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Improving early phoneme skills with a computer program: Differential effects of regulatory skills

Cornelia A.T. Kegel, Verna A.C. van der Kooy-Hofland, Adriana G. Bus *

Department of Education and Child Studies, Leiden University, The Netherlands

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ABSTRACT

Research findings: The study focused on 90 five-year-olds from fifteen Dutch schools. The children scored among the 30% lowest on literacy tests. Half were randomly assigned to a phonological skills program on the computer, the other half to a book program. Both programs consisted of 15 ten-minute sessions. During the phonological skills program children's mouse behavior was registered every tenth of a second. Intelligence, phoneme skills, and regulatory skills were tested. Children scoring average on regulatory skills benefited from teacher-free encounters with the phonological skills program, children scoring low or high did not. Typically, the lowest-scoring children showed more meaningless mouse activity and more random clicking. *Practice or policy:* Computer programs can be used to stimulate early phoneme skills of poorly performing kindergarten children, but not for all children. Children with poor regulatory skills did not benefit from the intervention program.

Dutch kindergarten children generally engage in literacy-related activities at home and in school. As a result most children develop some understanding of letter–sound relationships before formal reading instruction starts in first grade. However, not all children benefit equally from natural stimuli in their environments, partly as a consequence of poor regulatory skills (Bracken & Fischel, 2006; Gioia, Isquith, & Guy, 2001; Spira, Bracken, & Fischel, 2005).

Core regulatory skills are inhibitory control, working memory, and cognitive flexibility (Diamond, Barnett, Thomas, & Munro, 2007). Children with poor regulatory skills are less proficient in planning, organizing, and applying rules (Meltzer, 2007), are easily distracted and impulsive (Hughes, 2002), and have problems dealing with changing tasks (Moffitt, 1993). Whatever the causes – immaturity, neurological deficits, or child-rearing practices (Oh & Lewis, 2008; Ponitz et al., 2008) – we expected poor regulatory skills to interfere with the development of entry-level reading skills (Blair & Razza, 2007; Dally, 2006), and thought that regulatory skills would be better predictors of literacy skills than verbal or nonverbal intelligence (Diamond et al., 2007; Spira et al., 2005).

Knowing that computer programs can promote basic phoneme skills (Reitsma & Wesseling, 1998), we wanted the present study to test whether a cost-effective, 'teacher-free' computer intervention can provide purposive, additional practice in learning that phonemes in spoken words relate to letters in written words (e.g., Borstrom & Elbro, 1997; Byrne, 1998). We also studied differential effects of regulatory skills. Exposure to an individual training program on the computer might make too strong an appeal to regulatory skills, especially when these are comparatively poor in a child.

Five-year-olds with rather strong regulatory skills may not need an extra training program, but will achieve a ceiling in their performance as a result of a challenging daily environment that stimulates name writing, exposure to environmental print, and word games. However, we expected kindergarten children with intermediate to poor regulatory skills to be less able to benefit from incentives in their "natural" environment at home and in school, because they are less successful in inhibiting impulsive reactions and have more problems in planning and choosing the right steps to solve tasks (Diamond et al., 2007). Young children with poor regulatory skills need early interventions, but may profit less from interventions compared to same-aged children with intermediate regulatory skills.

Five-year-old participants eligible for treatment of phoneme skills played computer games once a week over a four-month period, 'teacher-free', i.e., without support from a teacher, peer, or other adult. By recording the position of the mouse on the screen every tenth of a second and also recording where the child clicked or hovered, we tested whether children with poor regulatory skills had more problems in planning and choosing the right steps to solve tasks. From recordings of mouse behavior we were able to derive how much time it took to solve the problems, whether random clicking and unnecessary mouse movements occurred, and how often the children resorted to the support and help functions of the computer program (Bippes et al., 2003).

* Corresponding author. Department of Education and Child Studies, Leiden University, P.O. Box 9555, 2300 RB Leiden, The Netherlands. Tel.: +31 71 527 1850; fax: +31 71 527 3619.
E-mail address: bus@fsw.leidenuniv.nl (A.G. Bus).

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The study addressed the following questions:

1. Is a computer program intended to fix attention on how written words relate to spoken words effective for children performing poorly on early literacy tests?
2. Do regulatory skills explain differential effects of the computer intervention program beyond verbal and nonverbal intelligence?
3. Are children's regulatory skills related to their computer behavior during the computer games?

1. Method

1.1. Participants

We selected 90 children out of 404 children from 15 schools. All selected children (a) spoke Dutch as their first language, (b) were 60 to 72 months old, and (c) were among the 30% with the lowest scores on screening tests for early literacy: a letter test, a rhyming test, name writing, and a word dictation test. Eligible pupils were randomly assigned by the main researcher to a condition, with the restriction that boys and girls, and children from the same school, were distributed about equally across the two conditions. Intervention and control groups were similar in age, gender, verbal (Peabody Picture Vocabulary Test; Schlichting, 2005), and nonverbal intelligence (Raven's Coloured Progressive Matrices; Van Bon, 1986). Groups differed marginally in parental education, $t(88) = -1.94$, $p < .056$ (Table 1). Children were very capable of using a mouse to operate the educational software, because computers were in use in the participating kindergarten classes.

1.2. Programs

1.2.1. Living Letters

The Internet program *Living Letters*, recently made available for schools and parents via subscription (www.Bereslim.nl), is aimed at practicing phoneme skills. The program uses the spelling of a familiar word like the child's name (Levin, Shatil-Carmon, & Asif-Rave, 2006) to draw attention to phonemes in spoken words (Bus & Van IJzendoorn, 1999; Ehri et al., 2001). The program uses the child's proper name unless the spelling is inconsistent with Dutch orthography (e.g., Chris or Joey). The program then switches to ‘mama’, another high-frequency name (Both-de Vries & Bus, 2008, in press). The first 20 games practicing the proper name and ‘mama’ (e.g., find your name; Fig. 1a and b) are followed by 10 games on the sound of the first letter (‘which one is the /m/ of mama?’; Fig. 1c), and 10 games to identify pictures that start or end with the first letter of the child's name or ‘mama’ (Fig. 1d). Each of the last 20 games is played twice in two consecutive sessions, thus constituting two-thirds of the program. All 15 sessions start with an attractive animation using two characters who explain the upcoming games; for instance, the two characters, Sim and Sanne, discover that their names start with the same sound. Errors when solving the games are followed by increasingly supportive feedback. First the task is repeated, next a clue is given (”Do you remember how the teacher writes your name?”), and lastly the correct solution is demonstrated.

Table 1
Descriptives of treatment (Living Letters) and control group.

	Living Letters ($n = 45$)		Control group ($n = 45$)	
Gender male/female	27/18		25/20	
	M	*SD*	*M*	*SD*
Age in months	64.67	3.25	64.58	3.33
Parental education (max = 8)	5.41	2.15	4.52	2.21
PPVT[a] (raw scores)	81.36	12.75	77.53	11.16
RCPM[b] (raw scores)	16.09	3.45	17.27	3.79
Screening				
- Letter knowledge (max = 10)	3.53	1.36	3.42	1.42
- Rhyming (max = 12)	9.98	2.19	9.29	3.15
- Writing *mama* (max = 6)	2.30	.93	2.39	1.11
- Writing words (max = 6)	2.24	.81	2.15	.75

[a] PPVT = Peabody Picture Vocabulary Test.
[b] RCPM = Raven's Coloured Progressive Matrices.

1.2.2. Living Books

The control group were given the Internet program *Living Books* (www.Bereslim.nl), made up of five age-appropriate picture storybooks on the computer. As text is orally available, children can “read” individually. Per session, the children “read” one book followed by questions. Each book was repeated three times.

1.3. Procedure

Fifteen sessions of approximately 10 min took place during morning hours at school over a four-month period (February–May). Children sat alone at the computer screen in their classroom or the computer room, with a headset on. Researchers logged children in on the Internet site and made sure they completed all fifteen sessions. A helpdesk was available for emergencies. After entering the child's name, the correct games appeared automatically and the session was discontinued after four games. When a child received all available feedback a game took at most 90 s extra. Mouse behavior was written to the data store of the provider and saved.

With written consent from parents three assessments took place: a pretest, a mid-test (for testing regulatory skills) after about 8 weeks, and a posttest immediately after the intervention. Each session took approximately 25 min. Testing took place in a room where only the child and examiner were present. In most cases the four Master's students who did the testing were blind to group allocation. The order of the tests was always the same, except for regulatory skills: computer and paper tests were counterbalanced, as were the tests within the two clusters. All sessions were videotaped and afterwards scored by Master's students blind for group allocation.

1.4. Measures

1.4.1. Parental education

Parents ticked their highest level of education on a scale ranging from primary education to university (1–8).

1.4.2. Intelligence

To test verbal and nonverbal intelligence we used Dutch versions of the *Peabody Picture Vocabulary Test* (PPVT; Schlichting, 2005) and *Raven's Coloured Progressive Matrices* (RCPM; Van Bon, 1986).

1.4.3. Phoneme skills

1.4.3.1. Word dictation. Five dictated words (i.e., *papa* (daddy), *Sim* (boy's name), *been* (leg), *jurk* (dress), *duim* (thumb)) were assigned one of the following codes (Levin & Bus, 2003):

(0) drawing-like scribble
(1) writing-like scribbles, but not similar to conventional symbols
(2) conventional symbols not representing sounds in the word
(3) one phonetic letter
(4) two or more phonetic letters
(5) invented spelling (readable but not spelled correctly)
(6) conventional spelling

The intraclass correlation coefficients for all double-coded words were high (r's > .99). The scores on the words were averaged (α's > .84) for pre- and posttest.

Fig. 1. The screenshots have been derived from four different games: selecting the proper name (a), selecting 'mama' (b), selecting the first letter of the name (c), and selecting the painting that starts with the letter of the child's own first name (e.g. Tom–tiger) (d). When the mouse skims a picture, as in d, the computer pronounces its name.

1.4.3.2. Phoneme identification. Children identified the first sounds of five CVC or CVCC words, the last sounds of five CVC or CCVC words, and named all three or four phonemes of five CVC, CCVC or CVCC words. Cronbach's alphas for pre- and posttest equaled .93 and .92, respectively.

1.4.3.3. Aggregate measure. Principal component analysis (PCA) resulted in one component explaining 63% and 73% of pre- and posttest, respectively. Component loadings ranged from .79 to .86. The distributions of the variables were normal. A higher score indicates better phoneme skills.

1.4.4. Regulatory skills

1.4.4.1. Stroop-like task (dogs). Following the Stroop paradigm, children had to switch rules by responding with an opposite, i.e., saying "blue" to a red dog and "red" to a blue dog (Beveridge, Jarrold, & Pettit, 2002). The task consisted of 96 trials distributed over four conditions, in which demands on working memory (remembering the name of one or two dogs) and inhibition of the most obvious response (e.g., saying "blue" to a red dog) varied. Incorrect naming and corrections were both scored as errors.

1.4.4.2. Stroop-like task (opposites). Children had to respond with the opposite to contrasting pairs of pictures (e.g., saying "fat" to thin) (based on Berlin & Bohlin, 2002). Incorrect naming and corrections were both scored as errors. This test measured working memory (memorising the names of the pictures) and inhibition.

1.4.4.3. Same tapping. The child copied the experimenter's hammer taps on cubes (Leidse Diagnostische Test; Schroots & Van Alphen de Veer, 1976). Each correct imitation in this working memory task was awarded one point with a maximum score of 12.

1.4.4.4. Peg tapping. The child tapped twice with a pencil after one tap by the experimenter, and vice versa (Diamond & Taylor, 1996). The task measures the ability to inhibit a natural tendency to mimic. The total score was the number of correct responses to 16 items.

Intraclass correlation coefficients between two independent coders were high for all four tasks ($r>.97$).

1.4.4.5. Aggregate measure. PCA revealed one component with high loadings (.61–.76) explaining 49% of the variance. Because square root and log transformations failed to normalize the measure, children were classified in three groups using quartiles (1 = first quartile, 2 = second and third quartile, 3 = fourth quartile). The distribution of this new variable was normal for both the treatment and the control group.

1.4.5. Computer behavior

From mouse behavior, registered and stored every tenth of a second, we derived the time between the question and the child's answer, the total time spent on mouse manipulation, number of mouse clicks, and type and number of support needed to solve the tasks. PCA on these four behaviors resulted in one component that explained 78% of the variance and in component loadings beyond .72. The higher the scores on this component, the more children showed problematic computer behavior, i.e., more mouse clicks, mouse movements and mistakes, and longer response time.

1.5. Data analyses

We conducted an ANCOVA with regression techniques to examine the effect of *Living Letters* on phoneme skills (Cohen, Cohen, West, & Aiken, 2003). Effect-coded *Living Letters* was entered in the model, after controlling for age, gender, parental education, PPVT, RCPM, and pretest score on phoneme skills. We hypothesized that treatment effects may be strong among children with average regulatory skills but, due to problems with planning and choosing the right steps, treatment may have a reduced impact in groups with poor regulatory skills and, due to ceiling effects, also in groups with high regulatory skills. Therefore, three categories were created: children scoring among the lowest 25% on regulatory skills ($n=23$), children scoring around average ($n=45$), and children scoring among the highest 25% ($n=22$). The categories were effect-coded by assigning a value of −1 for the base group (here, the 25% highest-scoring). Each of the other categories was assigned a value of 1 for one code variable and 0 for the other (Cohen et al., 2003). Subjects at each level of regulatory skills were appropriately divided to control and treatment groups. By cross-multiplying the coded level of regulatory skills with the coded variable of the treatment program we tested whether the three levels of regulatory skills responded alike or differently to the treatment.

To examine the effects of regulatory skills on computer behavior in the group of 45 children playing the *Living Letters* games we used a one-way ANCOVA model. Because relatively poor literacy skills may increase the need for feedback, we adjusted the computer behavior for differences on the pretest for phoneme skills.

1.5.1. Missing values

Incidental computer registrations that were lost due to technical problems were imputed by using mean scores within a set. One child was excluded due to too many missing data.

2. Results

2.1. Impact of Living Letters

Table 2 shows the means and standard deviations for phoneme skills and regulatory skills for treatment and control group. The correlations between predictors were mostly low and moderate at most, as shown in Table 3. The final results of an ANCOVA model to test main and interaction effects of *Living Letters* and regulatory skills on phoneme skills are presented in Table 4. There were no serious problems of multicollinearity (tolerance values>.10). Gender, age, parental education, PPVT, RCPM, and pretest score on phoneme skills were entered as centered continuous variables or effect-coded category (gender) at step 1. The explained variance equaled 35% ($F(6, 76)=6.91$, $p<.001$). By entering effect-coded treatment and regulatory skills in step 2, the increment to R^2 was 10%, $F(3, 73)=4.19$, $p<.01$, and by entering the interactions between treatment and regulatory skills in step 3, the increment to R^2 was 5%, $F(2, 71)=3.82$, $p<.028$.

One *SD* higher on the pretest meant .54 *SD* higher on the posttest (see Table 4). The group lowest on regulatory skills scored below the grand mean (.33 *SD*), the intermediate group scored beyond (.24 *SD*), and the highest group about average (.09 *SD* higher). The lowest regulatory skills level (RS^1) ($t=-2.28$, $p<.05$) and the intermediate level (RS^2) ($t=2.01$, $p<.05$) differed significantly from the grand mean. The *Living Letters* group did not score beyond the grand mean ($t=1.32$, ns). The significant interaction (RS^2Z) indicates that the *Living Letters* group outperformed the control group when children scored around average on regulatory skills, as is shown by the predicted values in Fig. 2. The group lowest on regulatory skills scored at a relatively low level at pretest, and their score did not improve as a result of the computer treatment. The group highest on regulatory skills scored just above the grand mean on phoneme skills at pretest, but showed no additional increase as a result of the treatment.

2.2. Computer behavior

Regarding computer behavior we expected especially children scoring lowest on regulatory skills to differ from children scoring in the normal or highest ranges. A planned contrast between the lowest scores and the rest, after controlling for phoneme skills ($F(1, 41)=7.89$, $p<.01$, partial $\eta^2=.16$), was significant ($F(1, 41)=11.83$, $p<.01$, partial $\eta^2=.23$ with 95% confidence limits from .11 to .81). Aggregate scores for children low, intermediate, and high on regulatory skills were 1.17, −.14, and −.19, respectively, with high scores indicating more problematic computer behavior.

Table 3
Correlations for all variables.

	Gender[a]	Age	Edu[b]	PPVT[c]	RCPM[d]	Pre[e]	Post[f]	RS[g]	Comp[h]
Gender	1.00	.19	−.22*	−.07	.18	−.22*	−.24*	−.03	.12
Age		1.00	−.09	.17	.14	.02	−.01	−.14	.16
Edu			1.00	.19	−.09	.10	.12	−.02	.13
PPVT				1.00	.09	.39**	.25*	.22*	−.11
RCPM					1.00	−.04	−.10	.03	.20
Pre						1.00	.57**	.12	−.42**
Post							1.00	.21	−.51**
RS								1.00	−.38**
Comp									1.00

For correlations with computer behavior $N=45$ and for other correlations $N=90$.
*Correlation is significant at the .05 level (2-tailed).
**Correlation is significant at the .01 level (2-tailed).
[a] Gender (−1 = girl, 1 = boy).
[b] Edu = Parental Education.
[c] PPVT = Peabody Picture Vocabulary Test.
[d] RCPM = Raven's Coloured Progressive Matrices.
[e] Pre = pretest scores of phoneme skills.
[f] Post = posttest scores of phoneme skills.
[g] RS = Regulatory Skills.
[h] Comp = computer behavior.

Table 2
Means and standard deviations for phoneme skills at pre- and posttest, and regulatory skills at mid-test; grouped according to treatment or control group.

	Living Letters		Control group	
	M	*SD*	*M*	*SD*
Phoneme skills (pre- and posttest)				
- Word dictation (pre) (max = 6)	2.45	.67	2.21	.80
- Word dictation (post) (max = 6)	3.39	.80	2.87	.61
- Phoneme recognition (pre) (max = 15)	5.13	4.86	3.84	4.70
- Phoneme recognition (post) (max = 15)	9.40	5.00	8.16	5.34
- Aggregate measure (pre)	.20	.94	−.20	1.03
- Aggregate measure (post)	.27	1.07	−.27	.85
Regulatory skills (mid-test)				
- Stroop task dogs (max = 96)	83.84	9.28	82.00	9.78
- Stroop task opposites (max = 48)	30.04	8.02	29.44	7.55
- Same tapping (max = 12)	6.64	2.40	6.67	2.06
- Peg tapping (max = 16)	13.29	2.36	12.33	3.24
- Aggregate measure	−.00	.92	−.23	1.01
- Transformed (1–3)	2.07	.65	1.94	.78

Cell sizes vary from 43 to 45 pupils.

Table 4
Final model of hierarchical multiple regression analysis of phoneme skills (Y) ($N=90$).

	B	SE	Tolerance	t	p
Intercept	−1.81	1.87			
Background					
- Gender (male)	−.10	.10	.82	−1.02	NS
- Age	.03	.03	.84	.94	NS
- Parental education	.08	.11	.86	.71	NS
- PPVT	−.01	.01	.68	−1.02	NS
- RCPM	.00	.03	.80	.01	NS
- Pretest (phoneme skills)	.54	.10	.75	5.62	<.001
Main effects					
RS^1 (low regulatory skill vs. mean)	−.33	.14	.67	−2.28	<.05
RS^2 (intermediate regulatory skill vs. mean)	.24	.12	.71	2.01	<.05
Z (Treatment)	.13	.10	.79	1.32	NS
Interaction					
RS^1*Z	−.15	.15	.65	−.97	NS
RS^2*Z	.33	.12	.69	2.74	<.01

Note. The results represent the final model with all variables included.

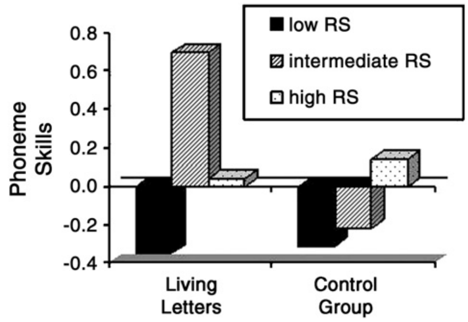

Fig. 2. The bars in this figure represent the predicted values in treatment and control groups as a function of Regulatory Skills (RS). The scores have been derived by substituting the regression coefficients in Table 4 and the effect codes in the regression equation (Cohen et al., 2003). For instance, for the middle-regulatory skills intervention group the outcome was derived as follows: $\hat{Y} = (-1.81 + (.24*1)) + (.13 + (.33*1)) = -1.11$. The grand mean was set to zero to give a better interpretable view of the differences between the groups ($-1.11 + 1.81 = .70$).

3. Discussion

In general, children with poor early literacy skills did not benefit from *Living Letters*, but as expected there were differential effects of regulatory skills. Children scoring in the normal range on regulatory skills did benefit from *Living Letters*. After treatment this sub-group scored on average more than half a standard deviation (.70 *SD*) beyond the grand mean on phoneme skills, a striking result considering the fact that the tests were rather distal from the program, i.e., requiring children to spell new words and identify letters in spoken words that had not been practiced yet.

Children with equally poor literacy skills but scoring among the lowest 25% on regulatory skills were less likely to benefit from the treatment program, probably because the regulatory demands of the program may have outstripped these children's regulatory skills. The group scoring lowest on regulatory skills needed more time to respond, clicked more often, spent more time manipulating the mouse, and made more mistakes (cf. Bippes et al., 2003). It seemed that the feedback loops built into *Living Letters* (e.g., providing cues to find the correct answer) were insufficient to counterbalance problems in planning and choosing the right steps.

Likewise, among children with high regulatory skills the computer treatment was no incentive for phoneme skills. They had relatively high scores on the pretest (approximately .53 *SD* above the grand mean), which may have made *Living Letters* less challenging to this group. However, given the fact that these children scored among the lowest 30% despite relatively strong regulatory skills, we can also suppose that relatively more subjects in this group are most at risk for reading problems due to a phonological deficit (Snowling, 2000). This becomes even more plausible when we take into account that this group showed the same computer behavior as the middle-regulatory skills group. In future reports we hope to expand the picture to include follow-up tests in grades 1 and 2.

Our results seem to refute the criticism that regulatory-skills tasks are not informative about learning problems because they do not relate to behavior in complex real-world situations (Brown, 1999). Lower scores on regulatory-skills tests typically coincide with problematic computer behavior. The alternative to this explanation is that poor literacy skills cause a need for more feedback, and more time and mouse clicks to solve the games. However, the present findings refute this hypothesis because after controlling for pre-tested phoneme skills the relation between computer behavior and regulatory skills still exists.

Another interesting result is that regulatory skills are predictors of school success beyond verbal or nonverbal intelligence. It is also worth mentioning that the results fail to support the hypothesis that gender explains differences in behavioral regulation, as suggested in the literature (e.g., Ponitz et al., 2008).

3.1. Future directions and limitations

As the program uses the child's own name, treatments are somewhat different for most children. This may have an impact on generalizability. In so far as we could test differential effects by contrasting effects of the proper name ($n = 36$) with effects of *mama* ($n = 9$), there was no evidence for different outcomes.

Further experiments should consolidate the differential effects of the program by testing regulatory skills prior to the experiment and by assigning equal numbers of children with low, intermediate, and high levels of regulatory skills to treatment and control groups.

The feedback and help options in the present program anticipated problematic regulatory skills, but were evidently insufficient to scaffold learning behavior and to correct for uncontrolled mouse behavior and distraction from the task. Given that the children with poor regulatory skills did not benefit from the intervention, there clearly is a need to individualize games by adapting content (e.g., more games practicing the same) and providing appropriate feedback (e.g., after one or more errors starting each new task with a reminder of relevant steps).

3.2. Implications

Computer programs can be used to stimulate early phoneme skills of poorly performing kindergarten children, although our current results also point to the weaknesses of computer programs. Children with poor regulatory skills did not benefit from the computer intervention, probably due to their failure to ignore distracters and to choose an adequate problem-solving strategy.

The program can also be used as a diagnostic tool to detect poor regulatory skills as a barrier to learning, thus also making it a valuable teaching aid.

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