the 9-week and from baseline to the 6-month data-collection points exceeded the upper bound of the 95% confidence interval. Mean postintervention Total Language scores for Groups A and B both from baseline to the 9-week and from baseline to the 6-month data-collection points were outside the 95% confidence interval for preintervention scores. Only the mean postintervention scores from baseline to 6-month follow-up were outside of the confidence interval for Group C. This outcome raises the possibility that the Expressive Language score gains made across the initial pre- to posttest period by Groups A and C and the Total Language score gains made by Group C across the same interval may be accounted for by measurement error (Semel et al., 2000).

The relation between SLC's schedule scores and participants' language score gains was also examined. Correlations between schedule scores for the 23 participants in Group A and the improvements in their language scores failed to reach significance (all rs < .366, all ps > .086, two-tailed tests). Thus, there was no meaningful relation between the measure of engagement with FFW within the range of schedule scores observed and subsequent gains in language-assessment scores after either 9 weeks or 6 months.

The schedule scores were significantly, but only moderately, correlated with the measures of exposure used in the trial, namely, number of days played ($r = .423$, $p = .044$); minutes per day played ($r = .504$, $p = .014$); and total minutes played ($r = .479$, $p = .021$), which highlights the fact that the SLC schedule score metric is more than merely a measure of exposure. For Group A, the three time-based measures also were significantly correlated ($r = .693$, $p = .001$, for number of days and number of minutes per day; $r = .972$, $p = .0001$, for number of days and total number of minutes; and $r = .817$, $p = .0001$, for number of minutes per day and total number of minutes). Correlations between these exposure-time measures and improvements in language-assessment scores for Group A failed to reach significance for the gains in scores made between the baseline and 9-week data-collection points for primary outcome measures (all rs < .344, all ps > .107, two-tailed tests) and secondary outcome measures (all r values < .407, all p values > .054,

Table 7. Summary of outcome measures for all groups at baseline and at 9-week and 6-month follow-up: Intention-to-treat analysis.

	Mean baseline score			Mean posttreatment score			Mean follow-up score		
Outcome measure	Group A Fast ForWord (*n* = 23)	Group B Computer (*n* = 27)	Group C Control (*n* = 27)	Group A Fast ForWord (*n* = 23)	Group B Computer (*n* = 27)	Group C Control (*n* = 27)	Group A Fast ForWord (*n* = 23)	Group B Computer (*n* = 27)	Group C Control (*n* = 27)
CELF–3[UK] Receptive Language[a]	68.74	69.19	68.59	72.22	72.22	72.44	73.48	72.74	74.48
SD	3.72	4.91	5.22	6.04	8.79	5.77	8.06	9.12	6.87
CELF–3[UK] Expressive Language[a]	67.74	68.22	68.19	68.35	71.26	68.81	70.91	70.00	72.30
SD	3.93	5.44	4.81	5.83	9.65	4.80	7.60	7.57	8.41
CELF–3[UK] Total Language[a]	66.43	67.15	66.41	68.09	69.89	67.70	69.83	68.85	70.48
SD	3.33	3.90	3.37	5.19	7.90	4.41	7.48	7.48	6.38
PhAB Alliteration[a]	81.13	80.63	79.78	83.96	81.67	83.11	85.22	82.96	81.56
SD	10.86	10.19	9.32	10.85	11.30	10.43	12.25	11.97	10.63
PhAB Rhyme[a]	80.74	80.81	82.78	87.04	86.15	84.67	90.78	82.15	82.00
SD	11.30	11.26	10.37	12.33	13.34	12.43	15.96	11.63	11.57
PhAB Spoonerisms[a]	83.96	84.41	80.33	87.09	87.11	82.89	89.87	87.30	86.44
SD	6.77	8.03	6.58	8.04	9.09	8.55	8.49	9.80	8.97
BAS II Word Reading[a]	87.70	85.22	79.52	89.22	84.56	83.11	88.96	85.56	82.37
SD	15.57	11.43	12.40	18.81	10.95	12.01	19.64	13.68	12.25
Bus Story Information[b]	−33.43	−34.93	−31.30	−32.00	−29.96	−25.70	−28.61	−29.00	−23.07
SD	14.12	13.77	14.34	13.19	18.90	17.39	17.84	19.81	23.13
Bus Story Sentence Length[b]	−23.43	−31.26	−24.37	−26.91	−24.89	−20.26	−19.17	−31.70	−28.89
SD	13.95	15.11	17.38	16.49	18.06	23.23	17.42	17.56	23.10
Bus Story Subordinate Clauses[b]	−36.91	−41.30	−41.00	−36.00	−41.41	−39.41	−37.52	−43.33	−39.85
SD	14.45	12.05	11.97	19.82	13.76	17.60	14.17	16.54	19.75
TOLD–P:3 Vocabulary[b]	−29.70	−19.33	−23.00	−28.61	−25.04	−24.22	−23.30	−25.74	−24.52
SD	16.97	18.64	17.63	17.74	18.75	13.57	14.14	19.58	17.63
TOLD–P:3 Grammar[b]	−17.65	−23.78	−17.11	−14.43	−17.33	−11.78	−10.13	−15.74	−13.74
SD	14.60	18.66	15.51	14.70	16.18	17.10	15.91	14.21	15.36

Note. Missing baseline data from 3 participants were imputed by means of Expectation Maximization. (SPSS for Windows, Release 11.5.0). Missing data from the 9-week collection point have been been replaced by the individual's baseline score for the appropriate measure. Missing data from the 6-month follow-up have been replaced by data from the 9-week collection point (see Table 8).

[a]standard score. [b]score.

Table 8. Summary of missing data by group by collection point.

	Baseline			9-week retest			6-month follow-up		
Outcome measure	Group A Fast ForWord (*n* = 23)	Group B Computer (*n* = 27)	Group C Control (*n* = 27)	Group A Fast ForWord (*n* = 23)	Group B Computer (*n* = 27)	Group C Control (*n* = 27)	Group A Fast ForWord (*n* = 23)	Group B Computer (*n* = 27)	Group C Control (*n* = 27)
CELF–3[UK] Receptive Language[a]	0	0	0	1	1	0	0	2	0
CELF–3[UK] Expressive Language[a]	0	0	0	1	1	0	0	2	0
CELF–3[UK] Total Language[a]	0	0	0	1	1	0	0	2	0
PhAB Alliteration[a]	0	0	0	1	2	0	1	3	0
PhAB Rhyme[a]	0	1	0	1	2	0	1	2	1
PhAB Spoonerisms[a]	0	1	0	1	2	0	1	2	0
BAS II Word Reading[a]	0	2	0	1	2	1	0	3	1
Bus Story Information[b]	0	0	0	1	1	4	0	3	0
Bus Story Sentence Length	0	0	0	1	1	4	0	3	0
Bus Story Subordinate Clauses[b]	0	0	0	1	1	4	0	3	0
TOLD–P:3 Vocabulary[b]	0	0	0	0	1	0	0	2	0
TOLD–P:3 Grammar[b]	0	0	0	0	1	0	0	2	0

[a]standard score. [b]score

Table 9. Summary of Group × Data-Collection Point interactions for each outcome variable.

Outcome measure	Group x Data-Collection Point interaction		
	Wilks's Λ	*F*	*p*
CELF–3[UK] Receptive Language scale[a]	.979	0.40	.811
CELF–3[UK] Expressive Language scale[a]	.906	1.84	.124
CELF–3[UK] Total Language scale[a]	.932	1.31	.268
PhAB Alliteration scale[a]	.975	0.46	.762
PhAB Rhyme scale[a]	.827	3.65	.007*
PhAB Spoonerisms scale[a]	.957	0.81	.520
BAS II Word Reading Scale[a]	.929	1.38	.245
Bus Story Test Information scale[b]	.980	0.37	.828
Bus Story Test Sentence Length scale[b]	.893	2.13	.080
Bus Story Test Subordinate Clauses[b]	.992	0.14	.968
TOLD–P:3 Vocabulary scale[b]	.932	1.31	.267
TOLD–P:3 Grammar scale[b]	.967	0.61	.653

Note. For all *F*s, *df*s = 1, 146.

*$p < .01$.

two-tailed tests), with the exception of the significant correlation between the TOLD–P:3 Grammar score gains and number of minutes played per day ($r = .473$, $p = .023$, two-tailed test). A similar pattern of non-significant correlations was observed in the case of gains in scores between the baseline and 6-month follow-up data-collection points. The TOLD–P:3 Vocabulary scores also were an exception, with gains significantly but negatively correlated with number of days played, minutes per day played, and total number of minutes played (all *r*s > –.579, all *p*s < .004, two-tailed tests). This outcome indicates that children with less exposure to FFW tended to make more progress in their vocabulary scores over the 6-month test–retest period. However, the number of comparisons involved and the possibility of Type I statistical error (Cohen, 1988) should be considered.

A similar pattern of significant intercorrelations between the three exposure-time measures was observed in the case of Group B for total number of minutes and number of days and total number of minutes and minutes per day (all *r*s > .662, $p < .0001$, two-tailed tests). However, the correlation between number of days and minutes per day failed to reach significance ($r = .301$, $p = .127$, two-tailed test). The correlations for Group B between the exposure-time measures and improvements in language-assessment scores between the baseline and 9-week data-collection points for the primary and secondary outcome measures also failed to reach significance (all *r*s < .334, all *p*s > .089, two-tailed tests). Moreover, there were no significant correlations between the gains in scores between the baseline and 6-month follow-up data-collection points and measures of exposure to the computer activities (all *r*s < .357, all *p*s > .068) except for the Alliteration and Spoonerism scores from the PhAB and minutes per day and total number of minutes (all *r*s > .393, all *p*s < .043, two-tailed tests). Once again, the findings must be considered with some perspective because of the number of comparisons, the possibility of associated Type I error (Cohen, 1988), and the additional possibility of Type II error (Cohen, 1988) arising from the relatively small number of participants.

Discussion

This RCT reports on the efficacy of FFW for children who were recognized as having marked receptive–expressive language disorders and either were being educated in a specialized language unit (Botting, Crutchley, & Conti-Ramsden, 1998; Conti-Ramsden et al., 2001) or were receiving outreach support in their mainstream schools from their local SLP services.

The results from this RCT reveal that while not all of the children in the study made progress, overall, the three groups made statistically significant gains in the scores for the primary outcome measures of Expressive and Receptive Language on the CELF–3[UK] at both the 9-week and 6-month follow-up points. However, because the gains were also measured for children who had no computer intervention, these improvements in performance may be a consequence of the ongoing intervention that the children were receiving. Alternatively, measurement error may be a factor in the scores of Groups A and C for Expressive Language and for Group C for Total Language. Another possible explanation is a common practice effect across all three groups.

Thus, the results of this RCT are surprising in that they revealed no additional benefit in primary language outcomes for children exposed to the computer games (including those in Group A, who were randomized to the FFW program) beyond that achieved by the control group, who were not exposed to a computer-based management plan. The only hint of intervention benefit was derived at the 6-month follow-up for the rhyming skills of the children exposed to the FFW computer games. But as mentioned earlier, these findings may have been confounded by Type I statistical error (Cohen, 1988) and by the effects of missing data from 4 participants.

Our findings do not agree with previous indications from single-case study, small-series, and beta-site trials (Bedi, Miller, Merzenich, Jenkins, & Tallal, 1999; Friel-Patti, DesBarres, & Thibodeau, 2001; Frome Loeb, Stoke, & Fey, 2001; Gillam, Crofford, Gale, & Hoffman, 2001; Gillam, Frome Loeb, & Friel-Patti, 2001) in which the efficacy of FFW has been described. Our different results may simply be the outcome of the strength of the RCT methodology for obtaining reliable assessments in health care (Chalmers, 1998). It is also possible that our participants differed in some unknown but meaningful way from the group described in Tallal et al.'s (1996) original report, in which the participants were a part of a subgroup in which temporal processing difficulties predominated. We did not measure temporal processing abilities directly in this study because deficits in temporal processing are not held to be a prerequisite for undertaking FFW. Our participants had severe mixed receptive–expressive SLI. They were recruited from eight different centers in Scotland and had appropriate baseline measures of language skills and nonverbal IQ. The children in the three groups were comparable on a wide range of measures. We chose to study this group of children not only because the power of the study was enhanced by constraining the participants to a closely defined clinical group but also because children with a significant receptive component to their SLI stood to benefit most from new interventions (as their progress is often disappointing with conventional treatment; see Law et al., 2003). Therefore, there was seemingly nothing unusual about our participants that might suggest that they would be unresponsive to FFW. They did, however, have more marked difficulties than some children recruited to FFW training studies (Tallal, 2000; Troia & Whitney, 2003).

With regard to whether the children had inadequate exposure to the computer games, there was no evidence that this was a significant factor. The FFW program is demanding, and our participants were encouraged to play the games for an hour and a half on 5 out of 7 days each week for 6 weeks. We also adhered to the external reward system advised by SLC to encourage each child's continuing participation. None of the external measures of computer exposure, such as total time played or number of days on which the games were played (i.e., measures which could be common to both computer arms of the study), yielded any significant difference. There also were no significant positive correlations between these measures of computer exposure and outcome, apart from the changes in Alliteration and Spoonerism scores from the PhAB between the baseline and 6-month follow-up for Group B, which is consistent with other evidence in the literature (Wise, Ring, & Olson, 2000). Merzenich et al. (1996) reported significant improvements in temporal processing—and by implication language-learning improvements—for all children exposed to a prototype of one of the games within the FFW program (i.e., the nonverbal circus sequence) after a minimum of nineteen 20-min sessions over 4 weeks. Only 1 child in our Group A played the FFW games for less time than this in total (380 min) over 6 weeks. Merzenich et al. also demonstrated a highly variable number of trials for their 11 participating children, who all showed significant gains in outcome measures of temporal processing. SLC attributes a schedule score to children playing the FFW games, which presumably captures some of the variability in the number of trials. This score is updated online. It is derived from a comparison of the target child's individual performance with a predicted level of performance based on that of children who participated in the beta trials. Although the schedule score is possibly a measure of the target children's progress through the games, it did not predict outcome on the language measures in this study.

In conclusion, this is the first RCT of FFW conducted on an intention-to-treat basis with blind assessment of outcome. Children with receptive–expressive SLI who were assigned to the FFW package of adaptive computer games showed no significant additional benefit of intervention on our primary measures beyond that found for control group SLI children and SLI children allocated to a series of generic computer games. The findings would suggest that the FFW stimulus modifications are not sufficient in and of themselves to confer additional therapeutic benefit for children with these more severe forms of receptive–expressive SLI who are already receiving intensive specialist therapy and educational support.

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