Chapter 2
Effects of an Adaptive Game on Early Literacy Skills in At-Risk Populations

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Introduction

Early interventions to prevent reading problems address concerns that an unacceptably large number of children are already, by 4 years of age, lacking in competencies fundamental to their school success. It seems therefore essential to develop effective and efficient intervention programs targeting not only competencies in the area of spoken language (Chap. 3 by Neuman, this volume) but also in the area of alphabetic knowledge. Programs targeting alphabetic knowledge aim at stimulating the understanding that letters refer to sounds and which letter relates to which sound. A subsample in each kindergarten classroom lacks this nascent awareness due to sparse experiences in the early years or inability to take advantage of their environment. The early delays in code-related skills translate into marked limitations in literacy and school readiness upon entrance to first grade, and this group's capacity to benefit from beginning reading instruction may be compromised. Research-based curriculum-level interventions narrow in noticeable ways the skills gap at school entry (Byrne et al. 2000; Duursma et al. 2008; Silva and Alves-Martins 2002; Snider 1995) but involve a considerable investment of resources. Moreover, they are adapted to the class and not to the individual though it is only a subsample that is in need of an additional or more intensive whole class program in preparation to reading instruction in primary education.

Computer-aided instruction may hold particular promise, especially for children disadvantaged by learning difficulties or socioeconomic status (Wilson et al. 2009). They can provide individualized feedback by responding consistently and adaptively to children's answers. In the mathematics field, this approach has successfully

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been used to train children on a core aspect of mathematical cognition: number sense (Wilson et al. 2009). From a Finnish study appeared that a computer application designed for remedial reading training in first grade can enhance letter knowledge, reading accuracy, fluency, and spelling of at-risk children (Saine et al. 2011). *Living Letters* is an analogous adaptive game designed to improve code-related skills that are required at school entry. The benefits of *Living Letters* were scrutinized in junior kindergarten children with compromised pre-reading skills. Well-controlled research was carried out with a threefold purpose:

1. Can *Living Letters* stimulate the development of early literacy skills?
2. Which features of the program are vital to boost development and school-entry skills?
3. Who benefits from the remedial computer program?

Living Letters: An example of a Computer Program to Remediate Lags in Early Literacy Skills

The program *Living Letters* is an example of computer-aided instruction in early literacy skills. The program modeled after spontaneous activities of young children who grow up in a literate environment may be a useful tool in preschool and kindergarten. Although a variety of skills resort under early literacy skills, most researchers and educationalists would agree on the importance of understanding that letters relate to sounds. *Living Letters* starts with the proper name because from developmental research in preschool age has appeared that the name is the starting point for code-related knowledge (Levin et al. 2005; Levin and Bus 2003). Close inspection of children's emerging name letter knowledge, phonemic awareness, and invented spellings supports the hypothesis that the initial letter of the proper name serves as an early decoder illuminating how sounds relate to letters. Most children can name the initial letter of the proper name earlier than other letters, most can locate the sound of the first letter in other words preceding other sounds (Tom, for instance, will recognize/t/in "tiger" prior to/p/in "pat"), and most children can use the first letter of the proper name first of all in their invented spellings (Both-de Vries and Bus 2008, 2010).

Familiarity with the written form of the proper name is an incentive for new activities that stimulate the development of code-related knowledge: children start talking about letters in the name ("that's my letter"), adults target children's attention to letter-sound relations in the name ("the word begins the same way as your name"), and children start playing games with the sound of the first letter of their name ("he has the same letter as I have"). The program *Living Letters* imitates this kind of natural activities with the proper name that take place in the homes from a very early age and that make young children pay attention to print as an object of investigation (Levin and Aram 2004). There are games that require recognizing the written form of the name, naming the first letter of the name, and identifying the sound of the first letter in words. The program thus alludes to surface perceptual knowledge of the proper name that most young children develop naturally when they encounter their name on personal belongings such as mugs and artwork (Levin et al. 2005; Levin and Bus 2003).

Efficacy of Living Letters

The software was designed as a remediation tool for reading disabilities but may also be useful in other populations associated with lags in early literacy skills, such as low-socioeconomic status (SES) children. Hereafter, we describe the first test of the program *Living Letters* during the junior kindergarten year in a low-SES kindergarten population. In this study participated 312 kindergartners (60% male) from 15 Dutch schools that served large numbers of low-SES families. Seventy percent of the parents in our sample had attended senior secondary vocational education at most (about 15 years of education). Only children who were about 4 years old ($M = 52.9$ months, $SD = 3.2$) at the beginning of the year in which the intervention was carried out and who spoke Dutch as their first language qualified for participation in the experiment.

We compared children who played the *Living Letters* games with children playing another computer game that did not include letters and sounds during a 3-month period. Stratified assignment guaranteed that in each classroom, the same number of children was submitted to the experimental condition and to the treated control condition. The software used in the treated control group allows us to conclude that improvement could not have been solely due to computer use in general or to extra attention from the teacher. In both conditions, children played the games at school with minimal supervision by the teacher. The computer program was programmed in a way that, when the child had made an error in an assignment, the game was not only repeated in the same session but also in the next session, with a maximum of two repetitions per game. Children thus received a variable number of sessions ranging from 7 to 17, with a mean number of 11.2 sessions ($SD = 1.88$), each lasting about 10 min.

After 3 months in which they played the games in total about 2 h, the children that received the target program outperformed the children in the treated control condition. On a series of tasks that assessed emergent writing, name letter knowledge, and phonemic sensitivity, experimental children scored higher than the control children. After aggregating the three scores into one factor score, control and intervention groups scored on average $-.06$ ($SD = .96$) and .20 ($SD = 1.01$), respectively. The autoregressor (pretest scores on emergent writing, name letter knowledge, or phonemic sensitivity) was a significant covariate, and working memory and inhibitory control were marginally significant, whereas other background variables (age, maternal educational level, PPVT, and nonverbal intelligence) were nonsignificant covariates. The intervention showed moderate-sized gains ($d = .68$), an effect that is large enough to enable a move from the 30th to the 50th percentile.

Results demonstrate that children can achieve substantial gains when they receive computer-aided reading instruction that specifically teaches target skills in a manner that matches children's skill level.

Foundational Features of Remedial Programs for Early Literacy Skills

Even when games provide instructions and practice just as curriculum-level interventions, they may coax children into habits of responding that are nonproductive when viewed from the perspective of practicing code-related skills: instead of solving the assignments, they may just click and enjoy the animations. The *blind eye* of computer-aided instruction can leave children to their own devices, opening the door to *free play* rather than playful engagement with the content (De Jong and Bus 2002). Children may complete the computer assignments without seriously attempting to solve the problems they pose with the result that the potential benefits of computer-aided instruction strongly reduce (Kegel et al. 2009). In line with this theory, we expect that computer programs that include continuous correction or confirmation of the child's responses modeled on human tutors reveal fewer errors in the computer assignments and more growth in target skills (Anderson et al. 1985; Graesser et al. 2012; Van der Kooy-Hofland et al. 2011).

As a critical test, the study probes the differences in error levels in completing program activities by comparing two versions of *Living Letters*. In one version, children received adultlike feedback that becomes more supportive as more errors are made in an assignment: (1) After the first error, the oral instruction is repeated, and children are encouraged "to listen carefully" to promote more thoughtful responses. (2) After the second error, the program provides oral cues to solve the task correctly (e.g., "Which sound do you hear first in your name?"), thus enabling engagement in other similar tasks independently. (3) A third error is followed by the correct solution with an oral explanation (e.g., "Listen; in that word you can hear the/p/of peter"). The program thus provides not only feedback to the accuracy of answers, but it also offers oral cues to correct and optimize children's responses (Wild 2009).

A randomized controlled trial (RCT) design was used to compare this version of *Living Letters* including feedback with a version of the target program in which children did not receive feedback (Kegel and Bus 2012). In both versions of the program, games and instructions were the same, and children received an identical number of trials and repetitions. The two programs differed only on the presence of an online tutor to provide oral reactions to children's responses. The feedback group outperformed the group without feedback by far. After correction for background variables and the autoregressor, children in the feedback condition scored on average more than one standard deviation higher than children who received instruction and assignments but no feedback. Mean scores of the feedback and no-feedback group on the factor score were .20 ($SD = 1.01$) and −.13 ($SD = 1.00$), respectively.

Moreover, when the program did not provide feedback, children made more errors in assignments. Both findings are well aligned with prior research (Azevedo and Bernard 1995; Meyer et al. 2010; Vasilyeva 2007) showing that instructions and assignments lose a lot of their impact when children do not receive immediate and personalized feedback to their responses to games. Overall, these results suggest that an intelligent tutoring system should be preferred to playing simple games. A vital element of computer-aided instruction is a computer tutor providing immediate corrections and explanations after each reply to an assignment, thereby imitating instruction through positive, responsive interactions with the teacher.

Regulatory Skills

It seems a plausible assumption that feedback may be vital in particular for children who are easily distracted by irrelevant stimuli. It is typical for the latter group of kindergarten children that they do not succeed to concentrate on a task and stay focused especially when their behavior is not continuously corrected. These children with underdeveloped regulatory skills score low on tests where they have to suppress spontaneous reactions and impulses that interfere with carrying out a task. It seems not too far-fetched to expect that in particular children with underdeveloped regulatory skills are more dependent on feedback to stay on task and benefit from computer-aided instruction. They may only succeed when the program corrects random choices and reminds children of knowledge and procedures for solving the computer assignment. Built-in feedback may therefore be especially useful when children experience problems in regulating their own learning and when they are easily distracted by details or environmental influences. To test this hypothesis, we assigned eligible pupils randomly to experimental conditions stratified for children's level of regulatory skills (Kegel and Bus 2012). To assess regulatory skills, we applied Stroop-like tasks among other tests. In the Stroop-like tasks, children had to switch rules by responding with an opposite, i.e., saying "blue" to a red dog and "red" to a blue dog (based on Beveridge et al. 2002).

Our findings do not corroborate the hypothesis that feedback is especially vital when children's regulatory skills are underdeveloped. Actually, both groups of children, with high and low inhibitory control, perform far better in the condition with feedback. However, especially in the condition without feedback, children scoring low on executive functions lag further behind those scoring high. Results thus indicate that all children benefit less from a program without feedback, but that especially a low inhibitory control group is less able to benefit from computer games when they do not provide correction and confirmation in reply to children's responses to games. In line with the hypothesis that a program without feedback may reward low inhibitory control children's tendency to respond randomly instead of strengthening thoughtful replies, the low inhibitory control children made significantly more errors in the assignments than high inhibitory control children.

Actually, all outcomes evidence a "dual risk" model (Belsky et al. 2007): Children with some risk (here: low inhibitory control) lag further behind when they are exposed to a less supportive environment (here: no feedback).

Differential Susceptibility

Effects of early literacy programs including *Living Letters* are moderate even though programs target foundational literacy skills and present very systematic instruction. By focusing on the whole group, we may overlook higher effects in susceptible subgroups as a priori defined. For instance, in evaluating experimental interventions in the domain of emotional and physiological development, researchers have found differential effects of their manipulations. Children with a fearful temperament appear to suffer most from persistent family conflict or low quality of day care but also to benefit most from supportive environments. Blair (2002) found that a comprehensive early education program significantly lowered the level of internalizing and externalizing behaviors of 3-year-old children with more negative emotionality but not in children with less negative emotionality. From this finding, it can be concluded that fearful temperament or temperamental emotionality is a "risk" under less supportive conditions but a susceptibility factor in a supportive environment. This is the essence of the novel hypothesis of "differential susceptibility." Some children may be more susceptible for the environment and learn more from instruction and less from a control condition.

Likewise, interventions may cause differential effects in the cognitive domain. If children do not practice name writing spontaneously and hardly elicit adult comments because they do not succeed concentrating on such activities, they might be dependent on a program that trains code-related skills and offers abundant practice and personalized feedback. The mainstream classroom environment is an obviously unsatisfactory environment for at-risk children. Overcrowded early literacy settings are likely to challenge at-risk students, who need abundant repetition for acquiring code-related skills. Regular education may fail to provide the kinds of intensive, closely monitored, and individualized practice that children at risk need to attain pre reading skills. Children who are not so easily distracted, on the other hand, might be less susceptible to a computer program, and a special program does not elicit more attention from these children than other opportunities for development enhancement. Children's environment offers many opportunities that can promote learning and development of skills that are also provided by the computer program.

To test this hypothesis, we selected groups physically differing in dopaminergic efficiency which is associated with decreased attention and more dependence on reward mechanisms (Robbins and Everitt 1999). The third exon of the DRD4 7-repeat allele has been linked to lower dopamine reception efficiency. This dopamine-related genetic polymorphism may therefore play a role in children's susceptibility to instructional experiences related to early literacy development. Having the DRD4 7-repeat allele may increase the risk for inattention and dependency on feedback provided in the instruction. In a sample of 182 four-year-olds from 15 junior kindergarten classrooms, it was studied whether effects of the computer program *Living Letters* are moderated by DRD4 (Kegel et al. 2011). Children with the 7-repeat allele were expected to be most susceptible to an intensive individual-orientated learning environment and show the largest increase in understanding the combination of how a name sounds and looks in the *Living Letters* feedback condition. It was also tested whether carriers of the 7-repeat alleles were more susceptible to negative effects caused by the absence of feedback in the computer program that may lead to erratic interactions with the computer program. They enjoy the animations in the computer program without making serious attempts to solve the computer assignments.

Children with the long variant of the DRD4 allele appeared to be more susceptible to the positive variant of the educational intervention program *Living Letters* (with feedback). Children with the long variant of the allele scored lowest after the negative version of the computer program (without feedback), although they did not differ significantly from the control group. The carriers of two short DRD4 alleles were less influenced by the two kinds of instruction, with or without constructive feedback. Effect sizes of *Living Letters* (with feedback) for the carriers of the long and short alleles strongly differed; they equaled .97 and .35, respectively. To the best of our knowledge, this is not only the first experimental test of genetic differential susceptibility in education but also the first experiment ever including in one design the contrasting effects of a negative and positive variation of an intervention.

Conclusion

Our conclusions are fairly straightforward and include three major points. First, computer-aided instruction can be a useful tool in early literacy education, even in kindergarten age (see also Chap. 5 by Roskos, this volume). Adaptive computer games designed to behaviorally train a particular aspect of literacy hold particular promise, especially for children disadvantaged by socioeconomic status. The current data show that a computer program is one instrument for raising the profile of remedial intervention that can add to a better starting position in first grade for young children from low-SES families. The benefit of the software was substantial, considering that the software was only used for a small number of short sessions. As the program was tested in a real resource room situation, this approach thus proved to be feasible in the school environment. We expect that the treated group who is better prepared to benefit from the reading curriculum will outperform the control group in first grade, but this is an important developmental issue for future studies to address.

Second, not only do computer games have the potential to render repetitive training entertaining, but they can also individualize instruction by constantly assessing children's performance and adapting feedback. Our finding that a group not receiving feedback did not outperform the control group demonstrates that a computer program without immediate individualized oral feedback is not a stronger stimulus for learning code-related skills than the daily experiences with written language, as children in the control condition experienced. To explain this finding, we assume that a computer program that does not provide correction and confirmation in reply to children's responses to the games may actually reward random responses instead of strengthening thoughtful replies. The evidence obtained here indicates that underachievement in children at risk for reading failure is preventable by promoting practice with a computer program that is modeled on typical early educational experiences in literate homes.

Third, not all children are susceptible to instruction and benefit from computer-aided interventions. Differential susceptibility implies that only part of the children are strongly dependent on a high-quality computer intervention as they suffer more from bad instruction and profit more from optimal teaching – teaching target skills in a manner that matches children's skills level and providing instruction through positive, responsive interactions. The less susceptible children seem to adapt to most opportunities that promote learning and development of early literacy skills without performing too well or too badly. We conclude that children differ in susceptibility to the quality of feedback and support provided in an early reading computer program, and that this susceptibility is associated with a genetic predisposition to dopamine-regulated reward- and attention-related mechanisms, independent of cognitive ability.

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