DIESEL-X: A Game-Based Tool for Early Risk Detection of Dyslexia in Preschoolers

Luc Geurts, Vero Vanden Abeele, Véronique Celis, Jelle Husson, Lieven Van den Audenaeren, Leen Loyez, Ann Goeleven, Jan Wouters, and Pol Ghesquière

Abstract DIESEL-X is a computer game that was developed to detect a high risk for developing dyslexia in preschoolers. The game includes three mini-games that test the player on three skills that are considered to yield outcome measures that predict the onset of dyslexia: the detection threshold of frequency modulated tones, a test on phonological awareness in which the player has to identify words that have the same phonetic ending, and a test on letter knowledge. In order to keep the motivation of the player high during testing, these tests are embedded in a computer game. We discuss the participatory design process that was adopted to design and develop the game, the rationale behind the design decisions, and we describe the resulting games.

Keywords Early detection of dyslexia • Games for dyslexia • Games for preschoolers • Participatory design

L. Geurts (✉) • V. Vanden Abeele • J. Husson • L. Van den Audenaeren
e-Media Lab, KU Leuven, Andreas Vesaliusstraat 13, Leuven 3000, Belgium
e-mail: luc.geurts@kuleuven.be; vero.vandenabeele@kuleuven.be; jelle.husson@kuleuven.be; lieven.vandenaudenaeren@kuleuven.be

V. Celis • P. Ghesquière
Parenting and Special Education Research Unit, KU Leuven,
L. Vanderkelenstraat 32, Box 3765, Leuven 3000, Belgium
e-mail: veronique.celis@ppw.kuleuven.be; pol.ghesquiere@ppw.kuleuven.be

L. Loyez • A. Goeleven
Department of Speech Language Pathology (MUCLA), University Hospitals Leuven Belgium, Kapucijnenvoer 33, Leuven 3000, Belgium
e-mail: leen.loyez@uzleuven.be; ann.goeleven@uzleuven.be

J. Wouters
ExpORL, Department of Neurosciences, KU Leuven,
Herestraat 49, Box 721, Leuven 3000, Belgium
e-mail: jan.wouters@med.kuleuven.be

J. Torbeyns et al. (eds.), *Describing and Studying Domain-Specific Serious Games*,
Advances in Game-Based Learning, DOI 10.1007/978-3-319-20276-1_7

Introduction

What Is Dyslexia?

Dyslexia is a neurodevelopmental disorder that is manifested by persistent reading difficulties in children who otherwise possess adequate intelligence and motivation (Gersons-Wolfensberger & Ruijssenaars, 1997; Shaywitz, 1998). With a prevalence of about 5–10 %, dyslexia is perhaps the most common and the most studied of all learning disabilities. Hence, the underlying causes of dyslexia have been the subject of many studies and of fierce debate among researchers. There is now a growing consensus that these insoluble and tenacious reading difficulties reflect a deficiency in phonologic awareness (Snowling, 2000). According to this phonologic-deficit hypothesis, people with dyslexia lack an awareness that words can be broken down into smaller units of sounds. People with dyslexia seem to be less sensitive for the sound structure of language—which is needed to recognize rhyming words, or words starting or ending with the same sound (Bradley & Bryant, 1983). In turn, this phonological deficit is assumed to be caused by difficulties in low-level auditory temporal processing. People with dyslexia tend to have difficulties processing linguistic and nonlinguistic stimuli that are short and enter the nervous system in rapid succession (Bailey & Snowling, 2002; Farmer & Klein, 1995; McArthur & Bishop, 2001). They tend to have difficulties with degraded speech perception or speech-in-noise (Boets, Wouters, van Wieringen, & Ghesquière, 2006a; McBride-Chang, 1995). Additionally, they show an impaired perception of dynamic aspects in the auditory signal itself, like amplitude and frequency modulations (Menell, McAnally, & Stein, 1999; Talcott et al., 2000; Talcott & Witton, 2002; Witton et al., 1998).

How Is Dyslexia Diagnosed?

While the underlying causes of dyslexia have become more and more disclosed, the actual diagnosis of dyslexia is still somewhat obtuse. The diagnosis of dyslexia is simply based on the prevalence of a child's poorly developed reading and writing skills despite normal intelligence, and despite remedial efforts. This implies that an official diagnosis can only be made after the negative consequences of dyslexia have manifested themselves. This poses a paradox, as with many developmental disorders, dyslexia should be detected as soon as possible. The younger the age at the start of remedial treatment, the larger the effect that can be attained (Fawcett & Nicolson, 1995; Hintikka, Mikko, & Lyytinen, 2005; Lefly & Pennington, 1991; Lyytinen & Erskine, 2006). Ideally, early detection of dyslexia enables preventive actions, in order to prepare the child *before* formal reading and writing instruction.

The problem is that no classical reading or writing tests can be taken from preschoolers as obviously children at this age have not learned yet to read and write. However, based on the growing understanding of the phonological deficit and delayed auditory temporal processing underlying dyslexia, other tests can be taken

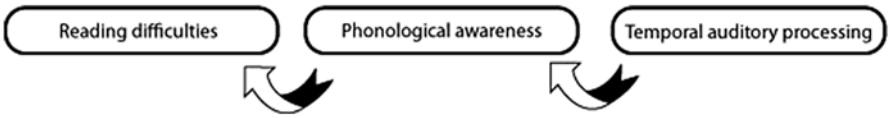

Fig. 1 According to the phonological deficit model, reading difficulties are caused by a lack of phonological awareness which in turn is caused by problems with temporal auditory processing

at this age, that allow for the detection of high risks for dyslexia. These tests do not target reading and writing skills, but include measurements of basal auditory and visual processing skills, speech-in-noise perception tasks, frequency modulation detection, end-phoneme recognition, rapid automatic naming tasks, and measurements of verbal short-term memory. In a series of experiments, Boets and colleagues have demonstrated that such tests can differentiate high risk preschoolers from low risk preschoolers (Boets, Ghesquière, van Wieringen, & Wouters, 2007; Boets, Wouters, van Wieringen, Desmedt, & Ghesquière, 2008; Boets et al., 2006a; Boets, Wouters, van Wieringen, & Ghesquière, 2006b). These studies confirm the theory that more basic processes in the brain are responsible for the observed deficits in learning to read and write (Fig. 1), yet they also show manners of assessing dyslexia before reading and writing difficulties have manifested themselves. The performance on these tests is a good predictor for the development of dyslexia.

However, in the discussions of aforementioned studies, Boets and colleagues also report it was difficult to grab and maintain the children's attention throughout the tests (Boets et al., 2006a; Laneau, Boets, Moonen, van Wieringen, & Wouters, 2005) which often lasted longer than 1 h. Even though the tests contained graphical embellishments (i.e., drawings and sounds), children's interest waned during testing. Consequently, test results showed a lot of variability, certainly when assessing threshold values where the "best performance" of the child is to be measured. This is typical for temporal auditory processing tests where children were tested on their perception of degraded speech, speech-in-noise, frequency modulation (i.e., detecting pitch variations) or amplitude variations. Some of these tests use a staircase procedure. Such a staircase begins with an easy detection task (e.g., which of the tree following sounds is different from the others, with one sound being markedly different) but then the manipulations gradually become more and more subtle, until the child makes a mistake. At this point, the staircase "reverses," and the task becomes easier again. When the child completes the task correct again, this triggers another reversal and the task becomes harder again. Such a staircase procedure is necessary for finding the threshold values of children; however, it is a lengthy procedure, and it is set out to find the level of difficulty where children "fail" to perform correctly. Therefore, not surprisingly, significant differences in Boets et al. experiments' results were found, but only at the group level. The results confirmed that the group of children with a high risk profile for dyslexia performed significantly worse on the tests at preschool age, compared to a group of children with a low risk for dyslexia. However, at an individual level, no reliable predictions could be made. Boets et al. stressed that more accurate measurements are needed to allow for risk detection at the individual level (Boets et al., 2006a).

Game-Based Remediation and Assessment of Dyslexia

More accurate measurements can possibly be achieved by finding better ways to increase the motivation of the child to take part in the test, and to attain a longer attention span. One way to increase a child's motivation and attention is via digital games (Gee, 2003; Kirriemuir & McFarlane, 2004; Malone, 1980; Prensky, 2001). By offering interactive and immersive audio-visual worlds, game designers realize an environment that rouses a child's senses and interests and stimulates exploration. But more importantly, well-designed games tailor to the skills of individual players, by continuously assessing performances and adapting the difficulty level of the task. By offering challenges that match the abilities of the players, game designers create a psychological state known as flow (Csikszentmihalyi, 1990; Sweetser & Wyeth, 2005). During a flow state, a player loses his sense of self and his sense of time and place. Flow is gratifying in and of itself; it is an intrinsic motivation that keeps a player playing. Moreover, this characteristic ensures that players deliver their best performances. As aforementioned, best performance measuring is necessary for temporal auditory processing tests. Finally, games offer reward systems that motivate players (Wang & Sun, 2011). Through scoring systems, experience points, badges that can be unlocked, etc. players are motivated to keep on delivering their best performance (Sailer, Hense, Mandl, & Klevers, 2013). These assumptions with regard to attention, motivation, and games have been confirmed by user evaluation and user testing of games with preschoolers (Barendregt, Bouwhuis, de Ridder, & Bekker, 2006; Hanna, Neapolitan, & Risden, 2004; Markopoulos & Bekker, 2003; Zaman, 2008). These researchers have demonstrated that while traditional user tests with preschoolers should last no longer than 30 min (Hanna et al., 2004), this time can be doubled when testing games (Zaman, 2008). It is therefore a valid assumption that administering "boring" tests via a game will lengthen the attention span of the preschooler. In sum, a well-designed computer game can provide a motivating environment, resulting in preschoolers' increased attention span and hence a higher accuracy and thus a better assessment.

Game-based assessment of dyslexia. The unraveling of the phonological deficit underlying dyslexia is combined with an increasing confidence in neuroplasticity (Merzenich et al., 1996), and the popularity of serious games (Michael & Chen, 2005) has spurred researchers to develop new game-based therapies to train phonological awareness, e.g., FastFoward (Tallal et al., 1996; Temple et al., 2003), Letterprins (Steenbeek-Planting et al., 2013), Nessy (Singleton, Thomas, & Horne, 2000), Dyseggxia (Rello, Bayarri, & Gorriz, 2012). However, we stress that the focus of this research project is not on the remediation of neurological deficits, but rather on the early detection of dyslexia, in preschoolers, before formal reading and writing education has been given. As a consequence, this tool can be considered as a screening tool, but not as a diagnosis instrument.

Game-based *assessment* of dyslexia in preschoolers is less common. To the best of the authors' knowledge, no validated game-based screening test for preschoolers exist today. Perhaps, most closely is the Lucid Rapid Dyslexia Screening tool (Singleton et al., 2000). The tests included in this screening tool are phonological

processing (i.e., a rhyming exercise), auditory sequential memory (remembering sequences of animal names), and visual verbal integration memory (remembering sequences of colors). The Lucid Rapid Dyslexia Screening test is standardized for British English speaking children however, which renders it useless for preschoolers outside of Great Britain. Moreover, the screening tool is also very much a test battery and not really a game (Juul, 2011). There is no use of simulations or animations, no rewards, no story line, no character development, etc. Another noteworthy effort is Magno-Fly (Ferwerda & Rehon, 2007) by Gaggi and colleagues, who are also in the process of developing serious games aimed at detecting children with a high risk for the development of dyslexia (Gaggi, Galiazzo, Palazzi, Facoetti, & Franceschini, 2012). However, the games they are developing underscore an alternative model of dyslexia, which attributes dyslexia to the dysfunction of cells involved in processing sensory information in general (Stein & Walsh, 1997). This is a controversial hypothesis as sensory dysfunction is absent in many cases of dyslexia and has no clear causal link to reading problems (Ramus, 2003). Hence, their game-based assessment does not underlie the phonological deficit and is therefore more experimental in nature. However, thus far, no information has been given with respect to validation.

Given the lack of game-based assessment in the area of Flanders, the DIESEL-X project was conceived. However, creating a good serious game is not straightforward. On the one hand, there is always the threat of sugar coating: a superficial embellishment of what is actually a boring task with a couple of fun animations and a little bit of game play. Good serious game design requires a seamless integration of the serious goal and game dynamics. The aim of serious games is "stealth learning" or in this case "stealth testing" (e.g., Shute, 2011): the children should be unaware of the fact that they are tested and the overall game experience should simply be fun. On the other hand, the fun factor should not intrude upon the serious goals. In the following chapters, we present the design process and the result: DIESEL-X, a game-based tool to test whether a five-year-old has a high risk of developing dyslexia.

A Player-Centered, Iterative, Interdisciplinary and Integrated Game Design and Development Process

In order to reconcile the intricacies of a game design process with the serious goals of dyslexia assessment, a player-centered, iterative, interdisciplinary and integrated (P-III) design process was followed (Vanden Abeele et al., 2012).

Player-centered process. In digital game design and development, player involvement is often limited to participation in usability and play tests (Pagulayan, Keeker, Wixon, Romero, & Fuller, 2003). Although such play tests are necessary, they do not offer players to participate in the creative part of the game design itself. This increases the risk of a self-referential design process, where designers or developers fall back on an I-methodology and design games as if they were for themselves (Oudshoorn & Pinch, 2003; Vanden Abeele & Van Rompaey, 2006). Even *if* designers were capable

of accurately reliving their own childhood memories and experiences and understanding cognitive, affective, and behavioral characteristics, preschoolers of today have grown up with digital games, and relate to it differently. Preschoolers of today are not the preschoolers of 30 years ago. Therefore, the P-III process specifies methods to involve the player throughout the design process: from ethnographically inspired inquiries at the start of the project, participatory design sessions during the design phase to play tests during the development, to ensure that the result is "meaningful play" (Deterding, Dixon, Khaled, & Nacke, 2011; Salen & Zimmerman, 2003). The specific methods employed during the design process of DIESEL-X will be detailed below.

Interdisciplinary team. Moreover, P-III stresses the importance of including all stakeholders, including, but not limited to, end-users, as co-designers of their technology. In the P-III design process of DIESEL-X, we involved the "creators" of the game (game designer, game developer, and digital artist), two dyslexia experts (a dyslexia researcher and a clinical specialist), several preschoolers, and one preschool teacher to create a truly interdisciplinary game design and development team.

Iterative process. P-III emphasizes the importance of early empirical evaluations with players via concept designs, paper prototypes, and early prototypes. During the design and development process, the application is presented to all stakeholders, to be discussed, tried out and particularly tested and evaluated. These empirical measurements feed the design process in a formative iterative manner. In DIESEL-X, over the course of 18 months, several prototypes were created and tested with preschoolers.

Integrated play and testing. Finally, P-III stresses the importance of integrating the serious goal with the game mechanic in a seamless manner, i.e., games should not be used as a treat in between boring tasks, but rather the task itself should be the game challenge. This requires a careful inspection of the task at hand and which game mechanic maps well to this task. How this was done will be detailed further below.

In addition to the four pillars discussed above, the P-III prescribes three phases: user and tasks analysis, game design, and game development, each with their own steps (Fig. 2). Whereas the illustration of the P-III process might suggest strict delineated boundaries, in reality these boundaries are fluid. During the design and development phase, a further understanding of the users and tasks is inevitable and in fact desirable. And obviously, some design ideas might already linger in the back of a designer's mind during the user and task analysis. Moreover, play tests during development might inspire the team to add some features in the design. Nevertheless, these phases demarcate the broad stages within the design process.

Phase 1: User and Task Analysis

The first phase of the P-III method focuses on a better understanding of the users, tasks (in this case, the tests) and the context in which assessment of dyslexia takes place. The result is not simply a report with a list of requirements, but rather a deep

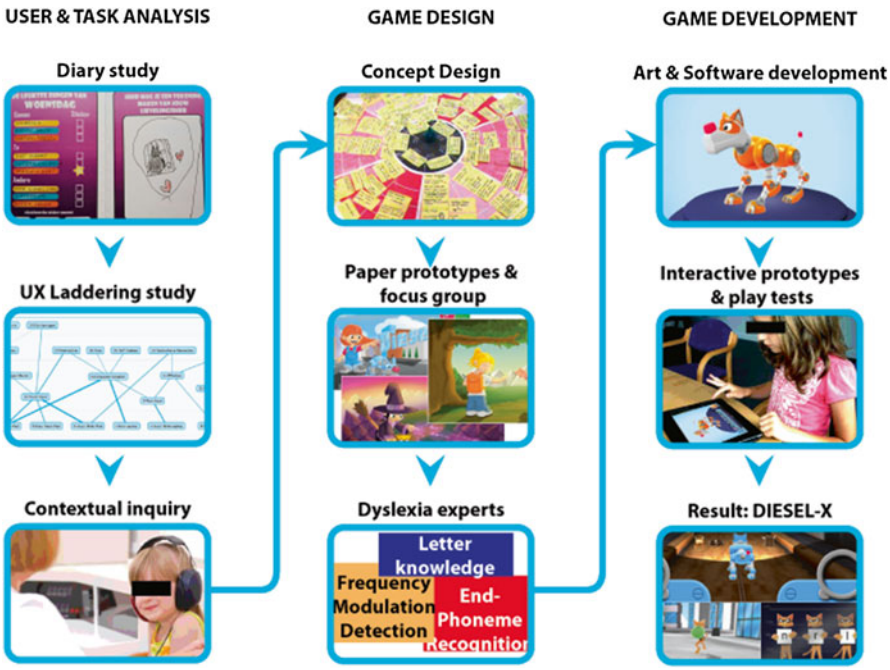

Fig. 2 P-III: A player-centered, iterative, interdisciplinary and integrated method for game design and development of game-based assessment of dyslexia

understanding of the problem domain and the players, and the many implicit rules. In addition, this phase aims to create an implicit bonding between researchers, designers, developers, and the target group, in this case preschoolers.

Diary study. We started our player-centered design process (Vanden Abeele et al., 2012) with a diary study. We wanted to understand better how and what constitutes "fun" for a preschooler, anno 2011 (Zaman & Vanden Abeele, 2007). Therefore, 15 preschoolers (2006) were recruited via two primary schools. These children were asked to keep a diary for 1 week. In this diary, children were asked to list their three favorite activities on three categories: (1) (computer) games, (2) television programs, and (3) activities in a general sense. From these three categories, preschoolers were asked to choose the most preferred item and to describe it via three key words. That way we wanted to get an overview of which characteristics appeal to 5-year-olds. Obviously, parental help was expected when filling out the diary. In addition, a fun daily task was included (e.g., make a drawing or a paper collage). These daily tasks were given as a sensitizing activity to ensure that the preschooler would feel involved (Visser, Stappers, van der Lugt, & Sanders, 2005). This "diary-week" was followed by an interview where the preschooler and researcher went through the diary together. It is important to note that the researchers here were equally game designers, game developers, and digital artists. Hence, this in-depth interview provided the creators of the game with a direct contact to end-users, which is paramount to avoid

Fig. 3 Excerpt of a boy's diary

a self-referential design. This interview took place at the child's house, so he or she felt at ease and could demonstrate when things were unclear to the researcher ("Show and tell"). A focus was on *deep understanding* of the target audience and their wishes. Figure 3 depicts an excerpt of a page in a boy's diary.

User experience laddering. After the diary study, a User Experience (UX) Laddering study (Zaman & Abeele, 2010) was conducted. UX Laddering is a combination of observations of preschoolers playing games, preference ranking exercises, and depth interviews. Twenty-five preschoolers were asked to play eight selected games, designed specifically for preschoolers, and then asked to rank them from most preferred to least preferred and to explain their preference. The aim of this study was to unveil which game attributes (i.e., game mechanics) link to specific gameplay preferences (game aesthetics). The results of this study is what is called a hierarchical value map (see Fig. 4), a graphical representation of how in-game attributes link to specific game experiences that are valued by preschoolers. Hence, this study provided a set of meaningful and useful design guidelines, directed at this young target group. This study is described in more detail in (Celis et al., 2013); its results will be briefly summarized here. Preschoolers seem to enjoy *collecting different items* through the game as this serves both as a challenge and as a reward system. This gives them a sense of victory and ultimately realizes a challenging gameplay-experience. *Touch input* is also clearly preferred

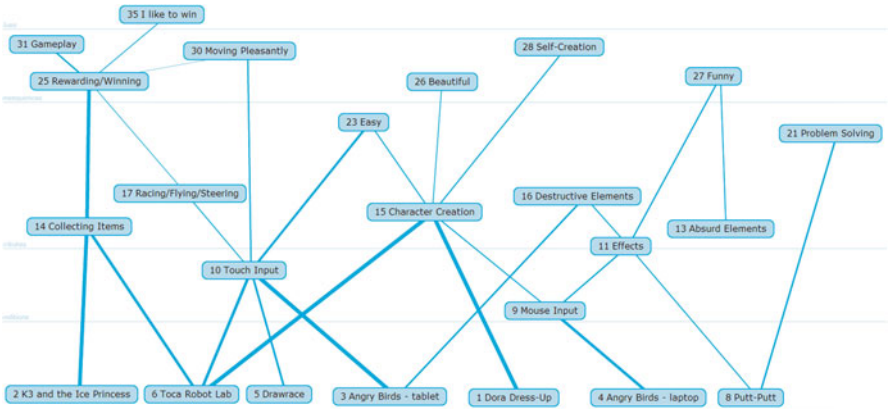

Fig. 4 The hierarchical value map: An overview of meaningful linkages across attributes, consequences, and values

over more classical input (keyboard or mouse), showing that preschoolers like the intuitiveness and physicality of interacting with their hands and fingers. *Character creation* allows for creative expression and is often implemented by providing a standard avatar, which can be outfitted with different clothes and accessories. Finally, implementing *visceral effects and visual gags*, *destructive elements* (exploding items, breaking walls, etc.) contribute to the aesthetic "Sense-Pleasure." This confirms that preschoolers have a sense of how things should be in reality and find it humorous when things deviate from the norm.

Contextual inquiries with dyslexia experts. Finally, to better understand the problem space of assessment of dyslexia, game designers and game developers followed dyslexia researchers during two days while they were conducting the traditional tests (Laneau et al., 2005) in schools, with preschoolers. This study was done according to the contextual inquiry method (Beyer & Holtzblatt, 1997). This implies that the observations were done in context (i.e., at the schools where the actual assessments would take place) and that the DIESEL-X researchers adhered to a master-apprentice model, where they were to learn from the dyslexia researchers as if they were interns. The open-ended nature of the contextual inquiries and the focus on observations, make it possible to reveal tacit and implicit knowledge of which dyslexia researchers themselves are not consciously aware. Tacit knowledge has traditionally been very hard for researchers to uncover. These observations contributed to a further understanding of the specific tests and measurements that needed to be embedded in the game, but more importantly of the context in which this needs to happen. These contextual inquiries provided insight in the problems of testing children in a school environment, with multiple interrupts by other children and teachers, obsolete ICT-infrastructure, the temporal structure of a school day with many playtime, the lack of reserved space for testing, etc.

Phase 2: Game Design

At the end of this user and task analysis phase, the Diesel-X researchers had established a deep understanding of the problem domain, and established report with their target group of preschoolers. At this point, the design phase can start during which the obtained insights are translated into design concepts.

Co-design sessions. Two brainstorm sessions were organized, taking several constraints into account: (1) the results of the first phase, i.e., the knowledge on how preschoolers experience the classical tests and the representative computer games, (2) the guidelines on motivational factors of a computer game for preschoolers, and (3) the goal of the game, i.e., taking accurate psychophysical measurements within a school environment. Adhering to a player-centered design methodology, all stakeholders were involved: a game designer, game developer, and digital artist, two dyslexia experts (a dyslexia researcher and a clinical specialist), several preschoolers, one preschool teacher, a researcher experienced with the traditional tests, and two kindergarten teachers). At the end of these brainstorm sessions, a list of ideas was created regarding the content and design of the game (see Fig. 5). The most valuable ideas were identified and three game concepts were conceived on the basis of these ideas.

Game concepts and focus groups. These three game ideas where transformed into three game concept (see Fig. 6) documents by the game designer and digital artist. Every concept was a one-page document which contained a splash image with the title, the protagonist(s) in their environment, and an antagonist where applicable. Furthermore, every document contained a brief description of the narrative and the goal of the game.

These concepts were again evaluated by the users (preschoolers) of the game via focus groups. In particular, 20 children (15 girls, 5 boys) of one kindergarten class participated. These children were divided into three focus groups of each six or seven participants. The focus group interviews were adapted to the characteristics and developmental limitations of preschoolers (Fuchs, 2005; Morgan, 1996). Firstly, the evaluation took place in their class room. This natural context increases the reliability and validity of the data (Golafshani, 2003; Patton, 1990) and minimizes the power differential between the researcher and the preschoolers (Eder & Fingerson, 2002) as the preschoolers are in a familiar place whereas the researcher is not. Secondly, at the start of the focus group, the researcher presented the three different prototypes, by means of a story of each approximately five minutes, accompanied by some illustrations (see Fig. 6).

Every story (i.e., game concept) was read aloud, illustrated through the visual image of the game environment and followed by a short discussion. Possible order effects were being counterbalanced by reading the three stories in different sequences. Next, every preschooler was given three small cards, depicting the three game concepts, followed by a voting session. After explaining the three game concepts (i.e., listening to the three stories and looking at their respective artwork), the children were asked to choose the concept card they liked most, but in such a way that the other children and the researcher could not see their preferred game

Fig. 5 Result of the first brainstorm session

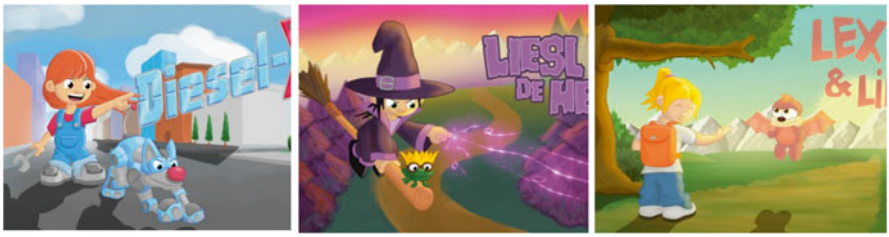

Fig. 6 Visual example of the three game concepts: (**a**) Diesel-X, (**b**) Liesl de Heks, and (**c**) Lex & Lilly

concept. Upon a signal of the researcher, the preschoolers unveiled their choice (they flipped their chosen card), all at the same time. With the chosen card in front of them, preschoolers were prompted to explain their choice. This process mitigated the risk for group influences and/or social desirability with respect to the researcher. Results showed that, even after this individual voting setup, 18 out of 20 preschoolers preferred DIESEL-X over the two other concepts. The boys liked Diesel ("a smart robot dog with wings"), the girls identified with Alex ("a though girly-girl") and they all liked chasing the mean cats ("I want to throw them in the bath with a lot of dirty mud"). As a result, the theme of "whizz kid Alex, and her robot dog having to save the city from obnoxious cats" was chosen to elaborate further.

Dyslexia experts. Finally, in close consultation with dyslexia experts, several tests were discussed that could possibly be embedded in the game. Three criteria had to be satisfied:

1. *Feasibility* of embedding these tests into a game-based environment. In other words, the test had to be suitable for computerization. Some tests require an administrator to carefully listen to the child's answer, hence requiring a level of automated speech recognition beyond what is currently feasible.
2. *Prediction rate success of the test*. The tests had to be scientifically accepted as a valid means to flag dyslexia. In addition, there was a wish for including tests at the different levels e.g., at the level of reading difficulties itself (e.g., letter recognition), at the level of phonological awareness (e.g., end-phoneme recognition), and at the level of temporal auditory processing (e.g., detecting frequency modulations).
3. *Integrated play and testing*. The test had to allow for an integration of a game mechanic in addition to the test itself. However, the test outcomes should only depend on the player's ability to perform well on the tasks at hand. In other words, the game dynamics should not interfere with the actual test data and yet motivate the player to perform at his or her best.

Upon these criteria, and following several discussions among the interdisciplinary team, three tests were chosen to be embedded in the game. The first test is a *frequency modulation* (*FM*) *detection task*, which tests the subject on a very basic sound perception skill (Boets et al., 2006a). The task is to discriminate an unmodulated pure (sinusoidal) tone with a frequency-modulated tone. Typically, an adaptive procedure is used to detect the threshold. Initially, a highly modulated tone is presented that is easy to recognize. As long as the subject's response is correct, the modulation depth is decreased. A three-interval three-alternative-forced-choice procedure was used, meaning that three tones are presented from which one (randomly selected) is frequency modulated. The second task is measuring *phonological awareness*, more specifically the subject has to recognize words that end with the same phoneme (e.g., glass and boss) (Boets et al., 2007). In each trial, four alternatives are presented with one of them ending with the same phoneme as a given reference word. The third task is assessing the subject's *letter knowledge* (Hulme, Bowyer-Crane, Carroll, Duff, & Snowling, 2012). When designing games that test the subject on specific skills, special care should be taken that possible confounding variables such as prior game experience, spatial skills, or problem-solving skills do not interfere with the test outcomes and affect the validity of the tests.

Game Development

Upon these choices, the game development phase started. Over a period of 18 months, the game was gradually developed and tested. The DIESEL-X game consists of three mini-games, each embedding a different test (FM detection,

end-phoneme, and letter knowledge), and that were developed and tested in consecutive order. Then, these mini-games were embedded in an overarching story line and a reward system was included.

Art and software development. The game was developed with the Unity engine[1] to run on Android tablets, specifically the Samsung Galaxy Tab 2. We chose the Unity engine due to its expansive community, affordable price, and ease of publishing code to multiple platforms. Art assets were produced using 3D studio Max[2] and Photoshop.[3] Auditory instructions and game dialogue files were recorded with professional actors in a studio. Player data were stored locally on the tablets using an SQLite database, and subsequently synchronized to a server-side MySQL database via a secure web service. Test administrators could inspect the data via this online web platform. More details on the logged data and the web platform are given in Plong, Vanden Abeele, and Geurts (2014).

Prototypes and play tests. Hence over a period of 18 months, 6 play tests with preschoolers were conducted. Intermediate versions of each mini-game were played by preschoolers, which allowed to correct for bugs, to balance the game with the abilities of the young players, and to ensure that the games can be played without the need of supervision. The focus of these play tests was "formative," meaning that the results were fed into the development process again, hence resulting in an iterative development process. As such, many of the play tests were conducted with the designer and developer present. The reason to continue this iterative feedback process is to guarantee that the final product still meets the ultimate goal: a game that is both fun to play and that allows for accurate measurements of the players abilities.

Results

The DIESEL-X game encompasses three mini-games, each of which has four levels. Hence, each mini-game is revisited four times in a linear, predefined sequence, so every preschooler is presented the same challenges. In between mini-games, the story unfolds through cinematic sequences. The game is meant to be completed in one session, which takes approximately 1 h, the exact time depends on how long preschoolers take to complete certain mini-games.

[1] http://unity3d.com/

[2] http://www.autodesk.com/products/3ds-max/overview

[3] http://www.photoshop.com/

Tailoring the Game for Preschoolers

First of all, the art style of the game was developed specifically to appeal to young children. The game and its cinematic sequences are rendered in 3D with a cartoony look and feel, with vivid colors and exaggerated proportions (see Figs. 8, 9, and 10). Care has been given to avoid gender stereotypes and to develop content that appeals to boys and girls. The preschoolers are guided with clear auditory instructions, which can be replayed at any time.

Story Line

In DIESEL-X, an evil gang of cat burglars has been creating uproar in the city. The policemen are helpless and the city lies in disarray. Luckily, one brave little girl, Alex, is smart enough to come up with a solution to tackle the cats. Players take on the role of Diesel, the robot-dog that was created by Alex. Together, they will help get rid of the pesky cat burglars once and for all!

Content

At the start of the game, a movie is shown that introduces the situation of the city and its rogue cats. This movie is meant purely to engage the children playing the game. From then on, the player will be prompted to play through the mini-games, by means of a blinking indicator on a map of the city (see Fig. 7). The preschooler has 12 "play tests," as each of the 3 mini-games has 4 levels, hence is to be played 4 times. However, with every level, the mini-game is placed within a new part of the city; although the game mechanic for every mini-game remains the same, the visual styling is different. After completing part of a mini-game, the player either unlocks a new color or gear to customize Diesel, or the player receives a spare part to build a space rocket. This process is repeated until the three mini-games have been played four times and are thus completed. During the course of the game, the player also works towards the end goal of building a complete rocket, necessary for shooting the cats to the moon. When the rocket is complete, the player is rewarded with an ending cinematic seeing the cats transported to the moon.

Mini-Games

As aforementioned, three tests (Letter knowledge, FM detection, end-phoneme recognition) were converted into three mini-games.

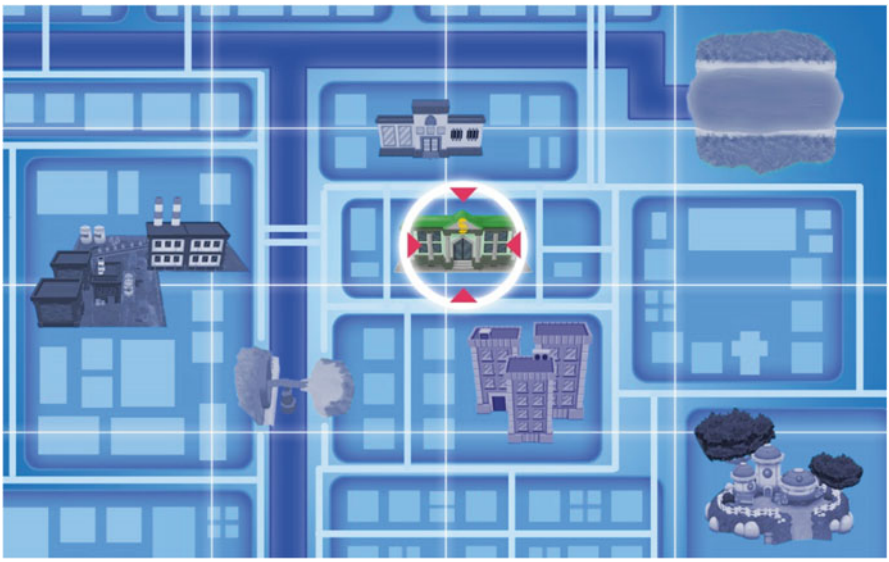

Fig. 7 Map of the city in which the DIESEL-X game takes place. The player has to enter several areas in the city in order to complete a task

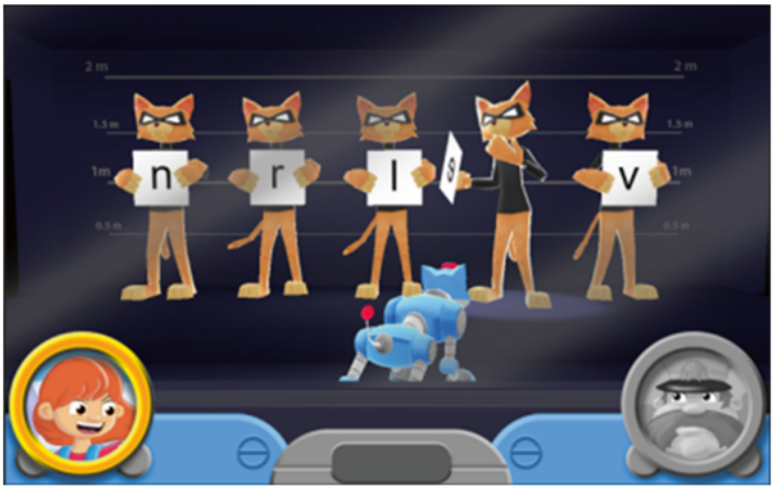

Fig. 8 The "Line Up" mini-game showing the main character, the robot dog Diesel, in the middle. Guided by instructions from Alex (girl at the *left*) and a commissioner (at the *right*), the player has to point to the "guilty" cat. The police officer mentions the letter held by that cat

Line Up (letter knowledge). "Line Up" works like a traditional police line up, where the victim of a crime has to identify the suspect (see Fig. 8). The players will have to use their knowledge of the letters of the alphabet to point out the right suspect. The commissioner introduces one of the victims, and the cat burglars are

Fig. 9 The "Chase" mini-game. Diesel chases three cats through the streets of the city. Each cat makes a sound, one of these being frequency modulated (the other two are pure tones). The player has to point to the cat generating this FM tone. As long as the player answers correctly, the modulation depth is decreased

called on stage. They are all holding a certain letter in their hands. The victim then shortly explains what happened and points out which of the cat is the suspect by calling him by the letter he is holding. This letter is repeated by the commissioner. The player now has to indicate the cat with the right letter so Diesel can point at him. Hence, this game tests the player's letter knowledge, which is known as a strong indicator for dyslexia (Hulme et al., 2012).

Chase (FM detection task). In "Chase," cat burglars have to be chased throughout the city, where Diesel tries to retrieve stolen diamonds and money from a bank robbery (see Fig. 9). The player will use auditory cues to detect which cat carries the stolen goods. Every time Diesel barks, the three cats being chased will come to a halt. Every cat is carrying a bag with stolen goods, which is "scanned" by Diesel. While scanning, the player hears either a pure tone (sinusoid) or a frequency modulated tone. Only one of the cats is carrying diamonds (FM tone), the other ones are carrying stones as a decoy (pure tone). The goal for the player is to point the odd one out, with every dilemma increasing in difficulty. It gets harder to detect which sound was the one with frequency modulation, since the modulation depth decreases as long as correct answers are given (according to a staircase procedure) (Boets et al., 2006b).

Lost objects (end-phoneme recognition). "Lost Objects" takes places in several abandoned locations throughout the city, where the cat burglars have hidden their secret stash of stolen goods (see Fig. 10). The player will have to identify which items to retrieve, relying on their recognition of the end-phonemes of said items. The game takes the player from the sewers to the rooftops, to an underwater setting, and finally

Fig. 10 The "Lost Objects" mini-game. Diesel finds several objects, and of them was stolen by the cats. Alex gives indications by mentioning a word that ends with the same phoneme. The player has to point to the "right" object

into a burning factory. Every time Diesel comes to a halt, five items are presented to the player. Alex, via radio, reads the names of the items aloud, and asks the player to indicate the item which has the same end-phoneme as a certain reference item.

Integrated Play and Learning

From the previous paragraphs, it should be clear that special care has been put into the game design of the mini-game, ensuring that the challenge at hand directly maps onto the skill being tested. However, at the same time care needs to be given that the mini-games only assess the player's letter knowledge, end-phoneme recognition and FM threshold, and not their overall gaming skills. Therefore, any game mechanic that would involve complex hand–eye coordination or require timely responses has been avoided. Preschoolers simply needed to tap large objects, and there is no time pressure. Preschoolers can take as long as they please. Play tests confirmed that preschoolers understood the tasks and did not experience difficulty entering their selection.

Motivation

The main hypothesis underlying DIESEL-X is that a game-based assessment increases motivation; hence, it increases the attention span. Therefore, besides the above challenges, several motivational aspects were added to the games.

Rewards. First of all, as mentioned before, preschoolers like to collect things in games, so the game was designed with collectable rewards in mind. However, we focused on intrinsic motivation; hence, rewards should have meaning for the players and be related to their actions. In this case, upon completion the player can unlock new colors for Diesel, playing with a different color Diesel through the rest of the game. Other rewards include unlocking new weapons, unlocking pieces of a rocket to get rid of all those cats, and unlocking new environments to play in. Also, the game rewards the player with auditory comments of both the commissioner and Alex to compliment the player on his actions.

Feedback. Because the game is meant as an assessment tool and not a learning tool, giving feedback about the correctness of the players' actions is tricky. Giving feedback about being right or wrong might indeed start a learning process for the player which might pollute some of the data being collected. Hence, we provided feedback indicating that the game registered the action of the player, but not with respect to the quality of the action itself.

In Line Up, the player needs to select the requested letter. If the game would give the preschooler feedback about the letters he or she selects, he or she might learn new letters while playing the game. Therefore, the choice was made to give the player some neutral feedback, acknowledging the action. We would like to point out that the game does not tell the player whether he or she was correct or not, because it is not the game's purpose of teaching the player any letter knowledge.[4] Visually, the player will see Diesel attacking the selected cat. The auditory feedback is given by Alex who will compliment the player on catching another cat.

In the Chase mini-game, correct response feedback is allowed, as is common in detection threshold measurements. Learning through feedback is considered less of an interfering factor. Also, the player needs to learn this task because identifying a frequency modulated tone from a pure tone is new for preschoolers. As a result, the visual and auditory feedback indicates whether the correct response is selected. The player will receive a bag with money or a diamond when a correct answer is given, and a bag with bricks in the other case. Also, when the player selects the right cat, Alex will compliment him or her on his action and the cat he caught will cry. When the player selects the wrong cat, he or she was tricked and he or she will see the cat being caught laughing.

In the Lost Objects mini-game, learning through feedback is avoided again. So just like in the Letter Knowledge mini-game, the player will receive neutral, acknowledging, and encouraging feedback. Only in the first two trials, he or she will receive feedback about being right or wrong. The game will first show the player what to do to make sure he or she understands his or her task. From the third trial on, the player will no longer receive correct response feedback, but will still be complimented on finding a lost item.

[4] In fact, giving feedback that is neutral turned out to be difficult as children tend to interpret feedback signals as positive or negative anyhow. Several iterations were necessary to design this feedback that was perceived as neutral. As a consequence, during play tests children sometimes turned to the test administrator to ask whether their selection was correct.

Discussion and Future Work

As illustrated by the description of the mini-games, the design guidelines mentioned before were taken into account. Touch input ensures that interacting with the game is intuitive. Players can collect different items throughout the game (gear for Diesel, spare parts of the rocket), giving them a sense of mastery. Character creation (unlocking colors and gear for Diesel) is included allowing for creative expression. Finally, showing different funny animations and a variety of environments between and during the tests ensures that playing the game keeps on being engaging in a visceral and humorous manner.

Whatever the performance of the players on the test, encouraging feedback is given throughout the game. This gives both dyslexic and non-dyslexic players a sense of mastery and success, which is needed to keep the motivation at a sufficient level. Prior experience on gaming is made irrelevant by adopting game mechanics that do not rely on typical game skills, such as fast and accurate eye–hand coordination. Although the evaluation of the game is beyond the scope of this chapter, empirical evaluation proofed that preschoolers preferred this game over the traditional tests and had no problem with sustaining attention over an hour.

Further studies are now being conducted in order to find the critical measures that allow for the detection of a high risk for dyslexia.

Conclusion

The DIESEL-X game-based assessment tool is one of the first attempts to incorporate lengthy and boring tests within a game-based application. Further studies are now being conducted to investigate the reliability and validity of the test results. If successful, this project might be an important first step towards a novel way of diagnosing neurological disorders in young children in general.

References

Bailey, P. J., & Snowling, M. J. (2002). Auditory processing and the development of language and literacy. *British Medical Bulletin, 63*(1), 135–146. doi:10.1093/bmb/63.1.135.

Barendregt, W., Bouwhuis, D., de Ridder, H., & Bekker, M. (2006). *Evaluating fun and usability in computer games with children*. Technische Universiteit Eindhoven. Retrieved from http://library.tue.nl/catalog/LinkToVubis.csp?DataBib=6:602065.

Beyer, H., & Holtzblatt, K. (1997). *Contextual design: A customer-centered approach to systems designs* (1st ed.). New York, NY: Morgan Kaufmann.

Boets, B., Ghesquière, P., van Wieringen, A., & Wouters, J. (2007). Speech perception in preschoolers at family risk for dyslexia: Relations with low-level auditory processing and phonological ability. *Brain and Language, 101*(1), 19–30. doi:10.1016/j.bandl.2006.06.009.

Boets, B., Wouters, J., van Wieringen, A., Desmedt, B., & Ghesquière, P. (2008). Modelling relations between sensory processing, speech perception, orthographic and phonological ability, and literacy achievement. *Brain and Language, 106*(1), 29–40. doi:10.1016/j.bandl.2007.12.004.

Boets, B., Wouters, J., van Wieringen, A., & Ghesquière, P. (2006a). Auditory temporal information processing in preschool children at family risk for dyslexia: Relations with phonological abilities and developing literacy skills. *Brain and Language, 97*(1), 64–79. doi:10.1016/j.bandl.2005.07.026.

Boets, B., Wouters, J., van Wieringen, A., & Ghesquière, P. (2006b). Coherent motion detection in preschool children at family risk for dyslexia. *Vision Research, 46*(4), 527–535. doi:10.1016/j.visres.2005.08.023.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read: A causal connection. *Nature, 301*(5899), 419–421. doi:10.1038/301419a0.

Celis, V., Husson, J., Abeele, V. V., Loyez, L., Van den Audenaeren, L., Ghesquière, P., … Geurts, L. (2013). Translating preschoolers' game experiences into design guidelines via a laddering study. In *Proceedings of the 12th International Conference on Interaction Design and Children* (pp. 147–156). New York, NY: ACM. doi:10.1145/2485760.2485772.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York, NY: Harper and Row.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: defining gamification. In *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments* (pp. 9–15). Retrieved from http://dl.acm.org/citation.cfm?id=2181040.

Eder, D., & Fingerson, L. (2002). Interviewing children and adolescents. In J. F. Gubrium & J. A. Holstein (Eds.), *Handbook of interview research: Context and method* (pp. 181–201). Thousand oaks, CA: Sage.

Farmer, M. E., & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin & Review, 2*(4), 460–493.

Fawcett, A., & Nicolson, R. (1995). *Dyslexia in children: Multidisciplinary perspectives*. London, England: Harvester Wheatsheaf.

Ferwerda, J., & Rehon, B. (2007). MagnoFly: Game-based screening for dyslexia. *Journal of Vision, 7*(9), 520. doi:10.1167/7.9.520.

Fuchs, M. (2005). Children and adolescents as respondents. Experiments on question order, response order, scale effects and the effect of numeric values associated with response options. *Journal of Official Statistics, 21*(4), 701–725.

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)* (pp. 1–5). doi:10.1109/ICCCN.2012.6289249.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy* (1st ed.). Palgrave Macmillan. Retrieved from http://www.amazon.co.uk/dp/1403961697.

Gersons-Wolfensberger, D. C. M., & Ruijssenaars, W. A. J. J. M. (1997). Definition and treatment of dyslexia: A report by the committee on dyslexia of the health council of the Netherlands. *Journal of Learning Disabilities, 30*(2), 209–213.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report, 8*(4), 597–607.

Hanna, L., Neapolitan, D., & Risden, K. (2004). Evaluating computer game concepts with children. In *Proceedings of the 2004 conference on Interaction design and children: building a community* (pp. 49–56). College Park, MD: ACM. doi:10.1145/1017833.1017840.

Hintikka, S., Mikko, A., & Lyytinen, H. (2005). Computerized training of the correspondences between phonological and orthographic units. *Written Language and Literacy, 8*(2), 79–102.

Hulme, C., Bowyer-Crane, C., Carroll, J. M., Duff, F. J., & Snowling, M. J. (2012). The causal role of phoneme awareness and letter-sound knowledge in learning to read combining intervention studies with mediation analyses. *Psychological Science, 23*(6), 572–577.

Juul, J. (2011). *Half-real: Video games between real rules and fictional worlds*. Cambridge, MA: The MIT Press.

Kirriemuir, J., & McFarlane, A. (2004). *Literature review in games and learning*. Bristol, England: Futurelab.

Laneau, J., Boets, B., Moonen, M., van Wieringen, A., & Wouters, J. (2005). A flexible auditory research platform using acoustic or electric stimuli for adults and young children. *Journal of Neuroscience Methods, 142*(1), 131–136. doi:10.1016/j.jneumeth.2004.08.015.

Lefly, D. L., & Pennington, B. F. (1991). Spelling errors and reading fluency in compensated adult dyslexics. *Annals of Dyslexia, 41*, 143–162.

Lyytinen, H., & Erskine, J. (2006, February 22). Early identification and prevention of reading problems. In *Encyclopedia on Early Childhood Development*. Retrieved from http://www.enfant-encyclopedie.com/Pages/PDF/Lyytinen-ErskineANGxp.pdf.

Malone, T. W. (1980). What makes things fun to learn? Heuristics for designing instructional computer games. In *Proceedings of the 3rd ACM SIGSMALL Symposium and the First SIGPC Symposium on Small Systems* (pp. 162–169). ACM, New York, NY. doi:10.1145/800088.802839.

Markopoulos, P., & Bekker, M. (2003). Interaction design and children. *Interacting with Computers, 15*(2), 141–149. doi:10.1016/S0953-5438(03)00004-3.

McArthur, G. M., & Bishop, D. V. (2001). Auditory perceptual processing in people with reading and oral language impairments: Current issues and recommendations. *Dyslexia, 7*(3), 150–170. doi:10.1002/dys.200.

McBride-Chang, C. (1995). Phonological processing, speech perception, and reading disability: An integrative review. *Educational Psychologist, 30*(3), 109. doi:10.1207/s15326985ep3003_2.

Menell, P., McAnally, K. I., & Stein, J. (1999). Psychophysical sensitivity and physiological response to amplitude modulation in adult dyslexic listeners. *Journal of Speech, Language, and Hearing Research, 42*(4), 797–803.

Merzenich, M., Wright, B., Jenkins, W., Xerri, C., Byl, N., Miller, S., & Tallal, P. (1996). Cortical plasticity underlying perceptual, motor, and cognitive skill development: Implications for neurorehabilitation. *Cold Spring Harbor Symposia on Quantitative Biology*, *61*, 1–8. doi:10.1101/SQB.1996.061.01.003.

Michael, D. R., & Chen, S. L. (2005). *Serious games: Games that educate, train, and inform*. New York, NY: Muska & Lipman/Premier-Trade.

Morgan, D. (1996). *Focus groups as qualitative research* (2nd ed.). Thousand Oaks, CA: Sage.

Oudshoorn, N., & Pinch, T. (2003). *How users matter: The Co-construction of users and technology (inside technology)*. Cambridge, MA: The MIT Press.

Pagulayan, R. J., Keeker, K., Wixon, D., Romero, R. L., & Fuller, T. (2003). User-centered design in games. In *The human-computer interaction handbook: fundamentals, evolving technologies and emerging applications* (pp. 883–906). L. Erlbaum Associates. Retrieved from http://portal.acm.org/citation.cfm?id=772072.772128&coll=GUIDE&dl=GUIDE&CFID=11163922&CFTOKEN=41481297.

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2nd ed.). Newbury Park, CA: Sage.

Plong, M., Vanden Abeele, V., & Geurts, L. (2014). Requirements for an Architecture of a Generic Health Game Data Management System. In B. Schouten, S. Fedtke, M. Schijven, M. Vosmeer, & A. Gekker (Eds.), *Games for health 2014* (pp. 114–124). Springer Fachmedien Wiesbaden. Retrieved from http://link.springer.com/chapter/10.1007/978-3-658-07141-7_16.

Prensky, M. (2001). *Digital game-based learning*. New York, NY: McGraw-Hill.

Ramus, F. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology, 13*(2), 212–218.

Rello, L., Bayarri, C., & Gorriz, A. (2012). What is wrong with this word? Dyseggxia: A game for children with dyslexia. In *Proceedings of the 14th International ACM SIGACCESS Conference on Computers and Accessibility* (pp. 219–220). ACM, New York, NY. doi:10.1145/2384916.2384962.

Sailer, M., Hense, J., Mandl, H., & Klevers, M. (2013). Psychological perspectives on motivation through gamification. *Interaction Design & Architectures, 19*, 28–37.

Salen, K., & Zimmerman, E. (2003). *Rules of play: Game design fundamentals*. Cambridge, MA: MIT Press.

Shaywitz, S. E. (1998). Dyslexia. *New England Journal of Medicine, 338*(5), 307–312. doi:10.1056/NEJM199801293380507.

Shute, V. J. (2011). Stealth assessment in computer-based games to support learning. *Computer games and instruction, 55*(2), 503–524.

Singleton, C., Thomas, K., & Horne, J. (2000). Computer-based cognitive assessment and the development of reading. *Journal of Research in Reading, 23*(2), 158–180. doi:10.1111/1467-9817.00112.

Snowling, M. J. (2000). *Dyslexia* (2nd Rev. ed.). Hoboken, NJ: Wiley Blackwell.

Steenbeek-Planting, E. G., Boot, M., Boer, J. C. de, Ven, M. V. de, Swart, N. M., & Hout, D. van der. (2013). Evidence-based psycholinguistic principles to remediate reading problems applied in the playful app Letterprins: A perspective of quality of healthcare on learning to read. In B. Schouten, S. Fedtke, T. Bekker, M. Schijven, & A. Gekker (Eds.), *Games for health* (pp. 281–291). Springer Fachmedien Wiesbaden. Retrieved from http://link.springer.com.kuleuven.ezproxy.kuleuven.be/chapter/10.1007/978-3-658-02897-8_22.

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in Neurosciences, 20*(4), 147–152.

Sweetser, P., & Wyeth, P. (2005). GameFlow: A model for evaluating player enjoyment in games. *Computers in Entertainment, 3*(3), 3. doi:10.1145/1077246.1077253.

Talcott, J. B., & Witton, C. (2002). A sensory linguistic approach to the development of normal and impaired reading skills. In *Neuropsychology and cognition series. Basic functions of language and language disorders*. Dordrecht, Netherlands: Kluwer Academic Publishers.

Talcott, J. B., Witton, C., McLean, M. F., Hansen, P. C., Rees, A., Green, G. G., & Stein, J. (2000). Dynamic sensory sensitivity and children's word decoding skills. *Proceedings of the National Academy of Sciences of the United States of America*, *97*(6), 2952–2957. doi:10.1073/pnas.040546597.

Tallal, P., Miller, S. L., Bedi, G., Byma, G., Wang, X., Nagarajan, S. S., … Merzenich, M. M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. *Science*, *271*(5245), 81–84. doi:10.1126/science.271.5245.81.

Temple, E., Deutsch, G. K., Poldrack, R. A., Miller, S. L., Tallal, P., Merzenich, M. M., & Gabrieli, J. D. E. (2003). Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from functional MRI. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(5), 2860–2865. doi:10.1073/pnas.0030098100.

Vanden Abeele, V., Schutter, B., Geurts, L., Desmet, S., Wauters, J., Husson, J., … Geerts, D. (2012). P-III: A player-centered, iterative, interdisciplinary and integrated framework for serious game design and development. In S. Wannemacker, S. Vandercruysse, & G. Clarebout (Eds.), *Serious games: The challenge* (Vol. 280, pp. 82–86). Berlin, Germany: Springer. Retrieved from http://www.springerlink.com/content/k667272157 41j3t0/abstract/.

Vanden Abeele, V., & Van Rompaey, V. (2006). Introducing human-centered research to game design: designing game concepts for and with senior citizens. In *CHI'06 extended abstracts on Human factors in computing systems* (pp. 1469–1474). ACM, Montréal, Québec, Canada. doi:10.1145/1125451.1125721.

Visser, F. S., Stappers, P. J., van der Lugt, R., & Sanders, E. B.-N. (2005). Contextmapping: Experiences from practice. *CoDesign, 1*(2), 119–149. doi:10.1080/15710880500135987.

Wang, H., & Sun, C.-T. (2011). Game reward systems: Gaming experiences and social meanings. In *Proceedings of DiGRA 2011 Conference: Think Design Play* (pp. 1–12). Citeseer. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.221.4931&rep=rep1&type=pdf.

Witton, C., Talcott, J. B., Hansen, P. C., Richardson, A. J., Griffiths, T. D., Rees, A., … Green, G. G. (1998). Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers. *Current Biology: CB*, *8*(14), 791–797.

Zaman, B. (2008). Introducing contextual laddering to evaluate the likeability of games with children. *Cognition, Technology & Work, 10*(2), 107–117.

Zaman, B., & Abeele, V. V. (2010). Laddering with young children in user experience evaluations: Theoretical groundings and a practical case. In *Proceedings of the 9th International Conference on Interaction Design and Children* (pp. 156–165). New York, NY: ACM. doi:10.1145/1810543.1810561.

Zaman, B., & Vanden Abeele, V. (2007). Towards a likeability framework that meets child-computer interaction & communication sciences. In *Proceedings of the 6th international conference on Interaction design and children* (pp. 1–8). Aalborg, Denmark: ACM. doi:10.1145/1297277.1297279.