In search of a science-based application: A learning tool for reading acquisition

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This is a story about the fate of a psychological application: from its conception to the optimistic vision surrounding its future. We hope that this application – an enjoyable learning game (www or mobile phone-based, available free of charge to the end users) for children – can at best help millions of children in their reading acquisition in the future. Its basis was created by following intensively the development of children with (N = 92) genetic (familial) risk for dyslexia from birth to puberty in the Jyväskylä Longitudinal study of Dyslexia (JLD)-project. We summarize some of the major findings of the JLD in order to facilitate understanding of the reasons and logic behind the development of the game. Originally intended as a research tool for reading acquisition, its potential for prevention of reading difficulties was quickly recognized.

Key words: Reading acquisition, learning game, dyslexia.

Countless studies have attempted to unlock the secrets of reading disorders (RD) by comparing children with and without RD. Almost without exception, these investigations are only instigated retrospectively after cognitive difficulties have been allowed to manifest for years. At that time not only is the child’s development affected in terms of acquiring the skills necessary to achieve reading, but also a child’s perception of his/her failure is emphasized through not attaining the same skills as classmates in school. By then, it is often too late to undo this damage in terms of helping the child to recover from this failure and, as a consequence, behavioral difficulties often ensue. Were research outcomes instead to give us advance warning of potentially avoidable developmental risks, then such studies could help us to support children earlier in their development and minimize these risk factors, for example, through the initiative of preventive training for those at risk for dyslexia. Many of the above problems have been addressed through research carried out in Finland for many years within our Jyväskylä Longitudinal study of Dyslexia (JLD)-project. This also created the foundation for the method that we have developed for prevention of reading difficulties.

Some 60 years ago, a Swedish dissertation (Hallgren, 1950) showed how children facing severe problems in learning to read may have a familial background of dyslexia. The first researcher to take this finding seriously was Hollis Scarborough (1990). She observed the psychological birth of dyslexia by following the individual histories of 22 children at familial risk for dyslexia. The use of this longitudinal design in her work facilitated observation of very important developmental phenomena. However, this was only a pilot study due to the small number of children and relatively few and infrequent follow-up assessments. Nearly two decades ago, the main author, Heikki Lyytinen, teamed up with his senior colleagues Timo Ahonen, Matti Leiwo and Paula Lyytinen to formulate an ambitious plan to extend this design and follow a large number of children with familial risk from birth (instead of from 2.5 years as in Scarborough’s study) and to compare them to non-risk children. An extensive battery of cognitive and language assessments for 200 children was then repeated at short intervals with the further inclusion of examination of the children’s learning environment.

At the beginning of the JLD, research was insufficiently informed as to the wide differences in the acquisition time and demands associated with learning to read in different alphabetic writing systems. Published results were based mainly on learning to read in English. Most of the related studies concluded and continue to conclude that reading acquisition is associated with the development of phonemic awareness and that, if learning to read is specifically compromised, it is due to a phonological deficit (Stanovich, 1988). On the other hand and at the same point in time, researchers with neuropsychological leanings thought that dyslexia results from genetically determined atypical development of cognition and the brain (Pennington, 1990). Accordingly, the observed phonological deficit, as well as the brain/gene atypicality had to be further specified. This is what we have been attempting since that time in the JLD. Although the JLD data participated in the identification of the first candidate gene for dyslexia (DYX1C1; Taipale, Kaminen, Nopola-Hemmi et al., 2003), this article concentrates on psychological findings only.

Had reading research been affected from the outset by concrete observations of learning to read a relatively transparent...
language such as Finnish, a lot of time would probably have been saved in the identification of the bottlenecks or barriers to reading acquisition. Finnish is an extreme example of transparency with symmetrical consistency at the letter-phoneme level. This leads to a relatively low learning burden as shown below.

Independent of the observed ease with which children learn to read Finnish (substantiated most convincingly by the high portion [more than a third] of children who learn to read without formal instruction before school entry), dyslexia is also prevalent among Finnish children.

At least in part due to the COST A8 action chaired by the first author from 1993–8, it is now agreed that English is a deviant among alphabetic writing systems in terms of the learning load (for details, see Seymour, Aro & Erskine, 2003). The foundations of reading in most transparent writing systems can be learned by storing, for fluent retrieval, 20–40 letter-sound connections (23 in Finnish). The number of consistent (i.e. where the relationship between the spoken and written language units is always the same) connections is close to 2000 in English with a large number of exception words which cannot be read by relating letters to sounds (thus relying on frequently committing the whole word to memory). We will return to this issue later when describing the learning game. Before that, let us relate the story of dyslexia by observing the development of readers of the very easy-to-learn Finnish language.

### THE JYVÄSKYLÄ LONGITUDINAL STUDY OF DYSLEXIA (JLD)

The goal of the JLD study has been to learn to (1) understand dyslexia by defining its precursors and (2) identify sufficiently early the children at-risk for whom we must (3) develop preventative training tools to overcome or at least minimize the consequences of dyslexia.

To attain these goals it was necessary to prospectively observe the development leading to dyslexia. Today, we have followed the children with familial risk for dyslexia for more than 13 years. Almost half (48/107) of these children faced at least some atypical difficulties in learning to read. Eleven of those who had initial difficulties were helped substantially by reading instruction during the first three grades, and a substantial portion of children obtained remarkable benefit from remediation offered by Finnish special education during the subsequent three grades. Consequently, by the end of the fifth grade, less than a quarter of the original at-risk children had perseverant reading difficulties. Most typically they continue to be less fluent than their classmates. This highlights the increasingly documented observation that, within the confines of a transparent writing system, the attainment of fluency is the main challenge for those with compromised reading skills.

The developmental routes of the JLD children who ended up with compromised reading have been analyzed in detail in a number of publications (such as Lyytinen, Erskine, Tolvanen, Torppa, Poikkeus & Lyytinen, 2006; for the most recent review of the JLD-findings, see Lyytinen, Erskine, Ahonen et al., 2008). We therefore concentrate only on those issues which are the most central in terms of understanding the development of techniques to help the (1) early identification of children in need of support and (2) provision of efficient preventive training. In order to know where this training should be focused, we have to identify the bottlenecks of dyslexia.

### Cognitive bottlenecks and early identification of dyslexia

The earliest indications concerning differences between risk and non-risk groups could be observed shortly after birth (see Table 1). The newborn brain responds differently to speech sound depending on whether it is affected or not by genetic vulnerability to dyslexia (Guttorm, Leppänen, Poikkeus, Eklund, Lyytinen & Lyytinen, 2005) and the very same event-related potentials (ERPs) also predict the development of language and reading skills (Guttorm, Leppänen, Hämäläinen, Eklund & Lyytinen, in press; see Fig. 1). Using a behavioral head turn paradigm, Richardson observed infants’ ability to differentiate short and long consonants (Richardson, Leppänen, Leiwo & Lyytinen, 2003), and Leppänen et al. (2002) using ERP measures showed this same differentiation at age 6 months. The categorical perception and associated brain response to the difference was clearly less reliable among at-risk than among non-risk infants.

Many of the observations of language development revealed delays and weaknesses from an early age as shown by Lyytinen, Eklund & Lyytinen (2005). If a child’s expressive speech is delayed (late talking), the likelihood of difficulties in learning to read is higher – albeit not all children with dyslexia have encountered such a delay. If this delay extends to language comprehension, then the risk is substantially higher.

Table 1 reveals that the groups performed differentially on a number of further measures showing high predictive correlations to reading acquisition. However, one measure is exceptionally predictive. This is the development of knowledge of letter names from the age of 4 years. As illustrated

### Table 1. Variables from different ages of the JLD children which show significant group difference and predictive correlation to reading at the end of the first grade

<table>
<thead>
<tr>
<th>Age</th>
<th>Variable</th>
<th>P &amp; D</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 yrs</td>
<td>Reading accuracy and speed</td>
<td>D</td>
</tr>
<tr>
<td>5 yrs</td>
<td>Naming speed</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>4–6 yrs</td>
<td>Phonological manipulation</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>5–6 yrs</td>
<td>Letter knowledge</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>5 yrs</td>
<td>Verbal memory</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>3–6 yrs</td>
<td>Phonological sensitivity</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>3–5 yrs</td>
<td>Infectional skills</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>2–3 yrs</td>
<td>Articulation accuracy</td>
<td>P</td>
</tr>
<tr>
<td>2 yrs</td>
<td>Maximum sentence length</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>6 months</td>
<td>Speech perception</td>
<td>P &amp; D</td>
</tr>
<tr>
<td>3–5 days</td>
<td>ERP to speech sound</td>
<td>P &amp; D</td>
</tr>
</tbody>
</table>

Note: P = Significant predictor; D = Difference between risk and non-risk groups.

Cognitive bottlenecks and early identification of dyslexia

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by Fig. 2, all children who ended up with reading problems showed substantially lower letter knowledge than other children and much more consistently than with any other predictive measure. In fact, among all JLD-children with dyslexia, the delay in the acquisition of letter knowledge was at the same relative level two years before school age as was the reading skill during the first three grades. With this finding, one of the most important practical goals seems to have been reached – children who are in real need of preventive practice can be identified in time. It is noteworthy that letter knowledge performance before school age was, however, not a complete predictor of reading acquisition, as shown by Puolakanaho et al. (2007) in the sense that although the most important goal was reached – i.e. all who ended up facing problems could be identified early as shown by Fig. 2 – a number of false positives were observed. Some children may have had insufficient opportunity to learn letters before entering school. Most Finnish children receive effective phonics-based school instruction during the first grade. It may often suffice in overcoming the risk reflected in the compromised learning of letter names.

For the identification of children in need of supportive intervention in reading acquisition, following the development during the year prior to school entry may suffice in the context of a transparent writing system such as Finnish. This monitoring should include reading-related indices such as letter knowledge as well as a predictor of the most important feature of compromised reading in transparent writing environments. That is, failure to automatize reading skill in terms of reading fluency (Aro & Wimmer, 2003). Related fluency is typically assessed using a serial rapid naming (RAN; Denckla & Rudel, 1976) task of familiar objects, colors, numbers or letters. Most children who, after struggling with the initial learning of decoding skills, also fail to automatize reading are “slow namers”. Among the JLD children who turned out to be dyslexic, two-thirds had problems which could be observed from traditional phonological tests, and half also showed poor scores in rapid naming tasks. However, one-third had close to normal or normal scores on traditional tests of phonology, but they were very slow at naming. The dramatic importance of slow naming is seen in our analyses of the developmental routes to dyslexia (Lyytinen et al., 2006). Two developmental subgroups ended up with severe reading problems. The members of the first such group have the characteristics of a well-known phonological deficit. The second was statistically clearly separable on the basis of slow naming. Taken together, these findings reveal that a substantial portion of the children at risk for dyslexia have difficulties in speech...
perception – their phonemic space is undifferentiated which means that they cannot immediately connect graphemes to phonemes. A substantial number cannot adequately retrieve the connection between spoken and written words and fail to automatize reading in a typical way.

How to overcome the bottlenecks?

In a transparent writing system, the letter-sound connections can be drilled efficiently and without complications. This is because the connections between sounds and letters that children learn are always the same. This stands in marked contrast to the situation of non-transparent writing systems such as English where none of the letters have the same sound in all written contexts. Therefore, an intensive drilling of connections between such small unit sizes may be detrimental in supporting the acquisition of reading skills in English.

Speech perception, phonological sensitivity and skill reflected in the ability to differentiate and manipulate speech sounds have an immediate effect on how much benefit a child gains from phonics instruction. If he/she is unable to differentiate certain phonemes from each other, this can take some time to learn and, in the most difficult situation, requires a great deal of drilling to learn such a distinction. This can be achieved without complications using letters in the context of transparent writing systems.

Our findings have led us to choose phonemic differentiation as the first and most important target for preventive training that a child at-risk for dyslexia needs. For that purpose, we have designed Ekapel, sometimes called the Literate game or Graphogame in English in the related publications (e.g. Hintikka, Aro & Lyytinen, 2005; Lyytinen, Ronimus, Alanko, Poikkeus & Taanila, 2007; Lyytinen et al., 2008; Saine, Lerkkanen, Ahonen, Tolvanen & Lyytinen, in press).

In-depth analyses of the JLD-data confirm that the ultimate problem for severely dyslexic children seems to be poor speech perception. These results (Pennala et al., in press) show that perception accuracy of phonemes (more specifically, of phonemic length which is a highly distinctive feature in Finnish) still explains reading skills even after controlling for all other best known predictors, including phonological skills. Thus, preventive training should address this problem in helping the child to differentiate the relevant phonemic space represented in the language.

The second most persistent challenge faced by children with dyslexia is the automatization of reading which must be attained in order to free cognitive resources for comprehension in reading. The attainment of this goal seems difficult. This has also been demonstrated in our research (Hintikka, Landerl, Aro & Lyytinen, 2008; Huemer, Landerl, Aro & Lyytinen, 2008).

The TRAINING GAME

The game was built originally for research purposes to offer an efficient way in which to observe the basics of the reading acquisition process. It focuses on the core issue of reading, namely learning the connections between spoken and written language. The player listens to one spoken item per event which requires his/her response. The player then connects the item heard to its written counterpart by choosing from several alternatives presented usually as falling balls to increase the gamelikeness.

When the opportunity to try the game free of charge was advertised, it soon become very popular in Finland. This motivated us to develop it further for training purposes. As an exercise, it follows the known phonics approach by systematically introducing first the spoken phonemes, then syllables and words. Because it is intended for children for whom reading acquisition is a real challenge, the most important goal was at first to make it sufficiently enjoyable to keep children interested in playing for long enough to attain the learning goal. The most natural reward for playing is the experience of success. Therefore, progression through the game is computationally controlled so that from the selections made by the child throughout the game, about 80% will be correct. The next step was to develop adaptation algorithms which use the opportunity to introduce ~20% of the items from the pool of new (yet to be learned) connections in such a way that they are optimally chosen to benefit the players’ learning. This has led to the development of mathematical models to reach this goal (Kujala, Richardson & Lyytinen, in press).

Figure 3 illustrates the “differentiation of the phonemic space” of a player. The auditory stimulus or target item is in the center and the letters outside of the circular space represent the written distractor (incorrect alternative) items the player has seen during the trials of connection building. If the shaded area around such a distractor widens maximally towards the distractor letter, it means that the player has never chosen it to represent the heard target item. The more inclined the shaded area is towards the target item, the more often the player has made an incorrect choice believing it to correspond to the target item. The shaded area represents the statistical uncertainty of our estimate of the true confusion probability. During the gaming, the confusabilities change as a function of exposure to the connections to be learned. This can be represented by drawing different superimposed uncertainty distributions corresponding to different periods of game-play to illustrate the change. The very same data can be used to guide the adaptation (allocation of the next items in the game for the player). Alternatively, the estimated confusabilities can be averaged to represent the mean results of a large number of players, as shown in Fig. 4. This illustrates some of the challenging differentiations that a beginning reader has to learn in Finland. Items such as /d/ and /b/ are uncommon in the Finnish language and they are phonetically similar to /p/ as well as visually to the letter “P”.

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The game is available via the Internet (see http://www.luki-mat.fi) to children who have parental permission. This is usually granted after a need has been identified with the help of a teacher from kindergarten or school (also by using means available from the same internet site). We believe that children with familial risk and/or low letter knowledge during the few months preceding school entry benefit from preventive playing in terms of avoiding unwanted failure experiences during the early months of school instruction. Therefore, we have recommended to kindergartens where all children in Finland have their pre-school year just before school that the game should be used during the last two months (April–May) and preferably with massed practice. This means short 5–15 minute periods several times per day for as long as children require to learn the letter-sound connections and, if possible, also the basic alphabetic principle in terms of how letter-sounds can be connected to assembled words. Today, more than 50,000 children in Finland have tried the game and very few have failed to benefit. The website provides Finnish parents and teachers not only with training and assessment tools, but also with basic knowledge about reading acquisition as well as information on maths and problems associated with learning basic mathematical skills.6

HELPING AFRICAN CHILDREN

We aim to maximize the effectiveness of the service with the hope of extending its support to include children who are in more pressing need than the Finnish children. Millions of African children have no or inadequate access to quality instruction in reading. The type of phonics game we have created is as effective for supporting learning to read the African languages, whose writing systems are relatively new and thus similarly transparent (changes in oral language have not had time to distance them from written language as is the case of English).

In Africa, multilingualism adds a new level of challenge in reading difficulties. In our pilot country Zambia, children are expected to learn initial literacy skills in their provincial language during first grade before starting English in second grade. Both languages are mandatory subjects in public schools, but in general the language of instruction is usually English. This educational program has been in place since 2001, and while it has been a success compared to the earlier all-English approach, reading difficulties are still very common. In a study by Matfwali (2005), 106 randomly selected third grade pupils who had participated in the new reading program were tested for their
English literacy skills. Only 46% could name the letters of the alphabet, and 29% could relate the given sounds to appropriate letters. Due to transparency, reading acquisition should have been possible for the majority of pupils during the first year of school. As this was not the case, we wanted to see if the Literate game could provide an insight into the possible reasons behind poor reading performance.

The learning game was piloted in the Cinyanja language (most common in Lusaka), and first grade children who received two hours of intervention improved in spelling and orthographic skills (Chilufya, 2008). However, Ojanen (2007) showed that Zambian children have unusual difficulties with vowels /a/, /e/ and /i/ even though the vowels are consistent in the Cinyanja language and did not present a challenge in Finnish (as shown in Fig. 5). Figure 3 illustrates this phenomenon: the Zambian player has repeatedly chosen the letter “i” for the sound /a/, letter “a” for sound /i/ and letter “a” for sound /e/. Otherwise, few other problems emerged. This tendency persisted into grades 3 and 4 (Kaoma, 2008) and suggests that children have learned English letter names instead of phonemes or letter names of their own language. This probably results from simultaneous teaching of English and Zambian languages and society’s general preference of English over local languages. The current reading program is relatively new and Zambian teachers are inadequately informed about the phonics of local languages which is a little studied area to begin with. Although Zambian expectations of learning to read a transparent language within one year seem realistic on the basis of experience from other countries, there are still many open questions. The Literate game can contribute to the development of better teaching methodologies. If its availability can be guaranteed, it will provide a training tool for children at-risk for difficulties which may also include insufficient instruction in developing countries. For this purpose, we have implemented the game in cell phones which are becoming increasingly available to African families.

Despite increased interest in local languages, English remains the official language of many African countries. There is very little availability of literature in local languages so reading material for African children is scarce unless they learn English or other languages in print. This is why we have initiated ways of using the game for the instruction of reading English. To this end, we have collaborated with English experts of reading instruction, but also seek to apply the experience that we have gained from teaching reading in more transparent languages.

The impetus behind the design of the English versions of the game lies with theories that support the primacy of the size of units learned – either small or large (see e.g. Ziegler & Goswami, 2005). Seymour’s (1997) foundation literacy theory provides the framework for the first of these theories in asserting that reading is acquired from small to large units in phases. In contrast, large to small unit theories such as that suggested by Goswami and Bryant (1990) suggest that children’s pre-school exposure to rhymes facilitates their ability to associate the onsets and rhymes of words with letter strings and by analogy with already known words. To date, two different versions (a phonics version with simultaneous learning of exception words and a version based on rhyme and analogy) of the English language game have been implemented within the context of the Graphogame project led by Ulla Richardson.

Computational mathematics introduced the concept of consistency to the selection of materials for the phonics version of the English language game. The consistency principle introduces those relations between letters and sounds that are the most dominant and most frequently occurring in the language. Given the vagaries that permeate the letter-sound relationships of the English language, this consistency relies more upon a hierarchy of dominance of the phoneme-grapheme relationship (derived from “rules”) and ordered by frequency of occurrence of this relationship.

Following extensive implementation of this phonics intervention in the UK, early results are extremely promising with the children playing the game (with or without recognized reading difficulties) showing greater improvement on standardized tests of reading than non-playing children. This outcome has obvious implications for the teaching of reading in general as well as for remedial purposes. As we stated above, we are in the middle of collecting data from the rhyme-version of our English game but the preliminary findings indicate that this version is at least as effective as our phonics version (Kyle, Richardson, Lyytinen & Goswami, 2009).

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NEW BEGINNINGS
Our present story ends with a new chapter. After more than a decade of research, we have identified the most salient developmental bottlenecks to children at familial risk for dyslexia, including poor speech perception in infancy and expressive language delay in toddlerhood. This has continued to manifest as poor letter knowledge acquisition and/or an inability to acquire fluent reading skills. We now move towards the creation of a new generation of interventional programs both generic and specific – interventions that actually seek to redress the imbalance of reading difficulty that, left untreated, can cause so much heartache to children in the early years of their school experience and, ultimately, can blight future career prospects. The implementation of an innovative computer game that rewards success and minimizes failure at the level of individual achievement is just the beginning of a new story that will help children in many educational contexts throughout the world. Thus, this is not the end of the story, it is just the beginning...

The following colleagues have made a substantial contribution in the summarised studies: Timo Ahonen, Mikko Aro, Kenneth Eklund, Tomi Guttorrn, Jarmo Hämäläinen, Paavo H.T. Leppännen, Paula Lytyinen, Anna-Maja Poikkeus, Anne Pualakanaaho, Asko Tolvanen and Minna Torppa. Tuomo Hokkanen, Ville Mönkkönen, Iivo Kapanen and Miika Torppa have made the programming of our learning games, and Juha-Matti Latvala (co-ordinator) and Ritva Ketonen (clinical services) have worked for the LukiMat www-environment. The Jyväskylä Longitudinal study of Dyslexia (JLD) has belonged to the Finnish Center of Excellence Program for several consecutive periods (#40166 for 1997 – 1999, and #48858 for 2000-2005 and #213486 for 2006-2011) and is supported by the Academy of Finland, the Niilo Mäki Foundation and the University of Jyväskylä.

NOTES
1 For more publications, see http://users.jyu.fi/~hlyytine/publications.htm
2 This distinction is manifested in the most usual spelling error (in the omission of doubling the letter to represent a long phoneme) observed among children with dyslexia.
3 False positives could be minimized by using dynamic assessment of letter name learning.
4 More than 95% of Finnish children become accurate readers during the first grade.
5 School entry at 7 years of age.
6 The service is under construction with funds from the Ministry of Education of Finland to a consortium of the University of Jyväskylä.

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