Chapter 1

General Introduction

1.1 Introduction

In Latin America, the educational situation is quite diverse in terms of quality and access to education. During the last two decades, there has been a general trend to increase state investment in education, which has increased coverage but not necessarily quality (Bellei, 2012). School achievement in these countries is highly influenced by, among other factors, socioeconomic status (SES), which reflects the employment opportunities for the parents, access to and quality of food, as well as access to good health systems (Bravo, Villalón & Orellana, 2011).

In Chile, socioeconomic status also determines the school system the children attend. Although modified during the last three years, traditionally, there were three different school systems, namely public schools, private subsidized schools, and private non-subsidized schools. Whereas public schools were entirely financed by the government, private non-subsidized schools were entirely paid by the parents. Private subsidized schools used a co-pay system for parents while partially receiving governmental funding. These different school systems mirrored the socioeconomic diversity among parents and strongly influenced the expectancies for the future in childhood and adolescence (Rosas & Santa Cruz, 2013). Given that private non-subsidized as well as private subsidized schools were allowed to select the students attending the schools, public schools have the highest number of children with learning disabilities in addition to a generally lower educational level and economic home environment (Bravo, 2011). If a child comes from an environment that is limited in language skills and does not receive adequate stimulation, there is a high probability that he or she will encounter serious problems when starting reading instruction in an educational institution.

Some language skills are fundamental for academic success, mainly because they are required for reading acquisition. Reading is of enormous importance because most of the instructional materials used are presented in written form. Language skills start to develop at very early stages, continuing throughout life. This development starts with the development of 'primary language skills' (oral expression and comprehension), followed by the development of 'secondary language skills' (reading and writing). It is generally assumed that to be able to

develop reading skills, one should first reach a certain level of oral expression and comprehension together with the appropriate development of cognitive skills; these capacities are suggested to allow children to take the next step towards written language (Bravo, 2006; Bravo, 2011).

Research has shown that phonological and cognitive skills among Chilean children attending kindergarten at private schools are generally better than those among children attending first grade in public schools (Bravo, 1997). These differences in learning progress related to the educational system in which children are enrolled, may for a large part be due to differences in home language environment before the formal start of education. In their turn, such differences in phonological and cognitive abilities can lead to distinct strategies in struggling readers; while children from middle socioeconomic classes rely on abstraction and lexicon access, reading whole words and identifying concepts, children from lower socioeconomic classes rely on visual-perceptive and sequential tools, mainly decoding words letter-by-letter (Riley & Riley, 1986). These dissimilar strategies are found using different tests, showing different skills and difficulties associated with each SES group. In third grade (when children are 8 years old), struggling readers from mid-SES showed poorer performance than normal reading classmates in tests related to verbal abstraction, analytic skills and complex figures configuration. In contrast, struggling readers from low-SES showed poorer performances, when compared to their normal reading classmates, in verbal short-term memory, visual recognition of sequences and visuo-motor coordination (Bravo, 1990). In addition, intervention helped poor readers from low-SES improve some verbal difficulties (e.g. poor vocabulary) by the age of 10, while sequential and perceptual visual processes, with and without verbal meaning, remained impaired after intervention. These lower visuo-perceptual skills may explain, according to the author, the poorer reading fluency that reading status (normal or struggling) categorization is based on (Bravo, 2011).

Some developmental disorders may enhance these disadvantages which many children have to cope with. Developmental Language Disorder (DLD) and Reading Disability (RD, also referred to as dyslexia) are language impairments affecting the acquisition of two different domains of language, namely spoken and written language, respectively. Since DLD affects spoken language, it is

possible to diagnose it from 3 years old on. By contrast, RD is only diagnosable after a significant period of formal reading instruction has taken place. Although the defining characteristics of DLD and RD are based on different domains of language, it has long been recognized that clinically these are highly comorbid (Bishop, 2014). Thus, in a summary paper combining a series of studies, McArthur, Hogben, Edwards, Heath, and Mengler (2000), showed that close to 50% of the children diagnosed with either DLD or RD, also turned out to fulfil the criteria of the other diagnosis. As a consequence, children with a delay in language skills, whose reading development also stays behind, may have significant problems in developing general skills in formal education.

In this context, it is essential to find inexpensive and effective tools to help children cope with their learning difficulties, brought about by their socioeconomic as well as developmental background. Such support in overcoming their learning difficulties may help children improve their academic performance. With the help of such tools, typically developing children, as well as those with developmental difficulties may develop the skills necessary to reach their full potential and be able to perform at higher levels in the highly competitive Chilean society. It would be desirable to enable the development of these skills, supported by the intervention tools, independently of family resources; resources that are not only economic but also educational. Serious computer gaming may fit these needs, being an efficient and effective way to reach socially disadvantaged children, while using resources already available in most schools. The infrastructural conditions are fulfilled in Chile, because the recent investment in education has introduced such technology in public schools.

In this Dissertation, we study the overlap between DLD and RD, and its relation to different language difficulties in children with DLD. We explore the feasibility to find diagnostic markers in children with DLD, that suggest an elevated risk for developing reading disability (RD). We investigate behavioural markers, such as comprehension (receptive language) skills, as well as neurophysiological markers. We study the comprehension skills of children with DLD which are commonly used to differentiate between two subtypes of DLD: the DLDe-subtype with only expressive difficulties and the DLDer-subtype with expressive and receptive language difficulties. To be able to do so, complementary measurement

techniques are used, including regular behavioural measurements along with ERP experiments to explore these differences at the neurophysiological level. The aim is to identify neurophysiological markers in children with DLD that may explain the development of RD in many of these children and the domains of overlap reported for DLD and RD. Moreover, we investigate the role these differences can play in the current diagnostic process to identify DLD-subtypes (DLDe and DLDer) and to determine the specific support needed for those children affected by reading difficulties. In addition to characterising the DLD-subtypes, we aim to explore the diagnostic potential of GraphoGame (GG). This serious game has been designed to train reading skills and may be used to identify, in the children's development and performance during the intervention, predictors of later reading difficulties. These predictors would be identified while, at the same time, training fundamental skills necessary for reading acquisition.

1.2 Developmental Language Disorder (DLD)

Developmental Language Disorder (DLD) is a condition that refers to a language deficit characterised by a significant deficit in language comprehension and/or production, despite normal nonverbal, intellectual, emotional, motor, and sensory abilities (Leonard, 1981). It is diagnosed when children fall behind their peers in language acquisition (Bishop & Clarkson, 2003). Around 7% of the children at kindergarten level in the USA are affected by DLD, 8% of the boys and 6% of the girls at that age (Tomblin et al., 1997) . Although DLD children comprise a highly heterogeneous group, some characteristics are quite common, such as weaknesses in morphosyntax and phonological processing impairments (Leonard, 2014). A study performed in English identified six different sub-groups of children within the DLD group, based on clinical and psychometric approaches, using tests and the teacher's opinion (Conti-Ramsden & Botting, 1999). These groups were classified as: only phonological difficulties; lexical-syntactic deficit syndrome; apraxia of speech; phonological programming deficit syndrome; phonological-syntactic deficit syndrome, and semantic-pragmatic deficit syndrome. However, as alluded to above, the distinction that is most commonly used considers the presence of only expressive difficulties (DLDe) or receptive difficulties in addition to the expressive language difficulties (DLDer).

DLD is a life-long condition with permanent mild language impairments, that, for many children, are not severe enough to establish a clinical diagnosis during adolescence or adulthood. Stothard, Snowling, Bishop, Chipchase and Kaplan (1998) reported the results of a follow-up study of 56 adolescents at age 15-16 years, who had been diagnosed with DLD at age 4 years, showing that the 26 adolescents classified as resolved-DLD at the average age of 5;6 years, still showed significant deficits in short-term memory and phonological skills. The remaining DLD-children with persistent deficits at average age 5;6 years, showed significant deficits on all tests of spoken language at age 15-16 years.

The way DLD manifests itself varies between different languages, being highly dependent on the specific characteristics of the language acquired. Children with DLD show areas of considerable weakness depending on the structure of the language they learn. For instance, children with DLD learning a language that allows a wide range of variation in the word order show greater word order variation than DLD children learning a language with rigid word order, a variation that is greater than the one seen in TD children (Leonard, 2014), and thus the errors that are characteristic for children in a given language differ between languages. As described by Leonard (2014) in his surface theory, a problem in auditory processing underlies the language difficulty. It is this auditory processing problem of children with DLD, in combination with the differences in language characteristics, that results in different weaknesses across languages. This relation between auditory processing and language characteristics is visible in the difficulties some children encounter with final inflections. For example, English speaking children with DLD, struggle with the verb final 's' in the 3rd person singular. In contrast, Italian children show no difficulties in verb inflections. It seems that Italian children show no problems with inflections because in this language, inflections are syllabic and pronounced with a long duration. On the other hand, the final 's' described earlier for English, is a morpheme of short duration which seems to present a greater difficulty for children with DLD, due to their auditory processing problem (Hsieh, Leonard, & Swanson, 1999).

1.2.1 DLD in Chile

In Chile, children with DLD (Trastorno Específico del Lenguaje (TEL), in Spanish) are divided into two groups by their comprehension skills, as mentioned above. After diagnosis, children have the opportunity to attend two different types of schools, regular schools with 'integration programs' in which specialists (e.g., phonoaudiologists or psychologists) pay special attention to children with language deficits, and the so-called 'Language schools', where only children with DLD are accepted. In the 'Language schools', children are regularly evaluated until they reach age appropriate levels of development. Children attend 'Language schools' from the age of 3, until 6 years old. If, by the age of 6, children's language skills are appropriate children may move to regular schools, otherwise they must go to schools with 'integration programs' (Ministry of Education, 2002; Ministry of Education, 2009).

Some studies indicate that the prevalence of language difficulties (including DLD) in Chile is higher than in other countries, affecting more than one-third of the preschool children coming from lower socioeconomic levels (Schonhaut, Maggiolo, Herrera, Acevedo & García, 2008). Even higher percentages have been reported using different tests and since there are different tools used within the Chilean system, these varying figures have been shown to influence the public policies applied (Schonhaut, Maggiolo, De Barbieri & Rojas, 2007). In addition, the prevalence of DLD has been shown to be higher in regions of the country with high inbreeding, such as Robinson Crusoe Island, where 35% of the children suffer from DLD (Villanueva, de Barbieri, Palomino & Palomino, 2008). Outside these regions and socio-economic classes with high prevalence of language difficulties, the percentage of DLD children in the Chilean general population is within the normal range as described in other countries, with around 4% of the children manifesting this impairment (de Barbieri, Maggiolo & Alfaro, 1999). The high prevalence of language impairment and its relation with socio-economic circumstances has also been reported for other countries in South America (Michelini et al., 2000; Pascucci, Lejarraga, & Boullón, 2002). These high prevalence numbers and their distribution within the Chilean country stipulate the need for more DLD-research and the provision of effective support to those with language difficulties.

1.3 DLD and RD: strongly related, not the same

The prevalence of the developmental language disorders RD and DLD is high enough to be considered an educational problem because of the significant impact these disorders have on social and academic development throughout the lifespan. In a review study, McArthur et al. (2000) showed that more than 50% of the children with diagnosed RD had impaired oral language. Similarly, 51% of the children diagnosed with DLD also showed impaired reading. These values vary a lot depending on the diagnostic tools and thresholds used, starting at around 20% of overlap (Catts, Adlof, Hogan, & Weismer, 2005) up to the values reported by McArthur et al. (2000). In clinical practice, DLD is diagnosed at a younger age (typically at age 3 or 4 years) than RD (after 1.5 to 2 years of reading education), and as a result, the comorbidity is reported whenever the RD traits have developed. When studying the comorbidity, as well as differences and commonalities, of DLD and RD, it may be important to consider the distinction most commonly used when diagnosing DLD. There are two groups of DLD typically distinguished in Chile, and other countries. Children with DLD are classified as having expressive difficulties or having expressive difficulties and comprehension difficulties (receptive difficulties), previously referred to as DLDe and DLDer, respectively. The relationship of those profiles of DLD with the development of RD is unknown. However, children diagnosed with both expressive and comprehensive difficulties have shown decoding difficulties when starting to read (Coloma et al., 2015).

One of the prevalent hypotheses to account for the considerable overlap between children with DLD, irrespective of their receptive and expressive skills, and children with RD is the comorbidity hypothesis (Catts et al., 2005), which postulates that DLD and RD are distinct disorders that co-occur. The hypothesis stipulates that RD-only children, and children with DLD and RD, show phonological impairments. On the other hand, DLD-only children perform, although still within the normal range, at the lower edge of the expected performance in phonological processing and may constitute the poor comprehenders group. The poor comprehenders group shows normal decoding skills but low reading comprehension. A second important hypothesis is the qualitative difference hypothesis (Bishop & Snowling, 2004), which assumes

that the profile of underlying language deficits determines the outcome at the behavioural level. In their review, Bishop and Snowling (1987) focus mainly on the contrast between phonological deficits and non-phonological language deficits to capture the relationship between DLD and RD, proposing a two-dimensional model considering both phonological and non-phonological language skills. In this model, children impaired in both the phonological and non-phonological language domains are described as *classic DLD*, whereas children with a normal performance level on both dimensions would be classified as *typically developing* children. Children with a phonological impairment but without any non-phonological language deficits are defined as *classic dyslexic*, and children without phonological deficits but with poor non-phonological skills are classified by this model as *poor comprehenders*.

An essential difference between both hypotheses is that the comorbidity hypothesis by Catts et al. (2005) considers phonological impairment as a trait that is only present in RD children, while the qualitative difference hypothesis considers it as a shared trait between conditions. Bishop and Snowling's qualitative difference hypothesis has evolved into the multiple-deficit model by Pennington and others (Pennington & Bishop, 2009; Pennington et al., 2012), which suggests that the profile of skills and developmental trajectory of the child together determine the clinical manifestation of developmental language disorders. According to this model, DLD and RD children share general traits, but other factors are condition-specific, meaning that presenting one of the underlying risk factors does not predict the manifestation of the disorder unless the child also has other deficits. For instance, rapid serial naming is expected to be a specific deficit for RD children, and not a shared trait between DLD and RD.

Despite decades of intensive research in the field of reading and language disorders, most studies focus on the distinction between both conditions, and not so much on the association and similarities between RD and DLD, or on shared markers that account for the difficulties commonly seen in both impairments. In clinical practice, the differentiation among developmental language disorders at the behavioural level relies on the discrepancy criterion, most notably in the diagnosis of RD; RD is characterized by problems with reading and spelling which are unexpected in view of the child's general cognitive and linguistic

abilities (McArthur et al., 2000). However, as argued by Stanovich (1994), and van Bergen, de Jong, Plakas, Maassen, & van der Leij (2012) the discrepancy criterion is invalid precisely because of the comorbidity mentioned above. Thus, reading fluency of children with DLD is generally poorer than reading fluency of typically developing children, and the language development of children with RD tends to stay behind as well. Moreover, and due to the comorbidity between different language impairments, Bishop (2014) proposes the use of the term 'specific', in reference to an unknown origin of the language difficulty, rather than to exclude other co-occurring disorders. There are many sources of similarities between DLD and RD and behavioural tests do not always discriminate between them. Neurophysiological correlates, measured with event-related potentials (ERPs), are presented as an additional source of information to assess and re-interpret the varying results obtained from behavioural measurements (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Lovio, Näätänen, & Kujala, 2010; Maurer, Urs, Brem, Bucher, & Brandeis, 2005; van Zuijen et al., 2012).

1.3.1 Neural correlates of a phonological impairment

A phonological impairment is considered a shared trait between DLD and RD, and is thought to lie at the origin of reading and literacy acquisition problems across languages (Bishop & Snowling, 2004; Leonard, 2014). When tested for phonological awareness (PA), DLD children show poorer performance than children with familial risk of RD. The latter group performs in between DLD and typically developing children (Gerrits & de Bree, 2009). In addition, children diagnosed with DLD who develop RD, as well as those who do not develop RD, show poorer phonological skills, as compared to typically developing children (de Bree, Wijnen, & Gerrits, 2010).

One way to explore the underlying deficits present in children with phonological impairment is by analysing phonological processing using ERPs as obtained from electroencephalography (EEG) recordings. The mismatch negativity (MMN) is an ERP component elicited by occasional mismatching (deviant) stimuli among a repetitive train of identical (standard) stimuli. It is a negative-going wave, largest at central midline scalp sites that peaks between 160 and 220ms. It is elicited without attention needed from the subject, and is thought to reflect an

automatic process that involves sensory memory to relate the incoming stimuli to the preceding one (Luck, 2014), showing brain activation while phonological processing is tested.

A diminished MMN has been found in RD children and in children at-risk of developing RD when presented with auditory stimuli (Lovio et al., 2010; van Zuijen et al., 2012). This effect has not been found in DLD children, who in turn show a diminished LDN (Late Discriminative Negativity; also referred to as late MMN, or just MMN; identified by the time window). The LDN is an ERP component that occurs under similar conditions as the MMN (i.e., occasional mismatching stimuli when presented among a repetitive train of identical stimuli), but occurs later than MMN, between 300 and 550ms (Luck, 2014). The LDN is thought to reflect sound discrimination and is more prominent in children than in adults (Bishop, Hardiman & Barry, 2011). LDN has been reported to be diminished in DLD children on different occasions and for different stimuli characteristics (Bishop et al., 2011; Rinker et al., 2007; Shafer, Ponton, Datta, Morr, & Schwartz, 2007). Generally, results reporting diminished or absent LDN in children with DLD are more consistent than the presence or absence of MMN found for both DLD and RD children. Some studies, however, have also found a smaller LDN in RD children. This reduction in LDN was found without the previously described reduced MMN (Halliday, Barry, Hardiman, & Bishop, 2014; Maurer, Urs, Bucher, Brem, & Brandeis, 2003; Schulte-Körne, Deimel, Bartling, & Remschmidt, 1998). The large discrepancies found in the results when phonological processing is studied may be in part due to different set-ups (acoustic or phonological feature tested, magnitude of difference between standard and deviant, stimulus onset asynchrony (SOA) and inter-stimulus interval (ISI) (Bishop, 2007), as well as to the overlap between the DLD and RD conditions that would distort the results giving the impression of mixed effects (Catts et al., 2005).

Intervention studies using GraphoGame (a serious computer game designed to train reading skills which will be introduced later in this Chapter) have described an enhanced MMN after a period of training. Lovio, Halttunen, Lyytinen, Näätänen and Kujala (2012), for instance, found a larger MMN after intervention, in children who were not able to read. Interestingly, they found this enhanced MMN response after a short period of only three hours of training. This change

in MMN was significantly correlated with changes in letter knowledge and letter recognition, accounting for the strong relationship between the development of phonological and reading skills. Previous studies have also shown a positive effect of a phonological intervention on reading and spelling skills (Schneider, Küspert, Roth, Visé & Marx, 1997), and the critical role that PA plays in reading acquisition (Liberman & Shankweiler, 1985; Wagner & Torgesen, 1987). The effect is also observed in the inverse way, from reading to PA, as developing reading skills affect phonological skills giving a specific structure to language knowledge spontaneously acquired (Wagner & Torgesen, 1987).

Another feature of interest of this MMN component is the development of its lateralisation in clinical and typically developing groups. As reviewed by Bishop (2007), the pattern of lateralisation may be different for children with literacy problems, as well as for children with DLD, compared to typically developing children.

Since direct comparisons between groups (TD, DLD and RD) are rare, a systematic study comparing groups employing the same set-up (features and duration of the stimuli, SOA and ISI) would be of high interest. Elucidating differences in neurophysiological features, and possible phonological origin of their impairments, between children with DLD that develop and those who do not develop RD, can be useful to identify the particular needs of each condition.

1.3.2 Neural correlates of reading skills

As described previously, both children with DLD and RD show difficulties developing reading skills. When studying the development of reading skills, the N170 (referred to also as N1) component appears a good candidate to assess the acquisition of such abilities. In adults, the N170 is an early negative-going component (peaking at around 170ms after stimulus presentation) that has been shown to be more pronounced at left occipito-temporal areas when orthographic stimuli are presented (words and pseudowords) as compared to non-alphabetic symbol strings. When symbol strings are presented, the N170 component is larger over the right occipito-temporal areas (Bentin et al., 1999). The notion of print tuning refers to this specific, automatic process to recognise print, that is, to distinguish letter strings from symbol strings. This specific process develops with exposure to print and is thus sensitive to training and intervention. The

development of the N170 component is sensitive to the child's letter knowledge; children with high letter knowledge show larger N170 responses than those with low letter knowledge. The pattern shown by children with high letter knowledge is nevertheless different from the one shown by adults, who show a left-lateralisation, while in children the N170 is right lateralised (Tjaden & Turner, 1997). Brem et al. (2006) reported that the N170 amplitude decreases with age from 15 to 30 years, showing that the system involved in print tuning continues to develop for several years after learning to read.

During the acquisition of reading skills, children that were later diagnosed with RD, were reported to show a slower development of the N170 response (Maurer et al., 2007). These RD children showed a non-significant difference between the responses elicited by letter strings, in comparison to responses to non-letter symbol strings, in kindergarten and in second grade. By contrast, their typically developing (TD) peers showed a significant increase in their response to letter strings as compared to symbol strings. Additionally, in a study published by Brem et al., in 2013, children attending kindergarten, who were later on classified as poor-readers in second grade, showed smaller N170 over the right-occipital region, as compared to children who became normal readers. Moreover, a study performed by Maurer et al. in 2011 analysed the behavioural responses on the repetition detection task. In this task, the child is asked to press a button every time (s)he sees a stimulus identical to the one presented immediately before the current stimulus. These stimuli can be words, pseudowords or symbol strings. Maurer et al. (2011) reported that typically developing 2nd graders more accurately detected the repetition of word targets than symbol targets; this effect was absent in RD children. The latter group also had slower reaction times for word targets than symbol targets, an effect that was not seen in the TD children. When the researchers analysed the N170 response, they found that the print-specific response decreased from 2nd grade to 5th grade in TD children. This reduction was not seen in RD children, whose response even slightly increased. Across time points, the N170 was larger for TD than for RD children in 2nd grade, but the amplitudes were equal in 5th grade (Maurer et al., 2011).

As mentioned above, the emergence and development of print tuning over time seems to be sensitive to training, since it develops with letter exposure. In young children,

without reading instruction, the learning of letter-speech sound correspondence triggers an initial sensitisation to print. In a study by Brem et al. (2010), this sensitivity was already obtained after a short training period of 3 to 4 hours playing GraphoGame, and was reflected in behavioural as well as in ERP and fMRI results.

1.4 GraphoGame, training reading skills through serious gaming

Games used and developed with a particular purpose other than mere entertainment, such as developing a skill of interest, are currently called serious games (also known under the term Digital Game-Based Learning, DGBL) (Mayer et al., 2013). An important characteristic of serious games is that they allow the inclusion of simulation (Susi, Johannesson & Backlund, 2007); serious games are an extension of typical video-games with particular characteristics that drive the learning process. Klopfer, Osterweil and Salen (2009), have defined digital-learning games as targeting knowledge acquisition.

Serious games have been applied to improve the teaching process in different topics and regions around the world (McTigue & Uppstad, 2019; Neto, Cerejeira & Roque, 2018; Rodrigues, Serpa, Macedo & Sousa, 2018). GraphoGame (GG) is a game designed in Finland to support the development of reading skills. It focuses on the grapheme-phoneme relation in an attractive and adaptive way to keep children's attention (Richardson & Lyytinen, 2014).

Since its initial design, GG has been applied in many other countries (e.g. United Kingdom, Switzerland, France, Norway, The Netherlands), and a Spanish version has been developed in Chile (Rosas, Escobar, Ramírez, Meneses & Guajardo, 2017). The study performed in Chile showed that children from low-SES schools improved their letter-sound association after the period of intervention (Rosas et al., 2017). The Chilean version of GG presents the children with an auditory input, after which the children must select the corresponding visual input. For example, whenever the child hears [a], he or she must select the letter 'a' written on the screen, among distractors. The game adjusts the difficulty of items presented for the child to perform with 80% accuracy, to keep the child engaged. GG trains letter knowledge first, moving on to short words and pseudowords, to finish with

long words. Different environments are presented during the game, so the child does not get bored by always looking at the same task. For example, sometimes the child must select the letter 'a' among four distractors; while another task requires the child to select as many letters 'a' as possible in a certain amount of time, with several distractors popping up during that time window. However, the primary task is always the same, hearing the auditory stimulus and selecting the appropriate written stimulus.

The fact that Chile put some good efforts in digital-training (Ministry of Education, 2012; Ministry of Education, 2013), and that GG has been tried and validated for the Chilean population, gives the opportunity to develop further research in the field, such as the one proposed here, namely to use GG as a training, but also as a diagnostic tool for different language impairments.

1.5 This Dissertation

The studies described in this Dissertation explore the heterogeneity of the DLD group, and the risk to develop RD. To do that, several behavioural tests assessing pre- reading as well as reading skills, along with tests of general cognitive abilities are administered to characterise the DLD group, as well as the two sub-types (DLDe and DLDer). Together with the behavioural studies, ERP experiments are administered to explore subtle differences in neurophysiological parameters, often invisible in behavioural measures. Finally, a period of 6 to 8 weeks of training with GraphoGame allows to assess progress and improvement in reading-related skills, that the different groups achieve. Using a serious game additionally gives the opportunity to explore differential development at the learning level. Collecting data while children are playing should allow assessing skills along with the training of specific skills in children with learning disadvantages. We hypothesize that children who develop RD do not benefit from the training period as much as TD children.

At the neurophysiological level, phonological processing is studied by analysing the auditory discrimination skills that allow children to detect a deviant stimulus among consecutive standard stimuli. We explore differences in phonological

processing that may allow identifying children that will develop RD at older ages. We hypothesise that children with comprehension difficulties show a diminished MMN, compared to children with better comprehension skills, reflecting their increased risk for reading difficulties. On the other hand, we expect that DLD children show a diminished LDN component, compared to TD children. In addition, we expect some enlargement in phonological processing markers, such as MMN and LDN, for all the children after the training period with GG. However, this change will not be the same for all participants, being bigger for TD children.

To explore reading skills, we study the sensitivity to relevant symbols, namely letters. To do that, we analyse the N170 component that develops when words and symbol strings are presented as visual stimuli. We hypothesize that children with comprehension difficulties show a diminished N170 component, when compared to children with better comprehension skills. After the training period with GG, which gives extensive exposure to letters, we expect an increase in the N170 component which will be more prominent in children with good comprehension skills.

The studies presented here aim to find specific neurocognitive and neurophysiological indicators that account for the heterogeneity among DLD children and the development of RD, and to explore the diagnostic potential of GraphoGame. Using different tools, we aim to better understand the small differences, and large overlap between DLDe, DLDer and RD, to enable the development of new intervention and remediation techniques.

Chapter 2 presents behavioural data in language and reading-related skills. We made group comparisons to explore the differences between DLDe, DLDer and TD children, as well as SES groups. We studied the differences in language skills before reading instruction, in kindergarten or first grade. Also, we explored the relation of these language skills to later language skills and reading fluency achieved in second grade. We thus analyse the early and concurrent predictors of reading fluency in this Chapter.

In Chapter 3, we explore group differences in phonological processing in DLD and TD children, reflected in MMN and LDN responses to deviant auditory

stimuli. We also relate behavioural measures, such as phonological awareness and comprehension skills, to these ERP responses. In addition, we explore how ERP responses in kindergarten or first grade relate to reading fluency in second grade.

In Chapter 4, we study differences in ERP responses to letter strings. We explore group differences between DLD and TD children in the N170 component when they are presented with letter strings in comparison to symbol strings. Apart from the group differences, we analyse the relationship between the amplitude of N170 and letter recognition and comprehension. As for phonological processing, we also explore the relationship between N170 amplitude in kindergarten or first grade and reading fluency in second grade.

Chapter 5 explores the effect of GraphoGame on children's reading-related skills, as well as how the different groups progress over six weeks of intervention with GG. We first explore the effect of GG intervention on PA, letter-sound association and pseudoword reading. In addition, to explore the possibility to use GG as a diagnostic tool, we explore the performance of the groups of interest (DLDe, DLDer and TD; good and poor readers) at the different levels of GG. We study how the different diagnostic groups (DLDe, DLDer and TD) and reading profiles in second grade (good and poor readers) differ in their progress and accuracy across the different levels in the game.

Finally, Chapter 6 presents a general discussion of the studies presented in this Dissertation, with their implications, limitations and future directions.

The recent decade has witnessed large changes in conceptualization of and terminology for language and reading difficulties in children, especially by the work of the CATALISE consortium (Bishop et al., 2016, 2017). To characterize the clinical population of children with DLD in Chile at the time of the study, we added an appendix, describing the clinical process for diagnosing DLDe and DLDer in the Chilean educational system. In this appendix, we also include a description of the assessments we conducted in addition to those used in the clinical diagnosis in order to study the differences and commonalities between DLDe and DLDer.