Evaluation of Pre-Codia, a Computerized Reading Aid for Readers Suffering from Dyslexia

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Abstract

We present a usability evaluation where Pre-Codia, a novel computerized reading aid for persons suffering from dyslexia, was compared to reading text on paper. Pre-Codia is supposed to ease the reading process for dyslectics by inserting small visual cues into the words according to a morpheme or syllable based segmentation. In a balanced, within-subject design, 16 dyslectic subjects silently read two Swedish texts (~900 words) matched in difficulty, one non-segmented on paper and one morpheme-segmented presented on a computer screen using Pre-Codia. All subjects were Swedish students from grade 8-9 (M=15 years), 11 boys and 5 girls, diagnosed as dyslectics. In Pre-Codia, the minimum word length before segmentation was kept fixed (≥4 letters) whereas font size, background/font color, line spacing, and hyphenation mark length between segmented words was set individually by each subject. Objective metrics showed that Pre-Codia-rendered text was read significantly slower (107 wpm vs. 119 wpm) whereas comprehension assessed via multiple-choice-questions was not significant. Two subjective task load ratings out of nine, Perceived difficulty and Perceived effort were significant, favouring Pre-Codia. It is also interesting to note that Perceived reading speed was amongst the seven non-significant ratings. In spite of the fact that objective reading speed was higher on paper, eight subjects preferred text rendered by Pre-Codia whereas three were indifferent towards mode of text presentation.

Key words: Dyslexia, computerized reading aid, morpheme based segmentation.

1. Introduction

What differentiates readers with difficulties from proficient ones? For many decades, it was assumed that dyslexia was primarily due to visual problems, hence the expression “word blindness”. However, recent research has shown that awareness of the phonological sound structure of a language plays an essential role in developing normal reading skills. Mann (1998) has identified three different aspects of language processing that a person has to master to be a proficient reader. The first, *phonetic awareness* is fundamental for understanding how letters translate into phonemes, the smallest contrastive sound units of a language. The second is *morphological awareness*, which is essential for grasping how sequences of phonemes

become morphemes, the smallest meaningful units of a word, and eventually how words are constructed from morphemes. Finally, Mann notes that a solid *working memory* skill is necessary for reading as it enables the reader to link words, sentences, and eventually full passages together into a meaningful discourse. Pre-Codia is intended to ease the reading process for dyslectics by aiding them when decoding words, thus it primarily addresses the phonetic and morphological awareness aspects of reading. Working memory may be indirectly supported since the effort otherwise spent on decoding the text can be put into understanding it instead.

Next, we will look closer at the phonetic and morphological aspects of decoding words as these processes are in focus here. This is followed by an overview of how Pre-Codia works together with some findings from a previous evaluation. After that, we will describe the experimental design of the current evaluation and present the results. Finally, we discuss our findings and present some concluding remarks.

2. From Letters to Words

For dyslectics, the fundamental deficit when reading stems from problems handling the conversion from letters to sounds, or rather graphemes to phonemes (Hatcher and Snowling 2002). The reason for this is that most spelling systems does not have a one-to-one the mapping between graphemes and phonemes, instead multiple graphemes may represent a single phoneme. For example, the English word *show* is made up of four graphemes (s, h, o, and w), but only three phonemes (<sh>, <o>, and <w>). English is in fact often cited as a classic example of a non-phonemic, and thus in this sense more difficult, spelling system. Most other languages have a more straightforward, but far from consistent, mapping between how words are written and how they sound. Being able to make out the phonemes is important since they represent the smallest units in language that actually make a difference. By replacing a phoneme in a word with another phoneme, you will end up either with a different word or a word that makes no sense at all. For example, by replacing <sh> in *show* by <l> you get the word *low*, but replacing it by <a> gives you the nonsense word *aow*.

Difficulties when attaching sounds to letters makes it hard to use sounding out techniques to identify words, which slows down the initial acquisition of reading skills. This deficit also makes it harder to get a feeling for a text since it is difficult to grasp its rhythm, or more accurately its syllabic structure. Syllables are clusters of phonemes that are a natural result from how we open and close the vocal tract when speaking. A syllable consists of a voiced phoneme, the vowel, surrounded by a few unvoiced phonemes, the consonants. Since dyslectics usually do not have problems with spoken language they often have a fair grasp of syllables although they have difficulties making out the individual phonemes. To utilize syllabic rhymes when training phonological awareness has proved useful for dyslectics when practicing reading skills (Goswami 2003).

Phoneme recognition is fundamental for decoding as it makes it possible to recognize the building blocks of language, but understanding how they are wielded together into words is equally important for reading. Morphemes are the smallest meaningful units in a language. For example, the word *show* is made up of one morpheme (/show/) whereas the word *showtime* is made up of two (/show/ and /time/). Apart from being word themselves, morphemes may also be used to signal semantic differences. For example, the word *times* is made up of a stem (/time/) and a plural marker (/s/). Understanding morphemes helps the reader to break an unfamiliar word into comprehensible units. Morphological awareness is a

key factor when automating the reading process. Among readers in the later elementary grades morphological awareness is important for understanding more complex words with several syllables. The reader who has trouble with morphology will have problems recognizing as well as pronouncing long words (Lundberg and Hoien 1999, Hutzler and Wimmer, 2004).

3. Precodia, a computerized reading aid

Pre-Codia is a computerized reading aid assumed to ease the reading process for dyslectics by highlighting the underlying structure of an arbitrary text chosen by the reader. In this respect, it deviates from the traditional training programs that usually supply the reader with a predefined training text which may not appeal to the reader to the same extent as when s(he) is allowed to choose a text according to his or her own preference. When using the program, the text is first segmented based on a linguistic analysis where the words are separated in their phonological and morphological components. The text is then presented on the screen with small visual cues inserted between either its syllabic or morphological elements. The reader may alter the distance between the segments at any time while reading, thus increasing, and decreasing the level of support as choosen. Moreover, it is possible to set the minimum length a word must have before it is presented with cues. The user can set other parameters such as font size, font family, line spacing, and background as well as foreground colour. By providing the affordances to adapt the text presentation to match each reader's individual preferences, the users of Pre-Codia are being able to read texts of different complexity in a way that suits them best (Figure 1).

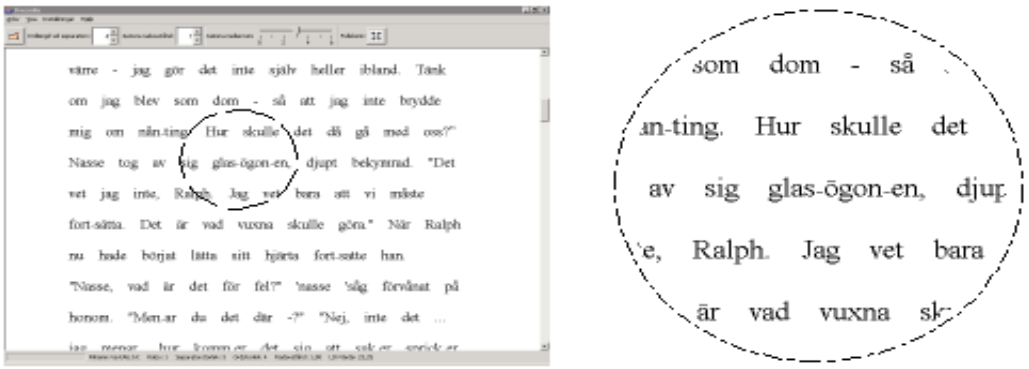

Figure 1. The Pre-Codia interface (left). The morphologic cues are visible in the word "glasögonen" (spectacles) in the enlarged portion of the screen (right).

The effect of using visual cues between syllables was evaluated in a previous study (Nilsson and Thunholm 2005). In a balanced repeated measurement experiment, 16 dyslectic subjects (age 16-18) silently read four different screen-presented texts using either three different cue sizes (2, 6, and 16 pixel length of hyphenation marker) or no visual cue at all, all other aspects of the presentation were kept fixed over conditions. Average reading speed without visual cues (non-syllable-segmented text) was 147 words per minute (wpm) whereas reading syllable-segmented text was significantly slower ($p < 0.005$) for all cue sizes, co varying negatively with increased cue size (113 wpm, 98 wpm, and 88 wpm, respectively). Reading comprehension was significantly worse ($p < 0.05$) when reading syllable-segmented text employing 6 and 16 pixel cue length compared to reading non-segmented. Subjective metrics also gave several significant results, non in favour of using visual cues: Six out of eight

subjective rating scales (Perceived: difficulty, effectiveness, reading speed, empathy, convenience and naturalness) scored significantly worse ($p < 0.05$) for syllable-segmented text.
Obviously, this was not a good result to say the least. Instead of aiding reading, it seemed that the introduction of visual cues between syllabic segments was outright counterproductive. We believe that the primary reason for this was that the subjects already had learned to cope with their lacking phonological awareness by recognizing whole morphemes or words instead. When we introduced cues into these, we thus made this recognition harder. Another reason may be that since the subjects read the texts silently, they may not have benefited from the syllabic structure of the text as much as they would if they were to read the text aloud. Now, we are primarily interested in silent reading and since syllabic cues did more damage than help, how would it be if we used morphological cues instead?

4. Experiment

The aim of the evaluation was to see how well reading morpheme-segmented text using Pre-Codia compared to using traditional text presentation on paper. In contrast to the previous experiment, we also wanted to see the combined effects of letting each subject alter all the settings in the program to his or her preferences. This experiment thus evaluates the merit of Pre-Codia as a reading aid compared to reading on paper rather than any singular aspect of how the text is presented in Pre-Codia.

4.1 Hypotheses

In order to assess the effects caused by reading morpheme-segmented text on screen by Pre-Codia and non-segmented text presented on paper, a repeated-measurement experimental design was adopted. The following null hypotheses were set for reading texts presented on screen and paper:

- No difference in reading speed
- No difference in comprehension
- No difference in subjective rating

The hypotheses were tested in SPSS v12 using the repeated-measurement General Linear Model (GLM). The significance level was set to 5% and the level of multiple comparisons was Bonferroni adjusted.

4.2 Design

We used a balanced within-subject repeated-measurement experimental design. Two conditions were used where each subject read two texts using both presentation formats. The conditions were balanced against presentation order and texts, giving us four combinations. These were repeated four times, giving us 16 experimental sessions. Each of the sixteen subjects was randomly assigned to one of the sixteen combinations.

4.3 Subjects

Sixteen subjects (eleven male and five female; mean age: 15) in the 8^{th} and 9^{th} grade that were diagnosed as dyslexics participated in the experiment. All had Swedish as their native language. The subjects were either enrolled at Nya Ängkärrsskolan in Solna, Stockholm (N=14), Sweden's only dedicated school for dyslexics, or were enrolled in a training program at SDC (Stockholms DyslexiCentrum, N=2). The intention was that those students that

belonged to the first quartile regarding silent reading proficiency should be excluded from the sample. A criterion for participation in the experiment was that the subjects' silent reading speed should not be too low (>70 wpm) since the experiment would then have taken too long to complete.

4.4 Texts

Three excerpts from the Swedish edition of the book Lord of the Flies (Golding, 2002) were used in the experiment. One excerpt was used as a training text and the two other were used in the experimental conditions. The difficulty of the texts was estimated using LIX (Björnsson 1968), a readability rating developed for Swedish text that is comparable to the Flesh index. A LIX rating of 25-30 is classified as easy to read. The Training text, extracted from page 48 and onwards (Swedish edition) was 935 words long (LIX=29). The experimental text denoted "A" consisted of 882 words extracted from page 182 and onwards (LIX=27). The experimental text denoted "B" was 865 words long and extracted from page 192 and onwards (LIX=27).

4.5 Apparatus

A Fujitsu Amilo laptop with a 15-inch TFT screen was used for the Pre-Codia (screen) condition. The minimum-morpheme-segmented word length was kept fixed (≥4 letters) whereas font size, background/font color, line spacing, and hyphenation mark length between segmented words was set individually by each subject. Depending on the selected font size and the size of the visual cues between morphemes, the number of pages varied (7-9 screens). The cursor keys, situated at the lower right-hand side of the laptop keyboard were used to turn pages. In the paper condition, the text was presented just as it appeared in a pocket book, e.g. using 11 pt. Times New Roman with left aligned margins and a line spacing of one. The number of paper pages amounted to three for both experimental texts.

4.6 Instructions

All subjects were instructed that it was the Pre-Codia application and not their individual performances that were being tested. They were instructed to read silently at a pace that was familiar to them. They were also instructed that at the end of each experimental condition (screen/paper), they would be asked to answer four questions referring to the text that they had read in order to check their retention. They were also instructed that they would be asked to rate their impression using nine different graphical rating scales.

4.7 Inventories

After each experimental condition, there were two inventories to fill in. The first was a comprehension test consisting of one open-ended question and three multiple-choice questions. The second inventory was a modified version of the NASA-TLX task load index (Hart and Staveland 1989). The following nine variables were rated on a graphical 100 mm scale with two anchor points (Low-High): Perceived difficulty, efficiency, understanding, (silent) reading speed, immersion, comfort, naturalness, concentration, and strain/effort.

4.8 Procedure

Since all subjects were unfamiliar with Pre-Codia, they started out by reading a training text using the software first. The different parameters that could be varied (font size, size of visual cue separating morphemes, line spacing, font colour and background colour) were presented by the experimenter and the subject was prompted to select a value for each of them before

starting to read (Table 1). If a subject discovered that s(he) wanted to change a parameter value, the experimenter changed it according to the subject's request. Each subject was given a training period of 4-5 minutes.

Table 1. Parameters set individually when reading, using Pre-Codia.

Parameter	Mean	Min	Max
Font size	20	18	24
Line spacing	0.34	0.1	0.8
Visual que length (0-6)	1	0	2
Font colour	Black (N=11)	Blue, red, white (N=5)	
Background colour	White (N=8)	Blue, red/pink, green, yellow, black (N=8)	

When having read the training text in screen mode using Pre-Codia, all the parameters were set according to the subject's demands and the experiment began. The subject first read either text A or B, presented in the screen or in the paper condition and then answered four questions and rated the reading experience on nine variables. Then the other condition was administered in the same way. Afterwards, each subject was asked which of the conditions s(he) preferred; text presented on paper or text presented using Pre-Codia. The whole experiment took between 40-55 minutes to administer depending on the subject's reading speed.

5. Results

All subjects performed well in the experiment and there were no problems with understanding what to do or how to do it. Although Pre-Codia was a novel program, none had any problems using it. The presentation of the results is divided into three sections: reading speed, comprehension, and subjective rating.

5.1 Reading speed

Reading speed was computed as words read per minute (wpm) based on the total time it took for the subjects to silently read the text. The null hypothesis regarding no difference in reading speed was rejected as there was a significant difference ($F[1,15]=9.804$, $p= 0.007$). The average reading speed when reading from paper was approximately 12 wpm faster than when reading from screen using Pre-Codia (Table 2).

5.2 Comprehension

Comprehension was enumerated as percent of correctly answered questions. There were small differences between reading on paper and using Pre-Codia and the null hypothesis was not rejected (Table 2).

Table 2. Reading speed and comprehension (N=16).

Condition	Reading speed (wpm)		Comprehension (%)	
	Mean	Std. dev.	Mean	Std. dev.
Paper	119	47.4	3.19	0.70
Pre-Codia	107	50.2	2.91	1.13

5.3 Subjective ratings

Subjective ratings were computed as percent of millimetres to the left of the tick mark on a 100 mm scale. The null hypothesis was rejected, as there were significant differences between the conditions. Perceived difficulty and Perceived strain/effort when reading from screen using Pre-Codia was significantly *less demanding* than when reading from paper ($F[1,15]=5.382$, $p= 0.035$ and $F[1,15]=6.556$, $p= 0.022$, respectively). None of the other seven ratings: Perceived efficiency, understanding (retention), (reading) speed, immersion, comfort, naturalness, or concentration was found to differ significantly (Figure 2).

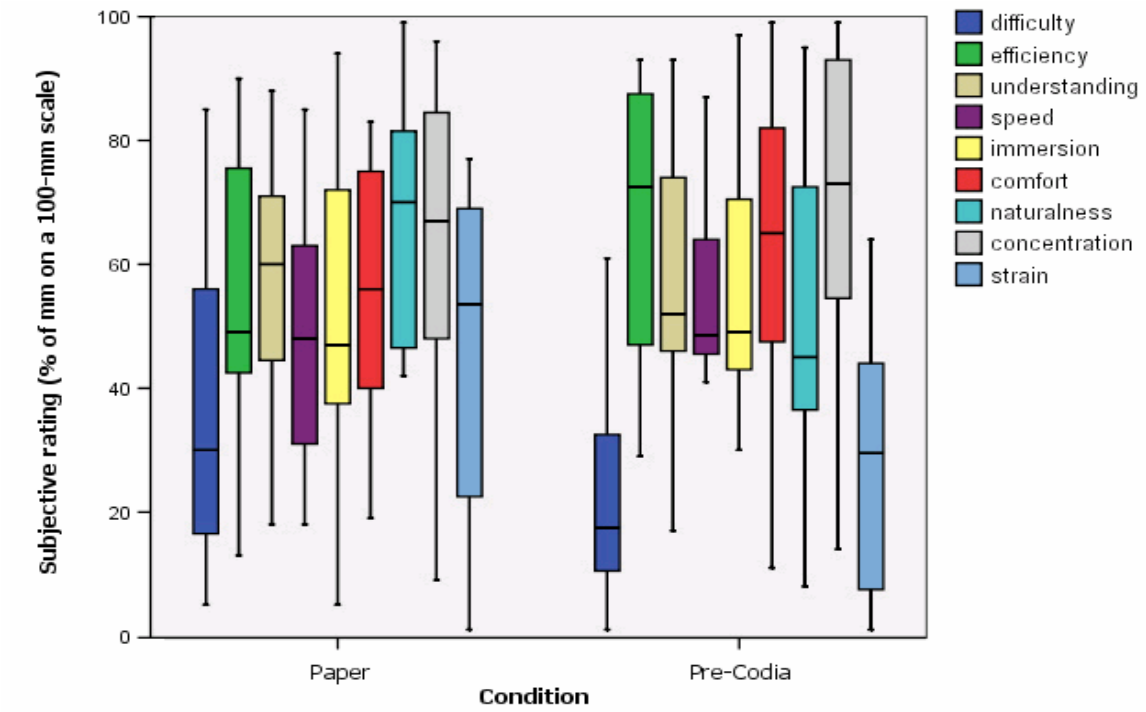

Figure 2. Box-plot of subjective ratings for Paper and Pre-Codia condition.

6. Discussion

In spite of the fact that objective silent reading speed was significantly faster by 12 wpm when reading from paper as compared to reading using Pre-Codia, perceived reading speed was not significant. This could be due to the fact that the number of electronic pages when reading with Pre-Codia were more numerous (6-9 pages) than when reading from paper (3 pages). The turn page cues could thus give the reader the impression that he was reading faster than he actually was, due to the more frequent page turns. 13 out of 16 subjects preferred to have the longer words in the electronic text parsed on a morpheme-basis, whereas three did not. Most subjects preferred to have the smallest division length ("1") when parsing words. Five of the subjects clearly stated that they preferred reading from paper in the natural way, although eight stated that they preferred reading from screen using Pre-Codia, employing morpheme-parsed text. It should be clearly stated that the effect of Pre-Codia is a combined effect of font size, morpheme-based parsing of words, font colour, background colour and line spacing. All these factors together constitute the positive effect of using Pre-Codia. It is possible that singling out one factor at the time, may not contribute to significant effects, but combining all factors together may yield the desired effect.

The most important aspect when suffering from dyslexia is after all that a proper word decoding takes place. It also appears that this decoding process is eased by changing background colour, lager font size, and increased line spacing. Compared to the fixed font size of 16 pt used in a previous experiment with Pre-Codia (Nilsson and Thunholm 2005), average font size chosen in this experiment was 20 pt.

The fact that none of the nine subjective ratings were in favour of text presented on paper whereas two (Perceived difficulty and Perceived strain/effort) were in favour of Pre-Codia shows the beneficial aspects of using Pre-Codia. Several limitations must be mentioned in the present experiment regarding generalizations. Minimum morpheme-segmented word length was set at a fixed value ($\geq$ 4 letters). This parameter value was thus *not* under the subject's control. It is possible that this value was set too low by the experimenter. This may account for the significantly slower reading speed. Since reading proficiency varies, it would have been better if the subject could vary this parameter while reading the training text as well. Only 8th and 9th grade students that had Swedish as their mother tongue participated. What is the outcome for lower grades and for grownups? An easy text was used. What is the outcome if texts with higher LIX values (35-45) are used? Will the outcome be the same? The subjects in this study only had a 5-min training period prior to using Pre-Codia. Will a prolonged training period result in a better outcome? The added value for the dyslectic reader of being able to select an arbitrary text was not assessed in this study, a feature that the authors regard as crucial.

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