Chapter 31
Technologies for Dyslexia

Maria Rauschenberger, Ricardo Baeza–Yates and Luz Rello

Abstract Nowadays, being excluded from the web is a huge disadvantage. People with dyslexia have, despite their general intelligence, difficulties for reading and writing through their whole life. Therefore, web technologies can help people with dyslexia to improve their reading and writing experience on the web. This chapter introduces the main technologies and many examples of tools that support a person with dyslexia in processing information on the web, either in assistive applications for reading and writing as well as using web applications/games for dyslexia screening and intervention.

31.1 Introduction

The *American Psychiatric Organization* defines dyslexia as a *specific learning disorder* which affects around 5–15% of the world population (American Psychiatric Association 2013) (more information can be found in this book in the chapter *Cognitive and Learning Disabilities*). A person with dyslexia has difficulties to read and write independently of intelligence, the mother tongue, social status, or education level. Hence, people with dyslexia understand the meaning of the words but do not always know how to spell or pronounce the word correctly. This means that children with dyslexia do not show any obvious difficulties in other areas. This is the reason why *dyslexia* is also called a *hidden* disorder. Often, this results in bad grades in school and frustration for the children (40–60% of children with dyslexia show symptoms of psychological disorders (Schulte-Körne 2010) like negative thoughts,

M. Rauschenberger (✉) · R. Baeza–Yates
Universitat Pompeu Fabra, Carrer de Roc Boronat, 138, 08018 Barcelon, Spain
e-mail: Maria.Rauschenberger@upf.edu

R. Baeza–Yates
e-mail: ricardo.baeza@upf.edu

L. Rello
IE Business School, IE University, Calle de María de Molina, 11-13-15, 28006 Madrid, Spain
e-mail: luzrello@acm.org

Y. Yesilada and S. Harper (eds.), *Web Accessibility*, Human–Computer Interaction Series, https://doi.org/10.1007/978-1-4471-7440-0_31

sadness sorrow, or anxiety) and the parents over many years. Moreover, these are common indicators for detecting a person with dyslexia.

As a matter of fact, children with dyslexia can learn the spelling of words or decode words for reading but they need more time to practice. For example, for German, Schulte-Korne et al. state that children need two years instead of one for learning how to spell phonetically accurate words (Schulte-Körne 2010). Hence, to give children with dyslexia more time to practice, avoid frustration and the possibility to succeed, early detection is needed. Although a person with dyslexia is able to gain reading comprehension and spelling accuracy, a certain degree of difficulty will most probably remain and assistive applications for reading and writing are helpful.

Even though language acquisition depends on the syllabic complexity and orthographic depth of a language (Seymour 2003), results show that similarities between readers with dyslexia in English and German are far bigger than their differences (Ziegler et al. 2003). Also, similar types of errors were found in texts written by people with dyslexia for English, Spanish (Rello 2014) and German (Rauschenberger et al. 2016). Multiple factors have been investigated to find the causes of dyslexia and measuring it, as well as the skills that need to be trained to improve reading and writing (Catts et al. 2017).

It has been argued that dyslexia might be mainly phonological and perception differences could be explained with electric oscillations (Goswami 2011). Furthermore, previous research has related speech perception difficulties to auditory processing, phonological awareness and literacy skills (Rolka and Silverman 2015; Tallal 2004). Phonological deficits of dyslexia have also been linked to basic auditory processing (Hämäläinen et al. 2013). The auditory perception of children with dyslexia has been proven to be related to the sound structure (Huss et al. 2011), as well as to the auditory working memory (Männel et al. 2016). Nondigital approaches, e.g., Jansen et al. (2002) try to predict the literacy skills of children with the phonological perception, phonological working memory processing, long-term memory, and visual attention (quoted after Steinbrink and Lachmann 2014).

Another line of research suggests that reading impairments are due to the visual-spatial attention and poor coding instead of phonological difficulties (Vidyasagar and Pammer 2010). In fact, non-similar sounds might be used as a compensation strategy to cope with dyslexia, which breaks down when we have phonetic ambiguity, that is, we see a symptom of the problem but not the real cause.

Apart from this, visual discrimination and search efficiency are being used as predictors for future reading acquisitions (Franceschini et al. 2012). Even more, recently, the missing visual asymmetry is proposed as one of many reasons which might cause dyslexia (Le Floch and Ropars 2017).

Lately, it has been shown that computer games are a convenient medium to provide an engaging way to significantly improve the reading (Gaggi et al. 2017; Kyle et al. 2013) and the spelling (Gaggi et al. 2017; Rello et al. 2014) performance of children with dyslexia. Additionally, it was shown that children with dyslexia could be detected easily and cost-efficient with a web tool that, among other things, analyses word errors from people with dyslexia (Rello et al. 2016).

A person with dyslexia has difficulties to learn how to read and write through their whole life depending on the assistive tools used as well as the detection date or/and intervention method duration (more information can be found in this book in the chapter *Assistive Technologies*). Since there are already various software tools, we present the main similarities through tables and point out key differences in the text.

The next section give an overview of applications to support people with dyslexia to make the web accessible when reading or writing as well as the relatively new field of online tools for screening and intervening with web technologies to cope with dyslexia. We argue that web accessibility for dyslexia is more than only tools which help to read and write (Rello 2015). We end with a discussion, future directions and conclusions.

31.2 Assisted Reading for Dyslexia

Assisted reading can be accomplished with the existing readers or new applications, especially designed for people with dyslexia. In both cases, what is important are the available features and how they can be customized. The British Dyslexia Association updated their *Style Guide* in 2018 on the presentation of content, writing style, and text to speech (TTS), which we take into account for the comparison of applications (British Dyslexia Association 2018).

In the next subsection, we give an overview of different approaches to design text customization, test simplification, and text to speech to improve the reading performance and/or comprehension for people with dyslexia.

31.2.1 Text Customization

How a text is presented and how a person with dyslexia likes to perceive it, is very personal (Gregor and Newell 2000). Therefore, different parameters can help to improve the readability for individuals depending on the customization.

But not every parameter improves the reading performance or comprehension. Various studies explore the different parameters for readability, comprehension, and reading performance. For example, studies provide evidence that the font type has an impact on the readability, i.e., *italics* and *serif* should be avoided (Rello and Baeza-Yates 2016, 2017; British Dyslexia Association 2018). Fonts like *Arial, Courier, Helvetica* and font families like *roman, sans serif* and *mono-spaced* are suggested to increase readability. On the other hand, fonts specifically created for people with dyslexia (Wery and Diliberto 2017) have not be proven better than conventional fonts (Rello and Baeza-Yates 2016). Also, there is evidence that the font size has an significant impact on the readability while line spacing does not Rello et al. (2013).

The background color is also important since people without dyslexia chose black over white as the most readable option compared to people without dyslexia (93.88%

Table 31.1 Parameters that can be customized in assistive reading tools

Parameter		Font	Size	Spacing
Tools				
AccessibleNews	Rello et al. (2012)		✓	✓
Amazon Kindle	Amazon (2018), Wikipedia (2018a)	✓	✓	✓
Apple Books	Apple (2018), Wikipedia (2018b)	✓	✓	
ClaroRead	Claro Software Ltd. (2015)	✓	✓	✓
DysWebxia	Rello (2014), Rello and Baeza-Yates (2014)	✓	✓	✓
Firefixia	de Santana et al. (2013)	✓	✓	✓
Google Play Books	Google (2018), Wikipedia (2018c)	✓	✓	✓
IDEAL	Kanvinde (2012)	✓	✓	✓
MultiReader	Petrie et al. (2005)		✓	
Text4All	Topac (2012)	✓	✓	✓
WebHelpDyslexia	de Avelar et al. (2015)	✓	✓	✓

compared to 60% Rello and Baeza-Yates 2017). A medium-scale study ($n = 241$) contributed that (1) background colors have an impact on the readability for people with and without dyslexia, (2) warm background colors are beneficial for the reading performance, and (3) cool background colors decrease the readability (Rello et al. 2017). Also, the background color is reported to be correlated with the size of the text (Rello and Baeza-Yates 2017). Another example is line spacing which has not been proven to have a significant effect on readability and personal preferences (Rello and Baeza-Yates 2017).

Already various guidelines British Dyslexia Association (2018), de Santana et al. (2012), Miniukovich (2017), WAI (2018) have been proposed, mainly with recommendations for readability on the web and digital devices. In Table 31.1, we compare the most important parameters to improve the readability of reading applications or/and recommended by guidelines.

The three most popular reading applications are: the *Amazon Kindle* (Amazon 2018; Wikipedia 2018a), *Apple Books* (Apple 2018; Wikipedia 2018b) (previously know as iBooks), and *Google Play Books* (Google 2018; Wikipedia 2018c). Nearly, all applications include the three parameters that should have an effect on readability. However, *MultiReader* can only change one parameter (Size) and two applications can change only two parameters, i.e., *Apple Books* (Font and Size) and *Accessible-News* (Size and Spacing). Apart from readers for e-books or other types of digital documents, the tools are mainly designed for a certain context like reading the news (*AccessibleNews*) or adapting existing web pages (*Text4all*). The *reading ruler* from WebHelpDyslexia is the only feature to address the confusion while reading and changing rows.

Table 31.2 Available text simplification features

Feature		Synonyms	Simplification	Definition
Tools				
AccessibleNews	Rello et al. (2012)			
Amazon Kindle	Amazon (2018), Wikipedia (2018a)	✓		✓
Apple Books	Apple (2018), Wikipedia (2018b)			✓
ClaroRead	Claro Software Ltd. (2015)			
DysWebxia	Rello (2014), Rello and Baeza-Yates (2014)	✓		
Firefixia	de Santana et al. (2013)			
Google Play Books	Google (2018), Wikipedia (2018c)		✓	✓
IDEAL	Kanvinde (2012)			
MultiReader	Petrie et al. (2005)		✓	
Text4All	Topac (2012)	✓		
WebHelpDyslexia	de Avelar et al. (2015)	✓		

31.2.2 Text Simplification

After a text is accurately displayed, the person needs to comprehend the text. One possible help to make understanding a text easier, is simplifying the content. Either a complex word will be replaced with the most simple synonym or various synonyms are presented at the user's request (Rello et al. 2013). Also, a dictionary function is useful to look up foreign words but also non-foreign words with a similar spelling like *quiet* and *quit* to precise their meaning in a given context.

In Table 31.2, we compare the available features for reading applications. The challenges for simplifying with synonyms are polysemic words (Rello and Baeza-Yates 2014). Especially, if synonyms need to be found in a sentence or short phrase as, e.g., in a *Twitter* tweet or a *Reddit* post. Additionally, simplifying depends a lot on the person's ability itself. Since dyslexia is a learning disorder and not a cognitive disability, the simplification depends more on the typographical errors and not on the complexity of the content. Research shows that people with dyslexia encounter specific difficulties with phonetically or orthographically similar words or letters (Wyke 1984; Rello et al. 2016; Rauschenberger et al. 2016). To raise awareness for these kinds of words, *ClaroRead* colors words with a similar pronunciation. Colors are also used to differentiate similar looking letters as in *SeeWord*. In Rello et al. (2013) it is also shown that people with dyslexia prefer to see synonyms of complex words rather than direct text simplification.

Table 31.3 Example tools with and without native text to speech

YES		NO	
Amazon Kindle	Amazon (2018), Wikipedia (2018a)	AccessibleNews	Rello et al. (2012)
ClaroRead	Claro Software Ltd. (2015)	Apple Books	Apple (2018), Wikipedia (2018b)
Google Play Books	Google (2018), Wikipedia (2018c)	DysWebxia	Rello (2014), Rello and Baeza-Yates (2014)
IDEAL	Kanvinde (2012)	Firefixia	de Santana et al. (2013)
MultiReader	Petrie et al. (2005)	Text4All	Topac (2012)
		WebHelpDyslexia	de Avelar et al. (2015)

31.2.3 Text to Speech

Text to speech (TTS) can be used to hear the text without the need to read it. This means that the written text is read to the user by an engine and not recorded before by a person as it is the case for audio books. These tools could be useful for a person with dyslexia as well as for a person with visual impairments among other disabilities. A TTS engine might support different languages and some are already included in popular operating systems. TTS APIs are available in the most used mobile operating systems such as Android or iOS and can be used by any application, although some people report difficulties while using them, for example in iBooks (Pipusbcn 2017).

In Table 31.3, we compare the availability of proprietary text to speech (TTS) in reading applications. This functionality can be used to follow the reading of a text or to confirm what a person has read as training. Useful features support this training with the control of speed, read word by word or read letter by letter line in the *IDEAL eBook Reader*. These features empower a person with dyslexia to learn and read (new, similar, or complicated) words.

31.3 Assisted Writing for Dyslexia

For a person with dyslexia, reading and writing remains a challenge through their life. A study of dyslexia on social media (interview with 11 participants with dyslexia; questionnaire with 492 participants with and without dyslexia Reynolds and Wu 2018) reports that writing is a bigger challenge than reading for a person with dyslexia. The study also reveals that people with dyslexia experience more often negative feedback on the writing which can trigger or increase their stress and anxiety. Therefore, spelling corrections, text suggestions, or dictation are useful features in the daily routine for a person with dyslexia.

In the next subsections, we present tools for spelling correction, text suggestions, and dictation.

31.3.1 Spelling Correction

The analysis of spelling mistakes from children with dyslexia in German and Spanish (Rello et al. 2016; Rauschenberger et al. 2016) shows real word errors as a very common error category, produced by phonetically or orthographically similarity of words or letters (Pedler 2005, 2007) (see also previous section).

Real word errors refer to words which are wrong in the context and are very similar to another word from that language like for German *Schal ("scarf")* and *Schall ("sound")*, for Spanish *pala ("shovel")* and *palabra ("word")* and for English *from* and *form*. These spelling mistakes are for a spellchecker very difficult to find due to the need to understand the semantic context of the sentence or phrase (similarly to text simplification). Spelling correction is useful also for a person without dyslexia since, for example, the frequency on the Spanish web of correct words is 4.63 times more frequent than for words with errors, apart from real word errors (Rello et al. 2016).

To target real word errors, spellcheckers base their approach on language models or on natural language processing. Next, we present some example applications:

- **Babel** (Spooner 1998) was the first to use an user model with human errors and rules addressing the permutation of letters to support the writing of a person with dyslexia. The approach was evaluated with errors from real people by measuring the frequency of suggestion of the correct answer, and the position of the correct answer on the suggestion list when suggested. *Babel* performance as a spellchecker was significantly better in finding real word errors for some key populations using new rules addressing the permutation of letters or user modeling with human errors.
- **PoliSpell** (Quattrini et al. 2013) uses an user model for boundary errors or real word errors and offers a simple user interface for a person with dyslexia to better distinguish suggested words. An evaluation of PoliSpell could not be found.
- **Real Check** (Rello et al. 2015) uses a probabilistic language model, a statistical dependency parser and Google n-grams to detect real-world errors. The evaluation was done with a corpus of real-world errors, comparison of other spellcheckers and an experiment to test the efficiency of the detection. The results from 2015 with a user study with 36 people show that people with dyslexia corrected sentences more accurately and in less time with RealCheck than with other spellcheckers.

31.3.2 Text Suggestions

The use of text suggestions is relevant for different digital contexts such as search interfaces (Morris 2018), text editors, or spellcheckers (Quattrini et al. 2013). As mentioned in the previous section, *PoliSpell* (Quattrini et al. 2013) provides a simple user interface for a person with dyslexia to show predicted correct words. Since a person with dyslexia has difficulties to distinguish phonologically or orthographically similar words (as described before), the visual layout of word predictions or suggestions is also relevant when writing. In addition, we already mentioned that in Rello et al. (2013), people with dyslexia preferred synonym suggestions instead of a direct simplification.

31.3.3 Dictation

Dictation, *speech to text* (STT) (Wagner 2005) or speech recognition (Juang and Rabiner 2004) is the reverse of text to speech from the previous section and means broadly that the spoken words or sentences are recognized and visualized as text. Historically was developed to integrate people with hearing impairments in oral communication. Although these tools are not specifically developed for people with dyslexia, it makes a real-time communication easier and probably with less spelling mistakes if the STT is well designed. A typical use case today are in mobile search interfaces (Morris 2018). Apart from that, speech recognition can be helpful for a person with *dysgraphia* (Mayes 2018) and is already used in professional areas like medicine, business correspondence, or legal briefs (Spehr 2010). With speech recognition included already in every smartphone, it is available for a broad audience and challenges are in accuracy, foreign accents, specific terminology, or language changes. SST is also researched and recommended as an alternative way of learning how to write (Haug and Klein 2018).

31.4 Dyslexia Screening

The previous sections focused on assistive tools for reading and writing when having dyslexia. This section introduces a relatively newer research area, which is the screening of dyslexia through web-based applications or games.

Detection and especially an early detection of dyslexia is important because an early intervention avoids negative effects of dyslexia such as school failure and low self-esteem.

Most current approaches to detect dyslexia require linguistic skills (i.e., phonological awareness, or letter recognition to apply e.g., a German spelling test Grund 2004), expensive personnel (i.e., psychologists), or special hardware (i.e., eye trackers or MRI machines).

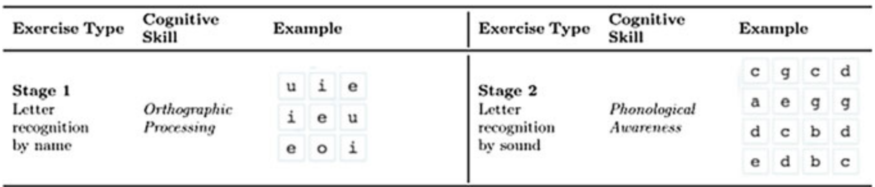
The rate of spelling mistakes and reading errors are the most common way to detect a person of dyslexia. Since people with dyslexia exhibit higher reading and spelling error rates than people without dyslexia (Coleman et al. 2008), there are diagnoses of dyslexia based on the errors score (Schulte-Körne et al. 1996). Very often children and their families already experienced lots of failures and frustration due to the, back then, inexplicable problems of learning how to read and write. Hence, spelling tests are forcing children with dyslexia to fail again under observation and puts additional stress and frustration on each child.

Hence, in recent years, computer games are being used to provide support for children with dyslexia in an engaging, convenient, and cost-efficient way (Rello et al. 2014; Kyle et al. 2013). Next, we give an overview of different approaches for screening readers and pre-readers using web applications/games.

31.4.1 Screening for Readers

Screening with applications for readers is mainly based on the perception of linguistic skills (Nessy 2011; Lexercise 2016; Rello et al. 2016) (e.g., phonological awareness, letter recognition) but also on visual or auditory short-term memory (Rello et al. 2016) or phonological processing (Rolka and Silverman 2015). Mainly, these web applications have been designed as a low-cost approach for nonprofessionals as a quick screening tool to identify people that may have dyslexia and should go to see a professional. An overview of the cognitive skills tested in some tools is given in Table 31.4. Next, we detail those tools for detecting children with dyslexia.

– **Dytective** (Rello et al. 2018, 2016) is a web-based game with different stages to detect dyslexia with machine learning prediction models. The stages exist in German, English, and Spanish. Each stage has a new task, e.g., search for a letter by its name in a letter grid (see Fig. 31.1, left) or search for a letter by its sound in a letter grid (see Fig. 31.1, right). *Dytective* in Spanish has an accuracy of almost 85% (Rello et al. 2016) while in English has 83% (Rello et al. 2018) for detecting a person with dyslexia. The most informative features on the individual level are how many correct and incorrect answers a participant has and they plan to include other languages in the future.
– **GraphoGame** (Lyytinen et al. 2015) is a game to teach and to evaluate early literacy skills. From their pre-analysis of children at risk in Finnish, they focus on the delayed letter knowledge. Measurements are, for example, the phonological manipulation, naming speed, or verbal short-term memory. It provides exercises for children aged two to six.
– **Lexercise Screener** (Lexercise 2016) is an English screening tool for detecting dyslexia. Children read familiar words and the parent records the child's response.



Exercise Type	Cognitive Skill	Example	Exercise Type	Cognitive Skill	Example
Stage 1 Letter recognition by name	*Orthographic Processing*	u i e i e u e o i	**Stage 2** Letter recognition by sound	*Phonological Awareness*	c g c d a e g g d c b d e d b c

Fig. 31.1 Example exercises of stage 1 (left) and stage 2 (right) from the dyslexia screener *Dytective* (Rello et al. 2016)

Table 31.4 Cognitive skills tested in different dyslexia screening tools for readers

Tools	Dytective 2016, 2018 (Rello et al. 2016, 2018)	GraphoGame 2015 (Lyytinen et al. 2015)	Lexercise 2016 (Lexercise 2016)	Nessy 2014 (Carbol 2014)
Languages	Spanish English	Finnish	English	English
Duration	10–15 min.	n/a	n/a	∼20 min.
Skill				
Memory general	✓	✓		✓
Working memory	✓	✓		✓
Visual word memory	✓	✓		✓
Visual sequential memory	✓			✓
Visual alphabetical memory	✓	✓		
Auditory sequential memory	✓			✓
Auditory phonological memory	✓	✓		
Processing speed		✓		✓
Language skills General	✓	✓	✓	
Alphabetic awareness	✓	✓		
Lexical awareness	✓	✓		
Morphological awareness	✓	✓		
Phonological awareness	✓	✓		✓
Semantic awareness	✓			
Syllabic awareness	✓	✓		
Syntactic awareness	✓		✓	
Executive functions General	✓			
Activation and attention	✓			
Sustained attention	✓			
Simultaneous attention	✓			

This requires phonological awareness from the parents, which might be difficult if the parents have been diagnosed with dyslexia themselves. Hence, a lack of objectivity needs to be taken into account.

– **Nessy** (Nessy 2011; Carbol 2014) is an English screening tool for detecting dyslexia. Exercises are designed to test many cognitive skills (see Table 31.4). It provides exercises for children aged 5–16 years and the test takes around 20 min. The research summary published on their website reports the results of the multiple regression analysis between the game and the *comprehensive test of phonological processing* (Bruno 2000) with a strong correlation of almost 0.8.

All of the web applications mentioned before are mainly designed for desktop or laptop computers as well as for tablets.

To sum up, all these screening applications are language dependent. This means on one hand that the content of the application needs to be adapted for every new language which is time and resource consuming. On the other hand, only people who already have language acquisition can be tested (i.e., children need a minimum knowledge of phonological awareness, grammar, and vocabulary of the child to detect or predict dyslexia). In practice, these tools can only screen children after the first year of school and not earlier. Therefore, new ways of detecting the risk of having dyslexia are needed for pre-readers.

31.4.2 Screening for Pre-readers

As we already pointed out, the difficulty in detecting dyslexia before children go to school is the missing phonological awareness. To detect dyslexia in a child before, they gain phonological awareness, new indicators of dyslexia need to be discovered beside the ones mentioned in the previous subsection.

Expensive approaches predict future language acquisition of pre-readers e.g., with brain recordings for newborns (Guttorm 2003), with *rapid auditory cues* for infants (Benasich and Tallal 2002), and with the perception of *visual-spatial attention* for kindergarten children (Franceschini et al. 2012).

As we have seen in the Introduction, other auditory and visual indicators do not require reading ability, and may be useful in detecting dyslexia with a web application. Hence, now we present different examples of approaches that aim to predict dyslexia in pre-readers. All of them base their approach on indicators mainly related to linguistic skills. This rationale is supported by the following assumptions: (1) dyslexia does not develop when children come to school, but is already there before, (2) linguistic related indicators can represent the difficulties a person with dyslexia has with writing and reading, and (3) dyslexia can be measured through the interaction behavior of a person. An overview of the cognitive skills tested in each application is given in Table 31.5.

– **AGTB 5–12** is a computer-based test for children from age five to twelve years old (Hasselhorn 2012). In Germany, one of the first applications that was addressing the visual and phonological working memory (quoted after Irblich et al. 2013), besides the linguistic skills and the working memory. On the product website, it is stated that the Cronbach's Alpha is between 0.58 and 0.98 for children from the age of five till eight (Hasselhorn and Zoelch 2012). *AGTB 5–12* is criticized for the lack of objectivity for some tasks because the supervisor has to decide the grading depending on the subjective knowledge (Irblich et al. 2013). Additionally, the duration of over an hour and the detailed instructions are not suitable for younger children. Although *AGTB 5–12* aims to screen pre-readers is not specifically designed for smaller children.

Table 31.5 Cognitive skills tested in dyslexia screeners for pre-readers

Tools	AGTB 5–12 2012 (Irblich et al. 2013; Hasselhorn and Zoelch 2012)	DYSL–X 2013 (Van den Audenaeren 2013; Geurts et al. 2015)	GC 2017 (Gaggi et al. 2017)	Lexa 2018 (Poole 2018)	MusVis* 2018 (Rauschenberger et al. 2018a)
Languages	German	Italian	Italian	English	German Spanish English
Duration	~87 min.	n/a	Endless	n/a	10–15 min.
Skills					
Memory General	✓			✓	✓
Working M.					✓
Short-term M.	✓				✓
Auditory sequential M.					✓
Auditory phonological M.	✓			✓	✓
Processing speed				✓	✓
Language skills General	✓	✓			
Alphabetic awareness		✓	✓		
Phonological awareness			✓		

**DGames* has the same functionality as MusVis

- **DYSL-X** (also called DIESEL-X) aims to predict the possibility of a child having dyslexia at the age of five (Van den Audenaeren 2013; Geurts et al. 2015). The three mini games are designed to measure dyslexia using for example indicators like letter knowledge, frequency modulation detection, and end-phoneme recognition (Geurts et al. 2015). The games (for example, see Fig. 31.2d) take one hour to complete. The indicators are, for example, finding a letter that the child has been told.
- **Game–Collection** (CG) has six games each with a different challenge and game-play (Gaggi et al. 2017). The games use visual and auditory elements and an evaluation was found only on the game interaction. The games explore the visual cues and the temporal time perception for predicting dyslexia at the age of five or six (Gaggi et al. 2012, 2017), although children of age three or four tested the games as well. In the game, called *Paths*, a shape with similarities to the letter *C* is used as an indicator (see Fig. 31.2a). The game, called *Fence Letters*, tries to distract a child while they close the lines to create a letter (see Fig. 31.2c). The usability test reported that children without dyslexia ($n = 17$) got a higher game score, winning a and using less time than children with dyslexia risk ($n = 6$).
- **Lexa** (Poole 2018) is a prototype to detect dyslexia by the auditory processing using oddity and rise time. The simple decision tree analysis of the lab study data (Data was collected by Goswami et al. Goswami 2011) was used to find

the most relevant features. A higher accuracy (89.2 vs. 53.8%) was found if no preprocessing of the feature related to phonological processing was applied. The researchers state that the biggest challenge in creating different rise times sounds and if a child is guessing the answer.

– **MusVis** (Rauschenberger 2016; Rauschenberger et al. 2018a) and **DGames** (Rauschenberger et al. 2018) address the visual and auditory perception with two different games. MusVis was developed based on the experience of a pilot implementation called *DysMusic* (Rauschenberger et al. 2017). The statistical analysis of the game measurements from 178 participants showed 8 significant indicators (e.g., total clicks, time to the first click, hits, and efficiency) for Spanish. Overall languages, four indicators are still significant (e.g., total clicks, time to the first click, hits, and efficiency). **DGames** (Rauschenberger et al. 2018) is a major update from *MusVis* with the learnings of its online study (see Fig. 31.2d). The evaluation of *MusVis* and *Dytective* showed that people with dyslexia do not make more mistakes, in spite that children with dyslexia are historically detected by the spelling mistakes they make. Consequently, non-related linguistic visual and musical content are included in *DGames*.

The web games presented focus mainly on a high-score gameplay, easy instructions, and colorful representation as well as story-based design. Besides AGTB 5–12 (Hasselhorn 2012; Steinbrink and Lachmann 2014), which is the only one that predicts the risk of dyslexia, all games are prototypes and have not been brought to the market until now. However, so far, no evaluation for the prediction accuracy of any of these games has been made public. Also, the focus for the prediction is mainly on having letter knowledge and phonological awareness.

31.5 Dyslexia Intervention

Nowadays, reading and writing is still one of the great abilities to be successful in our society. That is why after an (early) screening with the methods described in the previous section, it is crucial to start also with an (early) intervention. Indeed, an early intervention will give children with dyslexia the possibility to, (a) keep up with their peers in learning how to read and write, (b) avoid frustration, and (c) be not only defined by dyslexia. The success of the intervention depends on the time of diagnosis, mother tongue and the degree of difficulties a person has.

The idea to use computers for education exist quite a while as a historical overview from 1987 shows Kurland and Kurland (1987) and a few years later computer games were already used for learning a language, e.g., Tim 7 on Windows 95 (Soft 2000). But a person with dyslexia has specific difficulties, for example, in associating letter representations and the corresponding phoneme especially to organize the sequence, i.e., phonological awareness and information processing/sequence. That is why different approaches are necessary as well as many repetitions. A game has the potential of longer engagement and a better training effect. The advantages of web application

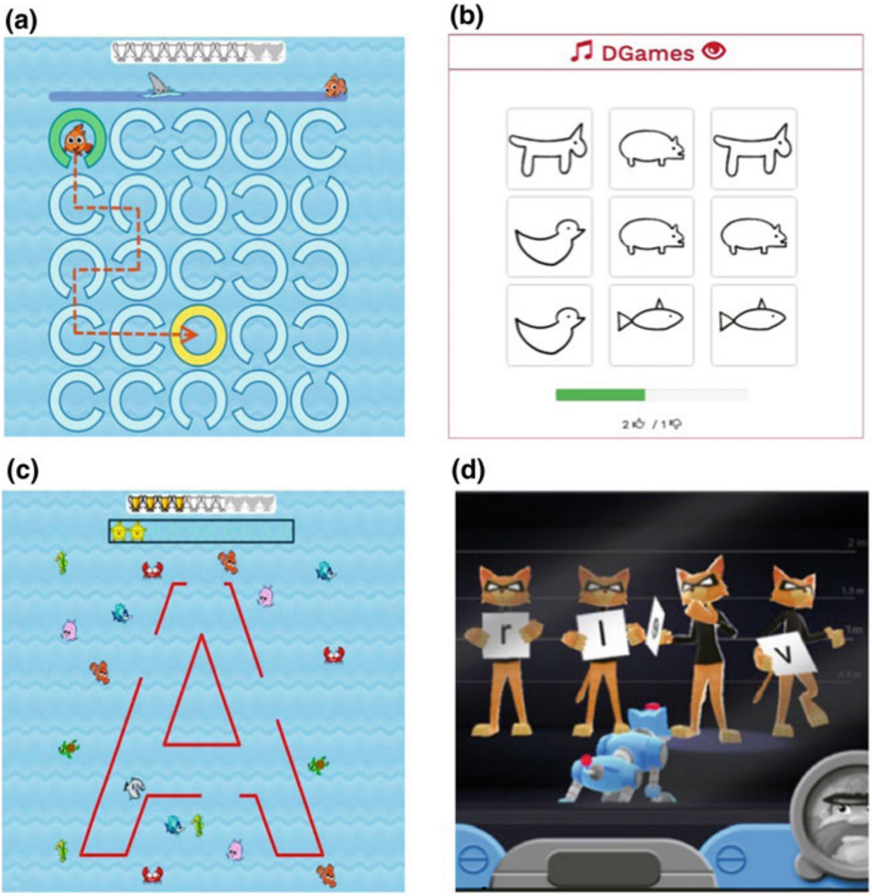


Fig. 31.2 Screen examples: **a** *Paths* game (Gaggi et al. 2012); **b** *DGames* (Rauschenberger et al. 2018); **c** Fence *letters game* (Gaggi et al. 2012); and **d** *DYSL-X* (Van den Audenaeren 2013)

games are: (1) automatically shaping an individual's learning curve, (2) engage in a fun way of learning, (3) potential of long-term commitment to repeat exercises, and (4) easily accessible through different devices, regions, and cultures. In the last decade, the intervention of people with dyslexia has increased with tools such as the examples that we present next. An overview of features for each application is given in Table 31.6.

– **Dyseggxia** is an iOS game made from the knowledge of the analysis from mistakes children with dyslexia made (Rello et al. 2016; Rauschenberger et al. 2015, 2016). The same learning approach is available in three different languages (Spanish, English Rello et al. 2014, and German Rauschenberger et al. 2015). The evaluation was done with 48 Spanish participants and showed that participants significantly improved their spelling compared to the control game (Rello et al. 2014). The

Table 31.6 Cognitive skills trained by applications for dyslexia intervention

Tools	Dysegg. 2014 (Rello et al. 2014)	Dytec. 2016 (Rello et al. 2017; Rello 2018)	Gale. 2016 (Serrano 2016; Dev 2019)	GC. 2012 (Gaggi et al. 2012)	Lern. 2007 (Flug 2016)	Nessy 2014 (Nessy Learning Ltd. 2019)	Proso. 2017 (Holz et al. 2017)
Languages	English German Spanish	Spanish	English Spanish	Italian	German	English	German
Type	Product	Product	Product	Prototype	Product	Product	Prototype
Skills							
Language Skills General	✓	✓	✓		✓	✓	✓
Alphabetic Awareness			✓	✓		✓	
Lexical A.			✓			✓	
Phonemic A.	✓	✓				✓	
Phonological A.	✓	✓	✓	✓			
Syllabic A.		✓	✓				
Syntactic A.					✓		
Orthographic Spelling			✓				✓
Morphological A.		✓	✓				
Analysis of Error Words	✓	✓					
Working Memory		✓					
Executive Functions		✓					
Cognitive Abilities		✓		✓			
Auditory Perception		✓					
Rapid Auditory Skills							✓
Visual-spatial attention		✓		✓			

reading skills were not improved with this training but the experience gained from building this application was used for DytectiveU.

- **DytectiveU** is a computer game that provides a holistic learning approach (Rello et al. 2017; Rello 2018). The 25 cognitive abilities related to dyslexia are trained with 40,000 exercises to also empower the strengths of children with dyslexia. Exercises are designed with the knowledge from the analysis of spelling mistakes from children with dyslexia and natural language processing techniques. A workshop was used to get a first feedback from families and professionals about the functionality, i.e., gamification strategy or use of reports. In a longitudinal evaluation, the participants either had only their professional treatment or additionally played DytectiveU. All participants, independent if having or not a learning disorder (dyslexia or ADHD), significantly improved compared to the control group after playing DytectiveU.
- **Galexia** (Serrano 2016) is an intervention app to train reading fluency and comprehension in a playful environment. The app uses two approaches: Repeating reading and a recent one on accelerated reading, which may *promote rapid and automatic word recognition*. The approaches are combined with a sequential training at syllable, word, and text reading level. The game has been developed to engage participants with the gameplay to play longer without thinking about the intervention purpose. The game is available for children in the second till the sixth grade. The evaluation was done with an intensive training over 6 weeks with 46 participants native Spanish speakers (either diagnosed with dyslexia or poor readers). The results show significant differences for all grades for all fluency reading measures and comprehension measures. However, it can be argued that any child would have improved with such an intensive training since a control group is missing. Galexia is in the Google Play Store in Spanish (Dev 2019) and English (Dev 2019).
- **Game–Collection** (Gaggi et al. 2012, 2017) has different games which aim to screen and treat children at an early age. The screening part of *GC* is described in Sect. 31.4.2. The suggestion is that a daily treatment with these exercises will improve the reading abilities of pre-readers. The additional assumption is that a game can engage and motivate participants to do this daily treatment. Therefore, the first evaluation was done with a high focus on playing the game for pre-readers. The results show that the game is enjoyable and easy to play (67% of the children). The game called *Wizards*, challenges the child with the question "Which sound came first?" as the pre-readers were not able to discriminate the phoneme "A" from "E". They plan to evaluate their prediction approach in the future.
- **Lernserver** (Schönweiss and Schönweis 2014) is a tool to treat dyslexia in German, defining the level of support the child needs from the standard spelling test i.e., *Mnsteraner Rechtschreibanalyse (MRA)* (Mannhaupt 2006), and providing support exercises. Since the screening is done with a conventional printed spelling test *MRA*, we do not include this screening tool in the previous section. The exercises are based on the analysis of 500,000 error words from children classified in 230 error categories (Schönweiss and Schönweis 2014). The learning exercises are selected with an algorithm and a therapist depending on the errors a child makes in

an initial test phase of 30–40 min. An evaluation with the *Landesinstitut für Schule* found out that 78.2% of the students ($n = 3798$) improved their writing using this tool (Flug 2016; BVL 2010) without a control group. Therefore, it is unknown if the students improved because of the intervention of the program *Lernserver* or the individual development of the children. In addition, children who did not attend sessions or showed a lack of interest in the program were excluded. This condition then increased the success rate of the study. Participants reported after the training session that they felt more comfortable writing (84%) and noticing their own mistakes (82%). Although *Lernserver* is not a game, participants reported they liked the application but did not like to reduce their free time.

– **Nessy Reading and Spelling** (Nessy Learning Ltd. 2019) is a web application to treat children between the age of 5 and 14 in English and defining individual support after using the *Nessy Screener* (see Sect. 31.4.1. The evaluation published on their website reports that students playing twice a week for 45 min improved on average their reading and writing skills after 18 weeks. Additionally, 84% of the participants reported having fun with this game. More details such as the evaluation measures used and the number of participants are not given.
– **Prosodiya** is a serious mobile game that targets the intervention by learning the syllable stress of the German orthography and embodied training (Holz et al. 2017) for children from ages of 6–12. The six parts and various subparts provide each time different linguistic or orthographic tasks and the whole game aims to use a *rule-based orthographic spelling training* (Holz et al. 2017). The individual training is designed with difficulty levels for each subpart and an integrated learner model. The preliminary study is mainly on the user experience and usability. Children reported that they liked the game which was confirmed by their parents. Additionally, the literacy process of participant was measured with the two standard tests for German: *Diagnistischer Rechtschreibtest* (DRT) (Müller 2003) and *Salzburger Lese-/ und Rechtschreibtest* (SLRT II) (Moll and Landerl 2010). The spelling improvement is reported for six children with the DRT and the reading improvement is reported for three children with the SLRT II. They plan to evaluate the intervention approach in a long-term study with more children.

In many cases, there are no more details probably because some applications are already products and other approaches are not open knowledge or are still under development. Similar approaches for intervention are *GraphoGame* (Lyytinen et al. 2015), *Lautarium* (Prölß 2016), mobile Intervention (Madeira et al. 2015), *LegaKids* (LegaKids Stiftung 2019), or *EasyLexia* (Skiada et al. 2014).

Applications, mentioned above, train mainly for only one language with the exception of *GraphoGame, Dyseggxia, DytectiveU* and *Galexia*.

Nevertheless, similarities have been found in the error categories of children with dyslexia having distinct native languages, e.g., German (Rauschenberger et al. 2016), English, or Spanish (Rello et al. 2016). The obvious reason these intervention approaches target only one language is that languages are different (e.g., in grammatical or orthographic rules). Also, adapting a technique to another language is very time consuming or the approach itself must be changed.

31.6 Discussion

Assistive technologies to improve reading and writing have been developed for years but many challenges remain. Not only people with dyslexia benefits from these developments but every person as well. Some of them are also beneficial for other disorders or disabilities such as text to speech for a person with visual impairments, text simplification for a person with cognitive disabilities or certain layout and presentation characteristics are also better for people without dyslexia, to mention just some cases.

Research is targeting dyslexia to avoid reading and spelling mistakes or to learn from the mistakes people with dyslexia make, which depend on the language. New approaches to screening (Rauschenberger et al. 2018a) or intervene dyslexia (Rello et al. 2014) are based in machine learning. In particular, how to create exercises for intervention depend on the language structure and are difficult to design, even though *DytectiveU* is already working on this. Also challenging is the degree of personalization on individual learning as well as the engagement to keep on practicing. The assumption is that an early detection for pre-readers is more helpful than traditional detection tests. An early detection means also early intervention and probably a faster and lasting knowledge of reading and writing.

Evaluating of a tool improved the reading and writing of a person with dyslexia can be easily examined by measuring the number of errors. But evaluating the longitudinal effect of learning considering external factors is much harder to study. The analysis of data collected through online experiments with a larger number of participants will improve future detection and intervention tools, surely involving machine learning and other data science methods. Indeed, since we are dealing with a social problem, we should make sure we detect everyone with dyslexia and interview many more people over the years instead of not detecting people with dyslexia that may fail at school. This applies for any prediction process related to health issues.

Another interesting recent result is that people with dyslexia do not see misspellings and then their comprehension is not affected by them. This is not the case for people without dyslexia, so adding misspellings in reading comprehension tests levels the field (Baeza-Yates and Rello 2017).

31.7 Future Directions

On one hand, the possibilities to explore dyslexia on the web, with the web, or for the web has increased successfully in the past years. On the other hand, little is known about the social effects: What kind of feedback is a person receiving when writing on the web with spelling mistakes? How is the, apparently, negative feedback affecting a person's writing or personality? Is the time and effort a person with dyslexia has to spend on writing correctly a daily bias because they can not spend time on other things to succeed?

So far, the focus is mainly on writing and reading itself and future research could take advantage of the strength that a person with dyslexia uses to compensate the challenges of reading and writing. As a person with visual impairments trains other perception competences, i.e., hearing or touch sense, a person with dyslexia must train other areas to compensate for the difficulties with texts. These compensation strategies might lead to a better understanding of dyslexia and improve the guidelines for presenting (digital) text or support (digital) writing. Apart from that, the bias a person with dyslexia faces in their daily routine on the web in social media or through conversations has an impact on each individual and on the content of the web. When exploring user created content or predicting diseases a multi-modal approach is needed (i.e., including different computer science fields such as HCI, IR, and ML; as well as other disciplines like psychology) to also capture comorbidity. Assistance when writing on a computer is helpful, but in mobile input techniques such as *swiftkey* or *t9*, an additional challenge is when the spelling of the word is not obvious. At this point, an insuperable issue is writing in different languages with the mobile input methods while having dyslexia. There is no tool to support a person with dyslexia when for example writing in English on Twitter and a moment later in German on Facebook or WhatsApp. Similar words in these languages are frequent (e.g., German *vor ("before/in front of")* and English *for*) and not detected or prevented.

Using web technologies not only to provide assistive but to set up online experiments or large-scale studies is another possible future direction of web accessibility. As well, in the future, the daily routine of the user with the Internet-of-Things for a person of dyslexia might give more information of the origin of dyslexia and how to design better assistive technology.

Recently, the behavior of searchers with dyslexia analyzing web search results have been explored to investigate the relation of lexical and esthetic features on their impact toward text judgment and readability (Morris 2018; Fourney et al. 2018). The formulation of a query, deciding the link to click, and the examination within the document negatively impacts a searcher with dyslexia. The study with 174 adults with dyslexia and 172 without dyslexia suspects that certain parameters improve the web search results readability for both populations, i.e., line length, image size, and sentence text ratio. The authors explored the choice of text relevance and found a central tendency bias, i.e., participants with dyslexia rated on average lower and in a smaller region on the ratings scale. The authors explain this with the assumption that a person with dyslexia has difficulties to differentiate between relevant and nonrelevant documents. More research needs to be done in this problem and other problems where the task is composed of several steps.

31.8 Authors' Opinion of the Field

The use of text customization, simplification, and text to speech are already very well studied with several assistive applications designed. It seems that these research areas has nearly reached their limit. Still updates need to be done for each new device or technology (e.g., tablet, smartphone, and reader), innovation approach (e.g., machine learning algorithm), design evaluation for Usability and User Experience (e.g., with the User Experience Questionnaire Rauschenberger et al. 2013) and especially for each new contribution of the understand dyslexia (e.g., a person with dyslexia is lacking a visual asymmetry Le Floch and Ropars 2017). However, only after we fully understand the difficulties of a person with dyslexia while reading a text, we might reach the end of our research.

The field has evolved and took new directions into the detection and intervention through web-based applications. It is not only about assistive tools to understand what has been written or how to write correctly. Rather, the web is now a place to explore and study dyslexia with web methods.

Communication, training, and support to limit spelling mistakes in the text are the obvious solutions to improve the writing of a person with dyslexia. Early detection is the key for supporting a person with dyslexia to succeed. They can succeed without it but then it is much harder. Therefore, we should not wait for a person to fail before helping.

31.9 Conclusions

The technology presented in this chapter gives an overview of different approaches on how to assist people with dyslexia. The main focus was to show different research areas and their use with relation to the web. The first two sections refer to technology for supporting reading and writing, in the line of traditional assistive web technology. The relative new research field of detection and intervention is creating applications accessible through the web to screen for a person with dyslexia or to treat a person with dyslexia, with newer ones using the power of machine learning. Additionally, this research area opens up the opportunity to use the web for medium-scale online experiments to prove a hypothesis related to underrepresented target groups. Web technologies are now daily used and people with dyslexia should be empowered to use the web through them, as well as use web games to engage for repeatedly and challenging tasks.

References

Amazon (2018) Amazon.com: online shopping for electronics, apparel, computers, books, DVDs & more

American Psychiatric Association (2013) Diagnostic and statistical manual of mental disorders. American Psychiatric Association

Apple (2018) iBooks - Apple (DE)

Baeza-Yates R, Rello L (2017) The impact of misspellings on reading comprehension for people with dyslexia. In: International dyslexia association annual conference

Benasich AA, Tallal P (2002) Infant discrimination of rapid auditory cues predicts later language impairment. Behav Brain Res 136(1):31–49

British Dyslexia Association (2018) Dyslexia Style Guide 2018

Bruno RM (2000) Comprehensive test of phonological processing (CTOPP). Diagnostique 24(1)

BVL LdUM (2010) (Bundesverband Legasthenie Dyskalkulie e.V.). Evaluation Modellprojekt LISA (Evaluation project on LISA). LeDy– Mitgliederzeitschrift Bundesverband für Legasthenie und Dyskalkulie e.V. 1:8–32

Carbol B (2014) Research brief: use of the dyslexia quest app as a screening tool. Schmidt & Carbol Consulting Group, Technical report

Catts HW, McIlraith A, Bridges MS, Nielsen DC (2017) Viewing a phonological deficit within a multifactorial model of dyslexia. Read Writ 30(3):613–629

Claro Software Ltd (2015) Claro software

Coleman C, Gregg N, McLain L, Bellair LW (2008) A comparison of spelling performance across young adults with and without dyslexia. Assess Eff Interv 34(2):94–105

de Avelar LO, Rezende GC, Freire AP (2015) WebHelpDyslexia: a browser extension to adapt web content for people with dyslexia. Proc Comput Sci 67(Dsai):150–159

de Santana VF, de Oliveira R, Almeida LDA, Baranauskas MCC (2012) Web accessibility and people with dyslexia. In: Proceedings of the international cross-disciplinary conference on web accessibility - W4A'12. ACM Press, New York, p 1

de Santana VF, de Oliveira R, Almeida LDA, Ito M (2013) Firefixia. In: Proceedings of the 10th international cross-disciplinary conference on web accessibility - W4A'13. ACM Press, New York, p 1

Dev P, Galexia Educational Games–Apps on Google Play

Dev P, GALEXIA Mejora Fluidez Lectora–Apps bei Google Play

Flug L (2007) Projekt-Evaluation Bremen: Erprobungsphase des Lernservers an Bremischen Schulen (Evaluation project in Bremen: Pilot study with Lernserver at schools in Bremen). http://bit.ly/2bVRdfD. [Accessed 06 Sept 2016]

Fourney A, Ringel Morris M, Ali A, Vonessen L (2018) Assessing the readability of web search results for searchers with dyslexia. In: The 41st international ACM SIGIR conference on research and development in information retrieval - SIGIR'18. ACM Press, New York, pp 1069–1072

Franceschini S, Gori S, Ruffino M, Pedrolli K, Facoetti A (2012) A causal link between visual spatial attention and reading acquisition. Curr Biol 22(9):814–819

Gaggi O, Galiazzo G, Palazzi C, Facoetti A, Franceschini S (2012) A serious game for predicting the risk of developmental dyslexia in pre-readers children. In: 2012 21st international conference on computer communications and networks, ICCCN 2012 - proceedings

Gaggi O, Palazzi CE, Ciman M, Galiazzo G, Franceschini S, Ruffino M, Gori S, Facoetti A, Gaggi O, Palazzi CE, Galiazzo G, Franceschini S, Gori S, Facoetti A (2017) Serious games for early identification of developmental dyslexia. Comput Entertain Comput Entertain 15(4)

Geurts L, Vanden Abeele V, Celis V, Husson J, Van den Audenaeren L, Loyez L, Goeleven A, Wouters J, Ghesquière P (2015) DIESEL-X: a game-based tool for early risk detection of dyslexia in preschoolers. In: Describing and studying domain-specific serious games. Springer International Publishing, Switzerland, pp 93–114

Google (2018) Google Books

Goswami U (2011) A temporal sampling framework for developmental dyslexia. Trends Cogn Sci 15(1):3–10

Gregor P, Newell AF (2000) An empirical investigation of ways in which some of the problems encountered by some dyslexics may be alleviated using computer techniques. In: Proceedings ASSETS'00, ASSETS 2000. ACM Press, New York, pp 85–91

Grund M, Naumann CL, Haug G (2004) Diagnostischer Rechtschreibtest für 5. Klassen: DRT 5 (Diagnostic spelling and reading test for the class 5). Deutsche Schultests. Beltz Test, Göttingen, 2., aktual edition

Guttorm TK, Leppänen PHT, Tolvanen A, Lyytinen H (2003) Event-related potentials in newborns with and without familial risk for dyslexia: principal component analysis reveals differences between the groups. J Neural Trans 110(9):1059–1074

Hämäläinen JA, Salminen HK, Leppänen PHT (2013) Basic auditory processing deficits in dyslexia. J Learn Disabil 46(5):413–427

Hasselhorn M, Schumann-Hengsteler R, Gronauer J, Grube D, Mähler C, Schmid I, Seitz-Stein K, Zoelch C (2012) AGTB 5-12— Arbeitsgedächtnistestbatterie für Kinder von 5 bis 12 Jahren (AGTB 5-12— Working memory tasks to test children at the age of 5 till 12)

Hasselhorn M, Zoelch C (2012) Funktionsdiagnostik des Arbeitsgedächtnisses (Functional diagnostics of the working memory). Hogrefe Verlag, Göttingen

Haug KN, Klein PD (2018) The effect of speech-to-text technology on learning a writing strategy. Read Writ Q 34(1):47–62

Holz H, Brandelik K, Brandelik J, Beuttler B, Kirsch A, Heller J, Meurers D (2017) Prosodiya – a mobile game for German dyslexic children. Springer International Publishing, Cham, pp 73–82

Huss M, Verney JP, Fosker T, Mead N, Goswami U (2011) Music, rhythm, rise time perception and developmental dyslexia: perception of musical meter predicts reading and phonology. Cortex 47(6):674–689

Irblich D, Diakonie SK, Renner G (2013) AGTB 5–12 –Arbeitsgedächtnistestbatterie für Kinder von 5 bis 12 Jahren (AGTB 5–12 - working memory tasks to test children at the age of 5 till 12). Praxis der Kinderpsychologie und Kinderpsychiatrie 62(5):1–389

Jansen H, Mannhaupt G, Marx H, Skowronek H (2002) BISC - Bielefelder Screening zur Früherkennung von Lese-Rechtschreibschwierigkeiten (Early detection with the Bielefelder screening of reading and spelling difficulties). Hogrefe, Verlag für Psychologie, Göttingen

Juang B-H, Rabiner LR (2004) Automatic speech recognition–a brief history of the technology development. Georgia Institute of Technology. Atlanta Rutgers University and the University of California. Santa Barbara 1(1):1–67

Kanvinde G, Rello L, Baeza-Yates R (2012) IDEAL. In: Proceedings of the 14th international ACM SIGACCESS conference on computers and accessibility - ASSETS'12, p 205

Kurland DM, Kurland LC (1987) Computer applications in education: a historical overview. Annu Rev Comput Sci 2(1):317–358

Kyle F, Kujala J, Richardson U, Lyytinen H, Goswami U (2013) Assessing the effectiveness of two theoretically motivated computer-assisted reading interventions in the United Kingdom: GG Rime and GG Phoneme. Read Res Q 48(1):61–76

Le Floch A, Ropars G (2017) Left-right asymmetry of the Maxwell spot centroids in adults without and with dyslexia. Proc R Soc B: Biol Sci 284(1865):20171380

LegaKids Stiftung. Legasthenie und LRS–LegaKids informiert und hilft (Dyslexia–Information and help with LegaKids

Lexercise (2016) Dyslexia test - online from Lexercise. http://www.lexercise.com/tests/dyslexia-test. [Accessed 18 Sept 2017]

Lyytinen H, Erskine J, Hämäläinen J, Torppa M, Ronimus M (2015) Dyslexia - early identification and prevention: highlights from the Jyväskylä longitudinal study of dyslexia. Curr Dev Disord Rep 2(4):330–338

Madeira J, Silva C, Marcelino L, Ferreira P (2015) Assistive mobile applications for dyslexia. Procedia Comput Sci 64:417–424

Männel C, Schaadt G, Illner FK, van der Meer E, Friederici AD (2016) Phonological abilities in literacy-impaired children: Brain potentials reveal deficient phoneme discrimination, but intact prosodic processing. Dev Cogn Neurosci 23:14–25

Mannhaupt G (2006) Münsteraner Screening zur Früherkennung von Lese-Rechtschreibschwierigkeiten (Münsteraner Early Screening for reading and writing difficulties.). Cornelsen, Berlin

Mayes SD, Frye SS, Breaux RP, Calhoun SL (2018) Diagnostic, demographic, and neurocognitive correlates of dysgraphia in students with ADHD, autism, learning disabilities, and neurotypical development. J Dev Phys Disabil

Miniukovich A, De Angeli A, Sulpizio S, Venuti P (2017) Design guidelines for web readability. In: Proceedings of the 2017 conference on designing interactive systems - DIS'17. ACM Press, New York, pp 285–296
Moll K, Landerl K (2010) SLRT II - Lese- und Rechtschreibtest (Reading and spelling test). Verlag Hans Huber, Bern
Morris MR, Fourney A, Ali A, Vonessen L (2018) Understanding the needs of searchers with dyslexia. In: Proceedings of the SIGCHI conference on human factors in computing systems - CHI'18, pp 1–12
Müller R (2003) Diagnostischer Rechtschreibtest für 2. Klassen (DRT 2). (Detection spelling test for class 2.). Beltz, Göttingen
Nessy. Dyslexia screening - Nessy UK. https://www.nessy.com/uk/product/dyslexia-screening/. [Accessed 18 Sept 2017]
Nessy Learning Ltd. Research Evidence - Nessy Reading and Spelling
Pedler J (2005) Using semantic associations for the detection of real-word spelling errors. Proc Corpus Linguist Conf Ser 1(1):N.N
Pedler J (2007) Computer correction of real-word spelling errors in dyslexic text. PhD thesis, Birkbeck College, London University
Petrie HL, Weber G, Fisher W (2005) Personalization, interaction, and navigation in rich multimedia documents for print-disabled users. IBM Syst J 44(3):629–635
Pipusbcn (2017) Use of text to speech in iBooks - Apple Community
Poole A, Zulkernine F, Aylward C (2017) Lexa: a tool for detecting dyslexia through auditory processing. In: 2017 IEEE symposium series on computational intelligence, SSCI 2017 - proceedings, pp 1–5
Prölß A (2016) Evaluation des computergestützten phonologischen Trainingsprogramms Lautarium zur Förderung des Schriftspracherwerbs (Evaluating the computer-based phonologischen spelling approach Lauarium). Doktor der philosophie, Technischen Universität Kaiserslautern
Quattrini Li A, Sbattella L, Tedesco R (2013) PoliSpell: an adaptive spellchecker and predictor for people with dyslexia. In Carberry S, Weibelzahl S, Micarelli A, Semeraro G (eds) User modeling, adaptation, and personalization. Springer, Berlin, pp 302–309
Rauschenberger M (2016) DysMusic: detecting dyslexia by web-based games with music elements. In: The web for all conference addressing information barriers – W4A'16. ACM Press, Montreal
Rauschenberger M, Füchsel S, Rello L, Bayarri C, Thomaschewski J, Silke F, Rello L (2015) Exercises for german-speaking children with dyslexia. Hum-Comput Interact-INTERACT 9296:445–452
Rauschenberger M, Fuechsel S, Rello L, Bayarri C, Gòrriz A (2015) A game to target the spelling of German children with dyslexia. In: Proceedings of the 17th international ACM SIGACCESS conference on computers and accessibility - ASSETS'15. Lisbon, pp 445–446
Rauschenberger M, Rello L, Baeza-Yates R (2018a) A tablet game to target dyslexia screening in pre-readers. In: MobileHCI'18. ACM Press, Barcelona
Rauschenberger M, Rello L, Baeza-Yates R, Bigham JP (2018b) Towards language independent detection of dyslexia with a web-based game. In: W4A'18: the internet of accessible things. ACM, Lyon, France, pp N.N
Rauschenberger M, Rello L, Baeza-Yates R, Gomez E, Bigham JP (2017) Towards the prediction of dyslexia by a web-based game with musical elements. In: Proceedings of the 14th web for all conference on the future of accessible work - W4A'17. ACM Press, Perth, pp 1–4
Rauschenberger M, Rello L, Füchsel S, Thomaschewski J (2016) A language resource of German errors written by children with dyslexia. In: Proceedings of the tenth international conference on language resources and evaluation (LREC 2016). European Language Resources Association, Paris
Rauschenberger M, Schrepp M, Cota MP, Olschner S, Thomaschewski J (2013) Efficient measurement of the user experience of interactive products. How to use the user experience questionnaire (UEQ). Example: Spanish language. Int J Artif Intell Interact Multimed (IJIMAI) 2(1):39–45

Rello L (2014) DysWebxia a text accessibility model for people with dyslexia. PhD thesis, Universitat Pompeu Fabra

Rello L (2015) Dyslexia and web accessibility. In: Proceedings of the 12th web for all conference on - W4A'15. ACM Press, New York, pp 1–4

Rello L (2018) Superar la dislexia. Una experiencia personal a través de la investigación. (Overcome dyslexia. A personal experience through research.). Paidos Educacion

Rello L, Baeza-Yates R (2014) Evaluation of DysWebxia: a reading app designed for people with dyslexia. In: Proceedings of the 11th web for all conference, W4A'14. ACM, New York, pp 10:1–10:10

Rello L, Baeza-Yates R (2016) The effect of font type on screen readability by people with dyslexia. ACM Trans Access Comput 8(4):1–33

Rello L, Baeza-Yates R (2017) How to present more readable text for people with dyslexia. Univers Access Inf Soc 16(1):29–49

Rello L, Baeza-Yates R, Bott S, Saggion H (2013) Simplify or help?: text simplification strategies for people with dyslexia. In: Proceedings of the 10th international cross-disciplinary conference on web accessibility, W4A'13. ACM, New York, pp 15:1—-15:10

Rello L, Baeza-Yates R, Llisterri J (2016) A resource of errors written in Spanish by people with dyslexia and its linguistic, phonetic and visual analysis. Lang Resour Eval 51(2):1–30

Rello L, Ballesteros M, Abdullah A, Serra M, Sánchez DA, Bigham JP (2016) Dytective: diagnosing risk of dyslexia with a game. In:Pervasive health 2016. ACM Press, Cancun

Rello L, Ballesteros M, Bigham JP (2015) A spellchecker for dyslexia. In: ASSETS 2015: the 17th international ACM SIGACCESS conference of computers and accessibility, pp 39–47

Rello L, Bayarri C, Otal Y, Pielot M (2014) A computer-based method to improve the spelling of children with dyslexia. In: Proceedings of the 16th international ACM SIGACCESS conference on Computers and accessibility - ASSETS'14. ACM Press, New York, pp 153–160

Rello L, Bigham JP (2017) Good background colors for readers. In: Proceedings of the 19th international ACM SIGACCESS conference on computers and accessibility - ASSETS'17, pp 72–80

Rello L, Kanvinde G, Baeza-Yates R (2012) Layout guidelines for web text and a web service to improve accessibility for dyslexics. In: Proceedings of the international cross-disciplinary conference on web accessibility. ACM, p 36

Rello L, Macias A, Herrera M, de Ros C, Romero E, Bigham JP (2017) DytectiveU. In: Proceedings of the 19th international ACM SIGACCESS conference on computers and accessibility - ASSETS'17. ACM Press, New York, pp 319–320

Rello L, Pielot M, Marcos M-C, Carlini R (2013) Size matters (spacing not): 18 points for a dyslexic-friendly Wikipedia. In: Proceedings of the 10th international cross-disciplinary conference on web accessibility, W4A'13. ACM, New York, pp 17:1–17:4

Rello L, Romero E, Rauschenberger M, Ali A, Williams K, Bigham JP, White NC (2018) Screening dyslexia for English using HCI measures and machine learning. In: Proceedings of the 2018 international conference on digital health - DH'18. ACM Press, New York, pp 80–84

Reynolds L, Wu S (2018) "I'm Never Happy with What I Write": challenges and strategies of people with dyslexia on social media. In: Proceedings of the 12th international conference on web and social media. The AAAI Press, Palo Alto, p 280

Rolka EJ, Silverman MJ (2015) A systematic review of music and dyslexia. Arts Psychother 46:24–32

Schönweiss F, Schönweis P (2014) Lernserver - Individuelle Förderung (Lernserver - individual intervention)

Schulte-Körne G (2010) Diagnostik und Therapie der Lese-Rechtscheib-Störung (The prevention, diagnosis, and treatment of dyslexia). Deutsches Ärzteblatt international 107(41)

Schulte-Körne G, Deimel W, Müller K, Gutenbrunner C, Remschmidt H (1996) Familial aggregation of spelling disability. J Child Psychol Psychiatry 37(7):817–822

Serrano F, Bravo SJF, Gómez-Olmedo M (2016) Galexia: evidence-based software for intervention in reading fluency and comprehension. In: INTED2016, pp 2001–2007

Seymour PHK, Aro M, Erskine JM (2003) Foundation literacy acquisition in European orthographies. Br J Psychol (Lond, Engl: 1953) 94(Pt 2):143–74
Skiada R, Soroniati E, Gardeli A, Zissis D (2014) EasyLexia: a mobile application for children with learning difficulties. Procedia Comput Sci 27:218–228
Soft U (2000) Tim 7, Deutsch, 5. Klasse
Spehr M (2010) Diktieren ist viel schneller als Tippen (Dictating is faster than typing)
Spooner RIW (1998) A spelling aid for dyslexic writers. PhD thesis, University of York
Steinbrink C, Lachmann T (2014) Lese-Rechtschreibstörung (Dyslexia). Springer, Berlin
Tallal P (2004) Improving language and literacy is a matter of time. Nat Rev Neurosci 5(9):721–728
Topac V (2012) The development of a text customization tool for existing web sites. In: The development of a text customization tool for existing web sites. Web accessibility initiative W3C
Van den Audenaeren L, Celis V, Vanden Abeele V, Geurts L, Husson J, Ghesquière P, Wouters J, Loyez L, Goeleven A (2013) DYSL-X: design of a tablet game for early risk detection of dyslexia in preschoolers. In Games for health. Springer Fachmedien Wiesbaden, Wiesbaden, pp 257–266
Vidyasagar TR, Pammer K (2010) Dyslexia: a deficit in visuo-spatial attention, not in phonological processing. Trends Cogn Sci 14(2):57–63
Wagner S (2005) Intralingual speech-to-text conversion in real-time: challenges and opportunities. In: Challenges of multidimensional translation conference proceedings. MuTra, Saarbrücken
Web Accessibility Initiative (WAI) (2018) World Wide Web Consortium (W3C)
Wery JJ, Diliberto JA (2017) The effect of a specialized dyslexia font, OpenDyslexic, on reading rate and accuracy. Ann Dyslexia 67(2):114–127
Wikipedia (2018a) Amazon Kindle
Wikipedia (2018b) Apple Books
Wikipedia (2018c) Google Play Books
Wyke MA (1984) Reading, writing and dyslexia: a cognitive analysis A.W. Ellis, London: Lawrence Earlbaum, 1984, p. 147. Behav Psychother 14(01):95
Ziegler JC, Perry C, Ma-Wyatt A, Ladner D, Schulte-Körne G (2003) Developmental dyslexia in different languages: language-specific or universal? J Exp Child Psychol 86(3):169–93