Indications for *why dyslexics read more accurately* with the font Dyslexie

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What indications can be found in the theories explaining dyslexia for the findings that dyslexics read more accurately when words are presented in the font 'Dyslexie'?

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Abstract

The current literature has found evidence in three different explanatory theories of dyslexia for the proposition that dyslexics will read more accurately when words are presented in the font Dyslexie. The researched theories are those of the phonological deficit, deficits in eye motor workings and visual attention span, and the effect of crowding. Because the characters in Dyslexie be clearly distinguished from each other, this font can provide assistance in acquiring good character-sound linkage, necessary for the development of phonological awareness. Clearly recognizable letters could also encourage a longer visual attention span, because fewer eye movements are necessary when words are properly stored in and retrieved from memory. Crowding effects decrease when a font is the right size and has proper inter-letter spacing, as well as sufficient space between words. Dyslexie meets these criteria, which could engender more accurate reading. However, this assertion requires further empirical research.

Keywords : dyslexia – phonological awareness – spacing – visual attention span – crowding

Main and sub-queries:

Main query:
What indications can be found in the theories explaining dyslexia for the findings that dyslexics read more accurately when words are presented in the font 'Dyslexie'?

Sub-query:
What are the most important explanatory theories of dyslexia ?
How can these theories can be linked to the influence of fonts on reading problems?

Today, children's series such as "Diary of a Wimpy Kid" by Jeff Kinney and "Geronimo Stilton" are popular; they have been ranking in the top 10 of the best-selling children's books for quite some time (http://www.bol.com; http://www.selexyz.nl for ranking of the Dutch translations). Kinney makes use of a different font of increased size, which emulates a hand-written look, and many comic strip drawings serve to illustrate the story. The books of Stilton also use an enlarged font, but it is otherwise more regular. Important words are bolded, rendered in color and in a different font. In addition, these books also feature pictures as well as texts in frames. Alledgedly – there is no known sceintific data – these books are especially well-liked by children with dyslexia and several libraries offer them in specifically marked sections like the Easy Reading Point or Easy Reading Square.

Dyslexia is defined as a disorder characterized by a persistent problem with the learning and/or smooth application of reading and/or spelling on word level (Dyslexia Foundation Netherlands [SDN], 2008, p. 11), from which about 3 % of Dutch children suffer (Health, 1995). Dyslexia occurs when children are left behind in reading level relative to that of their peers, when development in this area does not match what was expected on the basis of intelligence, as long as the child has received adequate education and remedial instruction does not appear to help (Ghesquière & Van der Leij, 2007). These last two points show the tenacity of the problem: despite good education and extra attention, the process of learning to read stagnates. In our culture, where language occupies such a dominant place, this means serious obstacles in education arise (SDN, 2008) which have life-long effects (Cain, 2010). Therefore, it is important to investigate what could be done to best support children who are afflicted in this way.

The literature shows more and more evidence that dyslexia is a reading problem that can appear in multiple ways (Bellochi, Muneaux, Bastien-Toniazzo & Ducrot, 2013; Bosse, Tainturier & Valdois, 2007; Cain, 2010; Lobier, Zoubrinetzky & Valdois, 2012; Martelli, Di Filippo, Spinelli & Zoccolotti, 2009). Not all dyslexics experience the same problems and some dyslexics suffer from several types of problems. It can be stated that dyslexie is a multifactorial phenomenon concerning a heterogeneous group. Knowing this, it becomes obvious that remediation sometimes will and sometimes won't have the desired effect. When a treatment plan is set up, careful diagnosis should be carried out in order to investigate which exact failings afflict the dyslexic child (Ghesquière & Van der Leij, 2007). Can those be found in the area of phonological skills, or are the eye motor workings underdeveloped or perhaps even disrupted? Depending on the diagnosis, remediation will be better directed and the child can work on a tailored strategy to decrease the burden of his disorder.

To date, the usual remediation of dyslexia is: more practice with reading. This increases the vocabulary which should then allow for a higher reading speed (De Jong & Van der Leij, 2005). However, children who read poorly do not like reading (Martelli et al., 2009). If an experience of success fails to occur despite frequent practice, it is likely that the student gets frustrated and that his motivation for learning to read decreases (Ghesquière & Van der Leij, 2007). The result may be that the child starts practicing less, reducing the chance of improvement (Martelli et al., 2009). The student therefor has landed in a negative vicious circle. In order to prevent this, it is important to make sure reading stays attractive.

Christian Boer, a graphic designer and himself afflicted with dyslexia, invented a new font, called Dyslexie. According to the designer, most fonts have a primarily aesthetic origin in which letters resemble each other, which is precisely what makes them so stressful for dyslexics. The designer suggests that his design makes every letter distinctive, to the extent that the differences between the letters is large enough to allow dyslexic readers to read easier and more comfortably than regular fonts (see Appendix 1 for an example of a text in Dyslexia). In most fonts, the /b/, /d/, /p/ and /q/ characters can be mirrored while retaining their appearance. Boer has the made the / b / stand more upright, the /d/ slightly inclined to the right, the /q/ more similar to a capital (uppercase) and all four characters have received, at the bottom of their circle, a slightly thicker line. The characters can no longer be mirrored while retaining their appearance, they considerably differ from the original letter (see Figure 1).

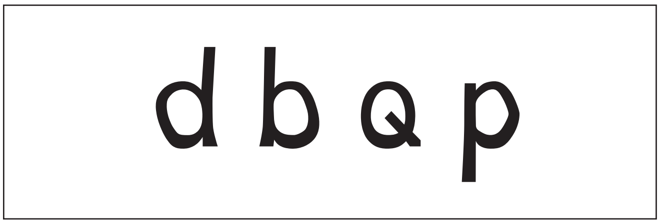

Figure 1. Differences between the /b/, /d/, /q/ and /p/.

In 2010, De Leeuw has, as a student at the University of Twente, researched the effects of this font on reading speed and accuracy. The study by De Leeuw compares the reading effects of Dyslexie with those of Arial, a common font belonging to the font group 'sans serif'. A 'serif' font contains small dashes at the ends of letters, in a 'sans serif' font these lines are missing (see Figure 2 for examples).

<u>Sans Serif typefaces</u>

Arial Regular, size 12
The lazy dog jumps over the quick brown fox

Trebuchet MS Regular, size 12
The lazy dog jumps over the quick brown fox

Dyslexie Regular
The lazy dog jumps over the quick brown fox

<u>Serif typefaces</u>

Courier New, size 11
The lazy dog jumps over the quick brown fox

Times New Roman, size 12
The lazy dog jumps over the quick brown fox

Bookman Old Style, New, size 11
The lazy dog jumps over the quick brown fox

Figure 2. Various fonts divided into 'sans serif' and 'serif'categories, visualizing the difference.

Because Arial and Dyslexie both belong to the 'sans serif' font group, they are similar in the sense that this font group evokes less crowding (Wilkins et al., 2007). In the study, 43 students did the One Minute Test and the Clapper Test; once in the font Arial and once in Dyslexie. In Dyslexie, fewer reading errors were made, but faster reading wasn't apparent. However, the study does not explain why Dyslexie engenders fewer reading errors.

The aim of this research is to find indications, based upon the current theories of dyslexia, to explain why dyslexics read more accurately when words are presented in the font Dyslexie. Utilizing a two-part question – what are the most common explanatory theories of dyslexia and how can these theories can be linked to the influence of fonts on reading difficulties – an answer will be sought systematically.

Several theories exist regarding the causes of dyslexia. The most recognized and general consensus is that of the phonological deficit (Bosse et al., 2007; Lobier et al., 2012; Ruffino et al., 2010; Sperling, Lu, Manis & Seidenberg, 2006; Vidyasagar & Pammer, 2009; Wagner & Torgesen, 1987). In recent years, however, growing evidence has been found that dyslexia can also caused in part by defects in the visual domain (Bellochi et al., 2013; Bosse et al., 2007; Lobier et al., 2012; Martelli et al., 2009; Vidyasagar & Pammer, 2009). For example, Bosse et al. (2007) found that both phonological deficits and deficits in visual attention span are independently related to dyslexia. Lobier et al. (2012) also found support for the hypothesis that not just phonological deficits, but also deficits in the visual attention span relate to dyslexia. Their research showed that the dyslexic group of children could handle less elements in both verbal and visual tasks than the control group and they were just as bad at visual tasks as they were at verbal ones. Facoetti et al. (2006) investigated whether there is a relationship between deficits in reading non-words and the visual attention span. The results of their study showed that especially dyslexics who fail at reading non-words had impaired visual attention, because they were bad at ignoring distracting stimuli in the top right corner of the eye, negatively impacting their reaction speed. Bellochi et al. (2013) investigated specifically the factor of eye motor workings as an explanation for dyslexia. They concluded that a motor failure is a secondary factor for dyslexia, because this defect could be reduced by training.

In relation to the visual attention span, a number of researchers focused on the effect of *crowding*, the negative effect that arises in recognizing symbols when other symbols (letters, characters or disruptive elements not related to text) provide distraction (Balas, Nanako Holtz & Rose, 2009; Bellochi et al., 2013; Martelli et al., 2009; Sperling et al., 2006; Spinelli, De Luca, Judica & Zoccolotti, 2002). Related to crowding is *spacing*, the space between the words and *inter-letter spacing*, the space between the letters of a word (Spinelli et al., 2002; Perea, Panadero, Moret-Tatay, & Gomez, 2012). If letters and/or words are too close to each other, the letters merge into one another so that the attention is distracted away from the reading of the word. Noise is another form of crowding that has no substantive addition to the text. For example: frames around the text, dots on the paper or a reduced contrast between the characters and the background. Spinelli et al. (2002) and Martelli et al. (2009) investigated the effect of crowding in the space between the letters within a word (inter-letter spacing) and the space between words (spacing). Spinelli et al. (2002) found that dyslexics had higher (i.e. worse) response times when reading words with distracting stimuli, such as other words, than the control group. In addition, the dyslexic children read faster when the space between letters within a word was moderately increased compared to normal inter-letter spacing. In the study by Martelli et al. (2009) it was shown that eleven year-old dyslexics needed more contrast and time to recognize long words than their peers. In addition, they required more space between letters and words and a larger font size than their peers. Wilkins, Cleave, Grayson and Wilson (2009) specifically investigated the effect of font and font size. They discovered that with a larger font size than standard, reading skill increased. Moreover, the *Verdana* font was compared to the font *Sassoon Primary*, with the former allowing for better and faster reading: the characters in Sassoon Primary look more alike than those in Verdana, making the letters difficult to distinguish (see Figure 5 for the differences, further down). Sperling et al. (2006) focused on the filtering of irrelevant visual information (noise), here taking the form of dots on a display screen, among twenty children from nine to fourteen years of age. Both the adult and the young among the poor readers were more affected by a high noise level than their control group.

As mentioned, the various explanatory theories will be examined to find indications for the findings that dyslexics read more accurately when words are presented in the font Dyslexie. Firstly, the most accepted hypothesis shall be considered: that of influence of the phonological deficit on dyslexia. Then, we will explain how the deficits in eye motor workings and visual attention span affects dyslexia. Next, the last theory concerning the effect of crowding will be explained. Per theory, the question will be answered of how it can be linked to the impact of fonts on reading problems. Finally, a relationship between these theories will be sought and discussed, as well as coupled to the workings of the font Dyslexie.

Hypothesis of the phonological deficit
(phonological core deficit hypothesis)

The definition of dyslexia indicates that there is a problem in the learning of reading and spelling (SDN, 2008). To understand this problem, it is useful to first explain how a language is structured and how a child learns to read f. A language is made up of characters, which in the western world are letters, and each letter represents a sound. The specifics of these sounds are dependent on the national language, as has an /a/ in English has a different sound than it does in Dutch. In Dutch, some letters have a unique and distinctive sound (eg /p/), while others have different sounds depending on the context in which they appear (eg, /c/). In addition, there are combinations of letters that represent another sound (eg /eu/). Each of these sounds is called a phoneme, being the smallest unit of sound that expresses the meaning of a word (/b/e /l /l/ or / b/a/l/l/). Being able to distinguish the various sounds is called phonemic awareness (Cain, 2010; De Jong & Van der Leij, 2005). With phonemes words are formed, which are then gradually stored in the correct order in the auditory memory (Ghesquière & Van der Leij, 2007). When a child learns how to read, they learn to recognize the characters that fit the sound, in what has been called the "character-sound link" (in Dutch: "teken-klankkoppeling"). After that, spelling is next ("ball" is spelled as /b/ /a/ /l/ /l/, forming the word /ball/) on the basis of sounding, coupled to tspelling rules. Orthographic knowledge is extended by the principle of decoding. Decoding is the skillof converting sounds to characters and vice versa, based on sound recognition (Cain, De Jong & Van der Leij). The newly learned words are stored in memory and in doing so build up a child's mental lexicon. Proficiency in decoding is evidenced by the ability to distinguish between existing and non-existing words, or non-words (Cain, De Jong & Van der Leij). The ability to manipulate and recognize phonemes in words is called phonological awareness (De Jong & Van der Leij). This will, for example, become clear in rhyming. A child with phonological awareness understands that / mouse/ rhymes with /house/, but /mouse/ does not rhyme with /milk/.

The processes involved in decoding are very similar to one another, but in the brain, these processes can be distinguished (Baddeley, 2003; Wagner & Torgesen, 1987). Verbal information (narration) is recorded directly through hearing in the auditory memory. However, verbal information that comes in visually (by reading), is first 'sounded' in the working memory, before being stored in the auditory memory (Baddeley, Wagner & Torgesen). This orthographic knowledge is used to correctly read and decode words, and enables an ever increasing link between writing and speech (De Jong & Van der Leij, 2005). When words are retrieved from memory quickly, we call the process automated. The greater the orthographic knowledge, the more knowledge is automated, the easier it is to decode unfamiliar words takes and the higher the reading speed will be (De Jong & Van der Leij).

Research indicates that the ability to recognize and manipulate phonemes, aka phonological awareness, largely relates to reading performance and that these two skills are independently related to general cognitive skills (Wagner & Torgesen, 1987). In addition, the phonological awareness is highly related to later reading skills (Wagner & Torgesen). In other words, phonological awareness is a significant predictor of the adequacy of ones reading ability. If there is a phonological deficit, there may be a slow reading speed, a slowly developed 'rhyming' consciousness or difficulties in the automation of word recognition (De Jong & Van der Leij, 2005). Dyslexics have a delayed processing speed when converting characters to sounds and for them the knowledge of letter/sound recognition is not correctly stored in their brain, which combined makes for a slower reading speed (Lobier et al., 2012; Sperling et al.., 2006). The visual information will thus be less adequately stored into the auditory memory.

The above makes it possible to discover the influence of fonts. The learning of letter-sound couplings gets a boost when a font makes a clearer distinction between the individual letters. This skill affects phonological awareness, the ability to manipulate and recognize phonemes in words. Since phonological awareness is causally related to reading (Wagner & Torgesen) this is an important part of the learning process. Decoding a written text is easier if the phonological awareness is high. This in turn has a positive effect on the reading speed and accuracy of reading skills, which also means reading errors will be reduced. Moreover, these positive reading experiences will not adversely affect reading pleasure, so that the frequency of practice can remain optimally high. One can conclude that fewer reading errors are made as characters look less and less alike.

Hypothesis of deficits in eye motor workings and visual attention span

Increasingly, researchers support the view that reading does not merely have a phonological origin. Reading also requires good eye motor workings and an adequate focus of visual spatial attention, or visual attention span (Bosse et al., 2007; Facoetti et al., 2006; Ruffino et al., 2010; Sperling et al., 2006; Vidyasagar & Pammer, 2009). The visual attention span is the ability to process a number of individual visual elements (Bellochi et al., 2013) simultaneously. It reflects the ability to make quick left-to-right eye movements, thereby filtering out all but the most important stimuli, which in the case of reading are: characters. This requires the ability to focus the attention long enough to process the information adequately: a sufficient attention span. This process is visible in the brain when brain activity is measured during a reading task. Studies in the past have made it clear that while reading, both the magnocellular and parvocellular visual systems are addressed (Bosse et al..) The magnocellular system is responsible for discerning the general outlines and can coordinate rapid movements, including eye movements. It represents the 'where' and 'how' system. In addition, this system plays a major role in focusing attention. The parvocellular system processes detail and color, and is also called the 'what' system. Although evidence is lacking for a causal link between deficits in the magnocellular visual system and dyslexia, this system does play a crucial role in the focusing of attention needed to read (Bosse et al. Facoetti et al. Sperling et al.).

Bosse et al. (2007) in their study found evidence for the proposition that a deficit in visual attention span causes dyslexia in a large subgroup of dyslexics. Inspiration for this research was found in the findings of other researchers that showed no phonological deficits among some dyslexic children. So the conclusion could be drawn that dyslexia affects a heterogeneous group and should be considered multifactorial. Although the study of Bosse et al. provides no reference to the use of fonts, it is nevertheless of interest to our thesis. This is because the study of Bosse et al. makes clear the contribution of the visual attention span in relation to dyslexia. The propositions of Bosse et al. is founded upon the *Connectionist multiple -trace memory model for polysyllabic word reading* of Ans, Carbonnel and Valdois (1998). The model explains that reading is supported by two systems: the global and the analytical system. In the global system, the knowledge of complete words is stored; in the analytic system, words are segmented on the basis of syllables and letters. This classification coincides with the aforementioned cellular visual systems. The study of Bosse et al. (2007) included two experiments: one with French children and one with English children. Both experiments used participants between nine and eleven years old. The control group was matched by age, not by reading level. The tests contained three components: reading comprehension, phonemic awareness and visual attention span. Each component was further split into three tasks. In the English experiment, non-verbal tasks were added as a control test; the researchers considered this necessary to rule out the influence of cognitive skills on the results. However, as expected, the group results hardly differed from one another on the nonverbal tasks. The French experiment showed that deficits in visual attention span explained dyslexia in 44% of cases. For 19%, phonological deficit was found to be the cause and for 15% and it was found to be a combination of both. For 22% no correlation was found. Results of the British experiment were very similar. Here, 34.5 % was responsible for deficits in visual attention, the same percentage was found for phonological deficits, 7% for both and 24% for no correlation. From these results, the conclusion may be drawn that a deficit in visual attention span and phonological deficit independently contribute to dyslexia and that they are significant predictors of reading skill.

The visual attention span plays an important role in the ability to deconstruct letters and syllables, as well as in reading speed and the ability to filter out stimuli. In addition, it is proposed that this attention span is even more important for the ability to read non-words than it is for common words (Facoetti et al., 2006). Non-words are not real words but seem like them. They need to be deconstrued into phonemes according to general rules of spelling (De Jong & Van der Leij, 2005). This skill is essential when learning new words, because children need to retrieve knowledge of words already stored in memory (Facoetti et al..) Thus, the existing knowledge is the basis for the ability of expanding and adding new knowledge. Facoetti and colleagues researched whether the slow results of dyslexics reading non-words were caused by a defect in the visual attention span. They divided 20 dyslexic children aged between nine and thirteen years into two group, one having a deficit when reading non-words and one having no such deficit. They were compared to one another, as well as to a control group of the same age. The heads of the participants were fixed in place and their eye movements monitored using a video camera. Participants were shown two circles (one left and one right) and had to react as quickly as possible when they saw a dot appear in the pre-specified circle. Examined were the number of correct answers and whether the response was different when dots appeared in either the left or the right circle. The response speed of both the control group and the group of dyslexic children without a non-words reading deficit, did not differ significantly when comparing the rate of response of the left-hand and right-hand circles. On the other hand, the group of dyslexic children with a non-words reading deficit did show a significant difference: the rate of response for the correct detection of the dots in the right-hand circle was considerably slower than those in the left-hand circle. Their analysis showed that the latter group struggled to filter out stimuli in the right corner of the eye and keep the focus on stimuli in the left corner. Especially when reading non-words, the ability to maintain visual spatial attention focused long enough is put to the test and here a subgroup of dyslexics will fail (Facoetti et al..)

Lobier and colleagues (2012) have also suggested that a significant proportion of dyslexics previously studied by them showed no phonological deficit, after which that they concluded that there must be more factors explaining the disorder; they also pointed in the direction of a visual cause. In the study of Lobier et al. dyslexic children were compared with children that could read normally on the basis of both visual verbal and visual nonverbal tasks. In the verbal tasks, numbers and letters were used; the non-verbal tasks made use of symbols. The dyslexic group failed equally at both tasks; i.e. they did comparably worse than the control group at both the nonverbal and verbal tasks. The researchers concluded that because dyslexics can process fewer visually supplied elements than people without this deficiency, dyslexics had a deficiency in visual attention from which their dyslexia stems.

Bellochi et al. (2013) also note in their review article the heterogeneity of the disorder. They discovered that the eye movements of dyslexics follow the same patterns as younger readers of the same reading level and that adults do the same with their eyes when they read difficult passages. With fast left-right eye movements, words are distinguished and decoded. The meaning of the word and/or phrase is then intended to become apparent. This process appeals to the orthographic knowledge and an efficient working memory. The rapid eye movements are seen as a sign that the reader has difficulty with the text. This can be a dyslexic reader, but also a skilled reader reading a foreign language or difficult text. From this, it follows that a-typical eye movements are not an attribute for dyslexia per se, but a phenomenon that occurs when reading a difficult text. Such rapid eye movements slow down the reading process and increase the probability of error (Bellochi et al..) To quickly decode a text takes a less heavy toll on working memory than slow decoding, after all, the information needs to be stored for a shorter period of time. Bellochi et al. concluded that deficits found in reading difficulties are secondary, and that the phonological deficit is a causal factor. Also, the oculomotor and visual attentional deficits appear to be trainable. Practicing the fixation of the eyes in the right place of a word decreases fast left-right eye movements over time.

The above research does not directly answer the thesis sub-query if arguments for to be the impact of fonts on reading problems can be found based on the hypothesis of visual attention span. However, on the basis of the above cited knowledge, an interpretation is possible. It has been argued that hard to read text evokes rapid, active eye movements which in turn causes a delayed processing of letters and words. The visual attention span is thus heavily taxed and has lower accuracy as compared with an easy-to- read text. If the font is difficult to read, the visual attention span comes under pressure. This could mean that a font has an indirect effect on the visual attention span. This thought leads to the hypothesis that when a font is easy to recognize, it taxes the visual attention span less, freeing up working memory for the decoding process. And that will benefit reading skills in general. This would need be verified via experimental research.

Hypothesis of the crowding effect

Studies into eye motor workings has brought to attention the phenomenon of crowding. It has been argued that for dyslexics, crowding is the cause of saccades, longer eye fixations and a higher number of fixations than normal readers. This slows down the reading process (Bellochi et al., 2013; Martelli et al., 2009; Spinelli et al., 2002). Crowding occurs when during the recognition symbols one is distracted by other symbols, or by disruptive elements not related to text (Bellochi et al.; Martelli et al.; Sperling et al., 2006; Spinelli et al.) An aspect of crowding is *spacing*, the space between the words, as well as *inter-letter spacing*, the space between the letters of a word (Spinelli et al. Perea et al., 2012). If letters and/or words are close to each other, the letters merge into one another so that the attention is distracted away from the word being read. Noise is another form of crowding, but with no substantive contribution to the text. Examples include: frames around the text, dots on the paper or the (lack of) contrast between the characters and the background. Because crowding has a negative effect on the reading process, it is of interest to examine whether the font Dyslexie excludes crowding as much as possible. In this thesis, the different types of crowding will be given a closer look, starting with the inter-letter spacing, then (word) spacing, and finally noise.

The inter-letter spacing is considered optimal if the letters that make up a word can be quickly identified as such and is seen as a remedy against crowding (Perea et al., 2012). Proper inter-letter spacing may also promote correct decoding, because it is easier to distinguish between the specific locations of individual letters. Compare for example the words *lie* and *lei*. The position of the /i/ determines the meaning and the sound of the word. This is called the 'undersecurity' of the character position within a word (Perea et al.)

Confusing character positions is an often reported problem for a lot of dyslexics (Vidyasagar & Pammer, 2009). If the spacing is too large, the individual characters are indeed recognized, but not the consistency of the letters to form a word (Perea et al.) Spinelli et al. (2002) investigated the effect of crowding with twelve year old dyslexic children. They did this by measuring verbal response times in a test which included both letters and symbols. First, a goal 'word', being a five-letter word or a string of five symbol,s was shown solo. Thereafter, the same goal 'word' or a slightly different one would be shown, again solo or surrounded by other words or symbol chains. By surrounding the goal 'word' with other, distracting information, crowding can be manipulated. The participant had to give a signal as soon as possible when a word/symbol chain was shown that was identical to the goal 'word', or another signal is the shown word/symbal chain differed. Spinelli and colleagues found that dyslexics were slower than the control group in recognizing the goal 'words' that were given in both solo and in crowding conditions. In addition, the response times of the dyslexics in crowding conditions was significantly slower than in the solo condition. In order to increase the reading speed of dyslexic children, a second experiment was performed. For this, words were presented in four different inter-letter spacing conditions in which the first inter-letter spacing was standard and smallest; with each following instance, the inter-letter spaccing was increased slightly, with the fourth condition having double the inter-letter spacing of the second condition (see Figure 3). The participants had to read the word aloud as fast as possible.

bordo

b o r d o

b o r d o

b   o   r   d   o

Figure 3. Four different conditions of inter-letter spacing, from Spinelli et al. (2002).

The second inter-letter spacing condition allowed all children to read faster than the standard inter-letter spacing, but the difference was significant only for the dyslexic group. The fourth condition provided for the slowest reading speed for both groups. From this study, it can be tentatively concluded that all children, but especially dyslexic children, benefit from a slightly increased inter-letter spacing. A reason to treat said conclusion with caution, is that Spinelli et al. limited their research to the recognition and reading of separate words only. Perea et al. (2012) went one step further, investigating the effect spacing has when reading a text. In their research they used the *Times New Roman* font, size 14, comparing the standard spacing with a spacing of +1.2. Compare *hotel* to *h o t e l*. They compared the results of a group of nine-year-old normal children with dyslexic children around twelve years of age. The normal children did not read significantly faster with the slightly larger spacing, while the dyslexic children did read significantly faster (81.9 compared to 74.1 words per minute). In addition, the control group showed no difference in accuracy, while that difference was again significant in the dyslexic group. Perea et al. confirmed in this study not only the findings of Spinelli et al. (2002) that dyslexics read words faster when the inter-letter spacing is increased slightly, they also showed that the increase of inter-letter spacing promotes speed and comprehension in reading texts, and that this spacing increase has no adverse effect on normal reading children.

In addition to inter-letter spacing, effects of manipulating the font size have been demonstrated (Martelli et al., 2009; Wilkins et al., 2009). Wilkins et al. (2009) have taken the Thai script as an example to explain the effect of font (see Figure 4). This script uses characters that Westerners are unfamiliar with. When characters are unknown, distinguishing between one character and another is more difficult than when they are known. A beginning reader must first become more adept at recognizing the individual letters. When these letters are larger, it is easier to make the distinction. This example makes clear that font size can contribute to the learning process of dyslexic beginning readers.

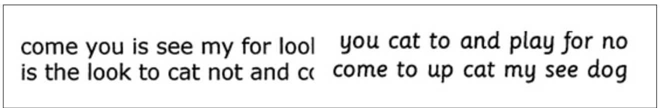

Figure 4. Fragment of a text in Thai to illustrate crowding effects with unfamiliar symbols, from Wilkins et al. (2009)

The font size that children are offered in books decreases as the target age of said books increases (Wilkins et al., 2009). Wilkins et al. (2009) have suggested that this size decreases faster than the progression of children's reading. Their research substantiates this assertion. In the first study they offered seven-year-old children without any reading disorder two similar texts in the Arial font. One text was in font size 22 and the other was in font size 26. It should be noted that font size 22 is usually offered to five year olds (Wilkins et al., 2009). The results showed that the sentences were read significantly faster in larger font. In the second experiment, they investigated the effect of different fonts. For this, the participants had to read words correctly and quickly (similar to the Dutch One-Minute-Test). In the initial test, the font *Sassoon Primary* (see Figure 5) was used, with the font size decreasing as the difficulty increased. Sassoon Primary is used extensively in British primary education. For the experiment, this list was adapted by keeping the font size the same, at 24 pt. Participants were presented both lists, the original and adapted ones. Results showed significantly increased reading skills, by approximately four months (meaning that the reading level reached in the modified test is similar to the reading skills of children who are four months older on average). Wilkins et al. (2009) noted that the font Sassoon Primary is well-known to cause children to make more reading errors, because the directions/lean of the characters has too many similarities meaning the characters look too much alike (Wilkins et al., 2007). In two experiments that followed, they examined if Sassoon Primary would be read slower than *Verdana*, an alternative font, which is known to have less similar looking/leaning letters. See Figure 5 below for a comparison of the two fonts. The results of these two studies showed that both the accuracy and the reading speed differed significantly in favor of Verdana. Moreover, 60% of participants reported a preference of reading in Verdana.

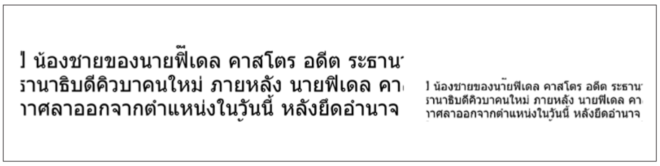

Figure 5. Verdana font (left) versus Sassoon Primary (right), from Wilkins et al. (2009).

From the above results it can be concluded that font size can make a positive contribution to the reading speed of normal readers. The same effect was studied by Martelli et al. (2009) for dyslexic readers. They investigated whether crowding is responsible for the slow reading speed characteristic of dyslexia in three experiments. In the first experiment, they subjected eleven dyslexic children and a control group of peers to a computer test in which letters and ten letter words had to be identified as quickly as possible. The background of the computer screen added more and more contrast as time progressed. For some items, additional noise was also added. This first experiment showed that dyslexic children need a higher level of contrast to distinguish between words, even though they rquired the same contrast as the control group when single letters were presented. In the control group, no difference was found between words and letters. When noise was added, both groups required more contrast. In addition, the dyslexics needed more time in order to identify the words than the control group. Martelli et al. concluded that dyslexics can process information less quickly and accurately than normal readers, unless they are given more time, and found confirmation for the proposition that dyslexia is adversely affected by crowding. In the second experiment, sixty children, half of which were dyslexic, were tested to identify letters in the vicinity of a letter to the left and a letter to the right of the target character. It was investigated whether spacing made a difference in the response times. In addition, they tested whether the font size had an influence on these times as well. The dyslexic children needed a higher amount of spacing in order to identify the correct target letter. However, the size of the character had no influence on the required spacing. In the third experiment they looked at the relationship between the reading of long words with a certain font size and inter-letter spacing. By increasing the print size, both the character size and the inter-letter spacing were increased. Said font size increases have a maximum range in practice, referred to as the critical print size (Martelli et al.) At a certain size, the effect on error-free reading levels off, until no further effect is noticeable. In this experiment Martelli et al. tested 29 children, including 13 that were afflicted with dyslexia. They were shown lists of words presented in four print sizes that had to be read aloud. The words that were read correctly were counted. All participants showed that literacy increased as the font size increased, up to a certain maximum. The critical print size was higher for the dyslexic children than for control group. In addition, the maximum reading skill of dyslexic children remained lower than that of the control group. From this research by Martelli et al. it can be concluded that dyslexics benefit from an enlarged font which also increases the inter-letter spacing, so that crowding is avoided. This increases their reading skill, even though it will in all likelihood remain lower than that of their peers.

The effect of noise was examined by Sperling et al. (2006). They found evidence for the hypothesis that the reading and language development of those with poor reading skills was further harmed by their inability to ignore noise. In their study they first compared adult readers, both good and poor, of about twenty years old. Then they performed the same experiment with children around the age of twelve. They asked the participants to respond as quickly as possible when they could distinguish moving ' signal-dots' from 'noise-dots'. The so-called poor readers among the participants (both children and adults) were found to be much less capable of doing so than the good readers. In addition, it was found that the absence of noise allowed the poor readers, both young and adult, to perform on a level similar to the good readers. The conclusion can be that crowding, when taking the form of noise, has a negative effect on the reading skills of poor readers while having no effect on good readers.

In summation, it can be posited that the effect of crowding causes reading problems. Serif fonts generate unnecessary noise, because the dashes in the letters create too many similarities making it more difficult to identify them. Various studies show that fonts that provide clearer distinctions between the individual letters engender fewer reading errors and a higher reading rate.
An enlarged font increases overall reading skill, as does increased space between the letters. The effect of increasing the space between the words is limited by a general threshold, regardless of the font type: a spacing slightly greater than standard will produce the best results. A font that is made to combat dyslexia must therefore take into account the effect of crowding.

Conclusion

To answer the question what evidence can be found for the findings that dyslexics can read more accurately when words are offered in the font Dyslexie, the scope of this thesis has been limited to the three most frequently mentioned and discussed explanatory theories, namely that of the phonological deficit, the deficit of the visual attention span (associated with oculomotor deficits) and the effects of crowding.

By studying these different explanatory theories, it has become possible to reconcile the theories, examining them in relation to each other and in relation to the use of different fonts. For starters, science has proven in various ways that there is a causal link between phonological awareness and dyslexia (Bellochi et al., 2013; Bosse et al., 2007; Wagner & Torgesen, 1987). Learning to read is a process in which knowledge and skills are piled up. If a letter is sufficiently different from other characters, this has beneficial effects on the acquisition of character-sound links, which means phonological awareness can grow. In the font Dyslexie, clear distinctions between the various letters can be seen (see Figure 1 and 2 and Appendix 1), which should be able to support the development of the phonological awareness. Thereby, a prime indication has been found for why dyslexics read more accurately when words are presented in the font Dyslexie. In addition, because less reading errors are made, the font can also contribute to an increase in reading pleasure and thus break the negative vicious circle.

There is another observation to be made. Above, it has been stated that as long as a student experiences success, the student remains motivated to practice, so he/she increases his/her vocabulary, which in turn has a positive effect on reading speed (De Jong & Van der Leij, 2005). A possible result is that over time, the effects of his/her dyslexia decrease or stabilize, at least with regards to the trained language. When the phonological awareness gets to a point where it is sufficiently well developed, an increase in reading speed can be expected. This implies that when children learn to read with the font Dyslexie, then besides accuracy, reading speed will also increase. To test this hypothesis, lengthy empirical research is needed, in which a group of young children vulnerable to the risks of dyslexia use the font Dyslexie for their reading education and their development is followed over the course of a few years. When their reading skills turn out to be higher than those of a control group, the proposition can be confirmed that the font Dyslexie positively influences both the accuracy and reading speed.

In the literature on the hypothesis of deficits in eye motor workings and visual attention span, no direct answer can be found to the question whether this theory can be linked to the impact of fonts on reading problems. However, the relationship between a phonological deficit and a deficit in visual attention span has already been proven (Baddeley, 2003; Bellochi et al., 2013; Bosse et al., 2007). Research shows that a hard-to-read text engenders active eye movements, which slows down the processing of the text (Bellochi et al.) The eyes need more time to decode the perception correctly. This delay makes additional demands on the visual attention span and a lowered accuracy will be the result. If the simultaneous processing of letters causes difficulty for a dyslexic child, the working memory is overloaded: first the individual letter needs to be recognized, then the series of letters must be converted to a word by ‘sounding’ (phonology). This will be stored in the working memory until the next words of the sentence are decoded, in order to grasp the meaning of the sentence. Both the visual memory and auditory memory are hard at work. Meanwhile, for a normally reading child words are automated and need only be retrieved from the auditory memory and hence are given meaning through the working memory (De Jong and Van der Leij, 2005; Ghesquière & Van der Leij, 2007). The hypothesis that stems from the examined literature is that when a font is easy to recognize (eg. Dyslexie) less eye movements are necessary and the visual attention span is taxed less (Bellochi et al., 2013; Facoetti et al., 2006; Lobier et al., 2012). This leaves more memory for the decoding process, which improves both the accuracy and reading speed. Again, an experimental study is needed to test this hypothesis, for example, by observing ocular movements when reading letters in the Dyslexie font compared to another sans serif font. If the findings confirm that less eye movements are necessary in order to recognize letters in Dyslexie and response times improve compared to the other font, then this can be interpreted as proof for the proposition that Dyslexie has a positive influence on the visual attention span positive.

The explanatory model of the crowding effect gives clear reasons for this thesis' sub-query regarding the impact of fonts on reading problems. Wilkins et al. (2007) showed that serif fonts especially have too many similarities between characters, and are therefore slower to read than sans serif fonts which have more internal differences. Dyslexia is a sans serif fonts. The crowding effect can be reduced by increasing inter-letter spacing, making sure the letters themselves are placed with sufficient distance from one another (Spinelli et al., 2002; Perea et al., 2012; Wilkins et al., 2009). Moreover, the distance between words should be sufficiently – but not too – great to see the consistency of the letters that form a word (Perea et al.). Wilkins et al. (2009), and Martelli et al. (2009) have argued for the importance of the size of a font. According to Wilkins et al. (2009), the fonts that children are offered by children's books are reduced prematurely. This is economically efficient (Wilkins et al., 2007), because more letters – and thus more words – will fit on a page. However, a larger font engenders a higher reading speed and increases the accuracy for all young readers. Nevertheless, this size increase is limited by a maximum, which means each font has a perfect size, which is larger for dyslexic children than it is for normal readers (Martelli et al.) In addition, dyslexics appear to be more sensitive to external noise than ordinary readers are. Dyslexics are more easily distracted and have more difficulty keeping their attention focused. This finding can also be seen in relation to the hypothesis of the visual attention span, because crowding disrupts the attention of the dyslexic child, adversely affecting reading results.

When the design of the font Dyslexie is examined more closely, it seems that this font could indeed promote accuracy in reading. The inter-letter spacing is slightly larger than usual and the shape of the letters differs from one another. In addition, the size of the characters seems right. However, this assessment requires further investigation: have inter-letter spacing, (word) spacing and font size been used appropriately? And does the design contain any unnecessary noise? Again, an experimental study could confirm these propositions; one similar to that of Martelli et al. (2009), in which different sizes and inter-letter spacings of the Dyslexie font are examined and compared.

Along with the above conclusions it should be noted that dyslexia is a disorder that afflicts a heterogeneous group, and is multifactorial in nature. This means there is a chance that not all dyslexic children will benefit from reading texts in the font Dyslexie. In this study, however, several indications have been found within three explanatory theories of the disorder dyslexia, so chances are that many children benefit in several different ways when texts are presented to them in the font Dyslexie.

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Appendix

Your own text in Dyslexie

Het huidige literatuuronderzoek heeft verschillende aanwijzingen gevonden in drie verklaringstheorieën van dyslexie voor de stelling dat dyslectici meer accuraat lezen als woorden aangeboden worden in het lettertype Dyslexie. De onderzochte theorieën zijn die van het fonologisch tekort, tekorten in de oogmotoriek en visuele aandachtsspanne, en het effect van crowding. Omdat de letters in Dyslexie zich duidelijk van elkaar onderscheiden, kan dit lettertype ondersteuning geven bij het verwerven van goede teken-klankkoppelingen, die nodig zijn voor de ontwikkeling van het fonologisch bewustzijn. Duidelijk herkenbare letters zouden ook de visuele aandachtsspanne kunnen bevorderen, doordat minder oogbewegingen nodig zijn als woorden adequaat in het geheugen opgeslagen zijn en opgehaald kunnen worden. Crowding effects verminderen als een lettertype de juiste grootte en inter-letter spacing heeft en woorden met voldoende ruimte uit elkaar staan. Dyslexie voldoet aan deze criteria waardoor meer accuraat gelezen zou kunnen worden. Deze stelling vraagt echter om nader empirisch onderzoek.

Appendix 1: An example of a text fragment (in Dutch) in the font Dyslexie