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**State-of-Science Review: SR-D12
New Technologies and Interventions for Learning Difficulties:
Dyslexia in Finnish as a Case Study**

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Summary

Recent research concerning the genetic background, neural basis and behavioural expressions of learning difficulties makes it clear that, in order to minimise their unwanted consequences, we need to use the most efficient and motivating training methods. Dyslexia, a serious developmental reading disorder, is selected as a case study in order to demonstrate the potential of scientific research in overcoming common learning difficulties. We know now that severe dyslexia has a genetic basis that compromises the neural resources necessary for the optimal acquisition of reading skill. We know also how the working brain creates the basis for reading, and further that, when using efficient methods, the associated brain networks can be reorganised to alleviate the difficulties that compromise learning. In most cases the 'bottlenecks' that can be released by additional practice are of narrow scope. This report summarises our research findings, demonstrating how we have uncovered ways in which to identify early enough children in need of support in reading acquisition in Finland and to help them to overcome reading difficulties. We emphasise – on the basis of research – that children should be helped before they face the risk of failing to learn to read in a comparable way to their classmates at school. If the child is helped early enough, the unwanted psychological consequences of a child having to rely on their own learning skills can be minimised.

1. Introduction

For more than a decade, the Child Research Centre at the University of Jyväskylä, Finland has been involved in cutting-edge research into learning disabilities. The Centre led the 1995-2000 Europe-wide research collaboration 'Learning Disorders as a Barrier to Human Development', involving 17 top European research laboratories. During 1994-2005, the Jyväskylä laboratory secured designated Centre of Excellence status for its Jyväskylä Longitudinal Study of Dyslexia (JLD). In the JLD, more than 200 children at familial risk for dyslexia and age-matched controls have been monitored longitudinally from birth to school age. The newly-conferred status of Centre of Excellence for the years 2006-2011 ensures that the JLD children can be further monitored throughout the course of their formal education. The JLD is the first large-scale longitudinal developmental study covering such a wide age range in order to uncover the routes to dyslexia. This monitoring has amalgamated contributions from multiple disciplines (psychophysiology, developmental, cognitive and social psychology, linguistics, behavioural and molecular genetics, etc.) in the analysis of a number of factors relevant to learning disabilities from new-born to primary school, including causality, diagnosis and intervention.

2. JLD results

2.1. *Early childhood*

The JLD focuses more on children whose risk has a familial rather than genetic basis although, in terms of genetic risk, the study has been involved in identifying the first candidate genes for dyslexia (for the first, see Taipale et al., 2003). Given the long-standing observation that dyslexia 'runs in the family' (known from Hallgren, 1950), familial risk is formulated on the basis of incidence of dyslexia in first-degree relatives. Today, a number of genes have been identified as involved in compromising reading acquisition.

Results from the JLD show that, as early as infancy, children with and without familial risk for dyslexia can be differentiated on the basis of psychophysiological (EEG) measures (Guttorm et al., 2005; for a recent

review, see Lyytinen, Guttorm et al., 2005). The event-related potentials (ERP) that reflect auditory sensory processing (in this case utilising both speech and non-speech stimuli) differ between groups and predict language and reading development.

The JLD results also show that, during the toddler years, delayed expressive language and, to some extent, delayed receptive language (among children at familial risk) can predict individual risk in terms of differentiating those children who do and those who do not end up with reading difficulties at school (Lyytinen, P., Eklund, and Lyytinen, H. et al., 2005; Lyytinen et al., 2006). From three years of age, the children's phonological skills join the language skills in terms of predicting this risk (Puolakanaho et al., 2004).

In practical terms, the single most easy-to-implement and reliable predictor of difficulty in later schooling in Finnish is the child's proficiency in letter knowledge between 3-6 years of age (Lyytinen et al., 2007) and more so, when combined with rapid naming measures (RAN, Rapid Automatisated Naming test; Denckla and Rudel, 1976) at the ages of 5-6 years (Lyytinen et al., 2006; Lyytinen et al., 2007). It seems, therefore, that, at the pre-school level and in the absence of intervention, low scores on both letter knowledge and rapid naming lead to accurate identification of children (with few, if any, false negatives) who later will experience reading difficulties in Finnish.

2.2. *Preschool*

In many cases, this early identification can be made on the basis of letter-sound learning, which is of no surprise given that the impact of including letters in phonological training programmes is additive (Bus and van Ijzendoorn, 1999; Ehri et al., 2001; Hatcher et al., 2004). In short, the single most efficient, predictive and practically applicable tool in terms of identifying children with the propensity to develop problems with literacy is their knowledge of letter sounds from the age of four years.

This difficulty with learning letter-sound relations has been observed to manifest itself as a 'bottleneck' to learning, irrespective of any heterogeneous influences that may have been exerted during the course of the child's preceding development (Lyytinen et al., 2006; for an overview of the results of the JLD study, see Lyytinen et al., 2004).

2.3. *Orthographic influences*

Although pre-school knowledge of letter-sound relations is the appropriate index of prediction of risk for reading difficulties, the nature or consistency of these relations is influenced by the orthography in question. In the Finnish language, the 23 letters have a regular and bi-directionally consistent relationship with the 23 sounds of the language. That is, when one hears the sound /ei/, it is always represented by its written form of 'ei'. Conversely, when one reads the written form of 'ei', it always represents the sound /ei/ and without exception. Unfortunately, this is not the case for more irregular languages such as English whereby hearing the sound /ei/ can provoke numerous potential letter combinations (e.g. *way, weigh, they, gain*, etc.) and, in turn, in the other direction, the reading of such letter combinations can provoke numerous potential soundings (e.g. *they* versus *key*).

As a direct result of the Jyväskylä involvement in the above-mentioned cross-linguistic research, results have shown that children learning to read and write in English take on average an extra two years to match the acquisition rates of children reading more regular orthographies such as Finnish (Seymour et al., 2003). Nonetheless, despite the more simplistic nature of the Finnish sound-letter relationship in comparison to the extremely complex nature of the English relationship, an increasing number of Finnish children still experience difficulty with mastering the skills necessary for proficient reading with comprehension.

Prevalence rates in Finland approximate to 6% of children who will experience difficulties with acquisition of literacy, while more than 3% will have more perseverant difficulties which ultimately will hinder fluent reading with comprehension. This prevalence compares with readers of English, of whom 4-8% face problems in the attainment of accurate and fluent reading and spelling. Although the focal point in the English language for the assessment of reading difficulty lies predominantly with accuracy of learning letter-sound relations, an additional and more commonly-implemented measure incorporates reading fluency, especially in those languages where the orthography is more regular (e.g. Holopainen et al., 2001; Aro and Wimmer, 2003).

2.4. *Earliest practical identification*

What, then, is to be done to reduce the increasing numbers of children who have the potential to develop short-term and long-term difficulties in acquiring probably the single most influential and judgmental index of an individual's capacity in the western world: literacy? In terms of identifying those children at risk for developmental dyslexia, such children can be identified on the basis of familial incidence (a parent or sibling indexed risk sourced from recognised difficulties in the family) and in terms of their performance on those early developmental indices that predict reading acquisition.

As previously mentioned, the 'bottleneck' to skilled reading, even with the minimal cognitive load exerted by the regular relationship between letters and sounds in the Finnish language, is the fluent and automatic retrieval of these letter-sound relations. Such difficulties have been shown in children with average to above-average intelligence and, surprisingly, even in a few of those children who have enjoyed good or precocious language development in general (Lyytinen et al., 2006).

The decade-long follow-up of children in the JLD has facilitated a unique and ground-breaking insight into the catalysts that precede and predict the developmental trajectories of those children who risk reading failure in the school years. Although the neonatal and toddler measures are important, the observations relating to the manifestation of a pre-school 'bottle-neck' derived from confounded letter-sound knowledge is the most amenable and practical application with regard to effective identification and intervention.

3. Development of the reading game

During the last five years, the Jyväskylä lab has pioneered the development of the computer game 'Literate.' The award of a Marie Curie Excellence Grant in 2004 has facilitated extensive development of this game under the name Graphogame. Centered in Jyväskylä, the Graphogame project is currently in the process of implementing the game in Finland, UK, Switzerland and Holland, with secondary collaborations involving Zambia, Estonia and Chile.

The primary aim is to provide a user-friendly contemporary platform to facilitate early identification of, and intervention with, children who index familial risk for reading difficulties. Secondary aims, largely fuelled by the generic nature of the contents in terms of being well suited to general teaching (and not only support for learning difficulties), as well as by popular request from educational professionals, include the extension of the facility to general reading acquisition in the whole-class environment and as support for non-native language learners.

The computer game is based on a simple concept of a 'catching game' that drills children in the translating of sounds to letters in both directions, to aid both spelling and reading. In relating phonemes to graphemes, the child is presented via headphones with a sound (a phoneme or larger unit of sound such as a syllable or word) and asked to catch with the mouse the corresponding falling ball target (the ball contains from a

single grapheme to a letter string or word). The target item is simultaneously presented with up to eight alternative falling balls (distracters), the content of which prevents selection on the basis of the target's first letter or other 'easy' routes to identification. The child's task is to catch the correct item before it reaches the bottom of the screen.

An important dynamic element is incorporated into the game. This facilitates adaptation to the level of each child's ability and, thereby, sustains motivation and thwarts frustration in that the optimum level of playing is adapted to their performance based on the previous trials. In short, if a child's learning progresses quickly, then the rate at which the balls fall increases and the number of distracter items also increases. Conversely, if the child starts to experience difficulty, the rate of ball falling will slow down and the number of distracter items will reduce. The adaptation to individual rate of learning guarantees a success rate which maintains motivation to continue.

Progression to subsequent levels is based on attainment of correct identification of 80% of targets with intermediate provision of extra practice for targets that prove problematic. The most recent versions of the game adapt to the child's level on-line using computational tools such as Bayesian statistics (see Kujala et al., in press).

In relating graphemes to phonemes, the child is presented with a visual array of letter combinations with the requirement to click on the correct combinations in the correct order to effectively 'build' the target delivered via headphones. (e.g. for the auditory target /GREEN/, the child is required to 'build' the correct word by clicking on the visually-presented but jumbled components 'gr', 'ee' and 'n' in the correct order). Incorrect attempts at assembly are prompted by the computer's pronunciation of the wrongly-spelled item (e.g. if a child clicks on the visual order 'ee', 'n' and 'gr', they are auditorily prompted that they have spelled the pronunciation /EENGR/).

3.1. *Language-specific game contents*

We believe that the adoption of the consistency principle within the training of letter-sound correspondences, irrespective of orthography, is the most appropriate way in which to approach interventions for training letter-sounds. The consistency principle introduces those relations between letters and sounds that are the most dominant and most frequently-occurring in the language. In the Finnish language, this consistency is simple and straightforward at the level of the sound to letter and back to sound (phoneme-grapheme-phoneme).

This is not to say that acquisition of fluent reading in Finnish is simple, as the language is agglutinative in nature whereby inflections quickly result in the generation of multi-lettered and polysyllabic words of much longer length than those typically deployed in the early stages of reading English.

In the context of the English language, this consistency is not simple at the level of the sound to letter nor from letter back to sound. Some English researchers argue for a hierarchy of dominance of the phoneme-grapheme relationship (derived from 'rules') and ordered by frequency of occurrence of this relationship (e.g. Seymour, 1986). Others argue for a hierarchical structure of the syllable where phoneme-grapheme consistency is strongest for onsets and rimes (e.g. Treiman et al., 1995). Currently, the English implementation adopts the hierarchical rule model and follows the learning course of: 1) typical and simple phoneme-grapheme relations (e.g. the /I/ sound in *sit* and the /T/ sound in *top*); 2) typical and complex phoneme-grapheme relations (e.g. the /E/ sound in *wait* and the /K/ sound in *duck*); 3) atypical and complex phoneme-grapheme relations (e.g. the /E/ sound in *great* and the /N/ sound in *knot*); and 4) exceptions to the rule relative to the specific phoneme-grapheme relationship (e.g. *their*, *put*, *shoe*, etc).

3.2. Finnish implementation

Results from preliminary implementation of the game in Finnish schools are extremely promising. Hintikka et al., (2005) and Lyytinen et al., (2007), have demonstrated an increase in letter knowledge in children with initially poor pre-reading skills. More remarkably, these results were achieved after only a short period of playing the game, such that risk children playing the game advanced from behind to eventually match the performance of non-game-playing, non-risk peers. The important factor here is that the playing field was leveled between the two groups and perhaps the impending development of children's negative perceptions of their own failure relative to their peers was thwarted: factors that are so crucial to children's self-esteem and optimum receptiveness to further learning.

These early findings have subsequently prompted the Ministry of Education in Finland to finance a nationwide implementation of the game on a general basis in every school and home connected to the internet.

3.3. English implementation

Within the context of the Graphogame development in the UK, the game according to the rule-based consistency/frequency hierarchy has already been piloted with nursery children indexed by familial risk for developing literacy difficulties. The game is currently being implemented in selected schools in both Scotland (Angus region) and England (Liverpool region). The focus of the current implementation is children recognised by their teachers as experiencing difficulties with the acquisition of literacy (including second language learners and children with profound general learning difficulties). Game playing has been under way since Easter 2007, and initial feedback from teachers is very encouraging to the extent that children are still extremely motivated to play the game and also, more importantly, teachers are already recognising a visible improvement in reading performance in the classroom.

4. Implications for further developments

The earliest possible identification of potential difficulties (be these genetic or socio-economic in aetiology), and subsequent implementation of intervention, are both critical to the education systems of all countries, in both the developed and developing world. Additional crucial factors pertinent to identification and intervention involve practicality and cost-effectiveness, as well as the persistence over time of the remediative effects of the intervention itself and its impact in terms of engendering long-term learning. These factors are fundamental to the research aims of the Jyväskylä group and the development and distribution of the computer game in different languages.

Aetiologically, while the difficulties pertaining to a smaller proportion of children are genetic in nature, an increasingly large number of children's difficulties are socio-economic or environmentally based. More recently, with increased trans-national mobility, especially within the European Community, there is also a growing requirement to support children who are placed in schools in different countries and faced with learning in a language that is not their mother tongue. These factors underlie the requests for a more classroom-wide implementation by participating schools in both Finland and the UK over the forthcoming 12 months. Furthermore, in some developed and developing countries, English is the chosen language of non-native communication. It is, therefore, also the intention to implement the English language version of the game in the context of second language learning in Finnish schools and Zambian schools at the start of the next school year.

Practically and cost-effectively, the onus lies with research to provide methods of identification and intervention that are quick and easy for non-specialist staff to implement and also cost-effective and realistic. Many contemporary interventions, while effective, are often considered too time- and manpower-consuming and too expensive to implement on a more general level (Fawcett, 2002).

The computer game developed by the Jyväskylä lab addresses all these issues. From the cost point of view, access to computers for children in schools in the developed world is now commonplace and moves are afoot to extend the game in the developing world to platforms (such as hand-held devices and mobile phones) that do not require computers *per se*.

In terms of *practicality*, in being child-friendly in its design, even very young children are able to navigate the game with ease. Furthermore, adult supervision of game playing is minimal, thus freeing teacher resources from the time-consuming supervision of individual children during remediation.

So far as *identification* is concerned, the key index of identification of potential difficulty (letter-sound proficiency) is incorporated into the initial stages of the game and, again, frees teacher resources while, at the same time, providing a quick and effective measure of a child's potential difficulty.

Lastly, on the question of *intervention*, having already identified areas of difficulty, the game then focuses on the training and remediation of these areas through game playing itself and thus, again, frees teacher resources from intensive individual teaching.

Most importantly, all of the above can take place within a proactive and enjoyable setting for the child in question, freeing him or her from the often long-lasting negative feedback that results from repeated failures.

Technological innovation, therefore, can undoubtedly help children with severe learning difficulties to avoid the daily failures typically experienced in traditional face-to-face or group-based teaching environments.

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