Sensory processing in children and adults with learning difficulties.

By

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ABSTRACT

Sensory processing refers to the ability to register and modulate sensory information in order to enable and learn adaptive responses to the environment and facilitate engagement in daily activities, and it depends on the maturation of the nervous system. Previous studies have indicated failures in sensory processing in neurodevelopmental disorders, however, the characteristics and extent of such problems are not clear with respect to other learning difficulties due to inconsistent literature, lack of systematic approaches, and a strong emphasis on phonological processing alone. Four studies were designed to compare sensory processing profile of participants with and without learning difficulties, using Dunn’s framework (1997) of four quadrants: Registration, Seeking, Avoiding and Sensitivity. Study 1 investigated the relationship between multisensory processing and literacy skills in children. Study 2 investigated sensory profile and learning difficulties in adolescents. Study 3 investigated sensory profile and its association with reading difficulties in adults. Study 4 focused on children and comorbidity as a variable that may influence the sensory profile. Results identified clear differences in the sensory profile between groups with and without learning difficulties. Accordingly, children with learning difficulties would present a profile of high frequency of sensory-related behaviours which is widespread across the sensory dimensions, while adults would have high frequency of such behaviours in only one quadrant of the sensory profile. Regression analyses showed that Registration (a profile of high neurological threshold and passive regulation) predicts the likelihood of presenting learning difficulties at all ages. Furthermore, low scores in Seeking (lack of active behaviours) were associated with learning difficulties in children. The findings suggest an atypical frequency of sensory-related behaviours associated with a range of learning difficulties. Future research should assess the sensory abilities across the ages, including performance in cross-modal tasks, and the use of neuroimaging techniques to obtain more insights of brain functioning.

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CHAPTER 1

INTRODUCTION AND THESIS OVERVIEW

A remarkable feature of the human brain is its ability to interact with the environment through its varied receptors. Every moment people have to rely on sensory cues that invade each of their sense receptors. Regardless of conscious attention, people receive constant information from their own bodies and the surrounding environment that gives them an idea of what is going on, and therefore what actions they should take (Calvert, Spence, & Stein, 2004). This varied information is presented at a specific time, in a particular space, and for a certain duration, and should be integrated by the nervous system for its accurate apprehension. However, as with every human feature, there are individual differences in the process in which people receive and organise the information (Ayres, 2005). According to Cisek and Kalaska's, (2010), human behaviours are conceptualised as a continuous interaction between an individual and his/her environment, and the nature of such interaction is sensorimotor. Hence, cognitive processes such as learning are driving by this sensorimotor interaction and so, are influenced by the sensory processing/integration abilities (Koziol, Budding, & Chidekel, 2011).

As an illustration of this interactive and multi-stimuli environment in our daily life, let's think about a regular student that attends a regular primary school. This person is seated and trying to stay as still as possible –following the indications of the teacher – while looking, listening the teacher, and taking notes. At the same time, on his/her inside this student is experiencing a large set of complex processes, such as the visual recognition of the letters on the blackboard, and the translation of the speech into letters. In addition, he/she is trying to ignore other basic bodily needs, like moving, or feeling hungry. And do not forget emotional reactions and the fact that it is likely that this student is surrounded by other students.

The illustration presented above tried to exemplify the continuous integration of sensory inputs from all of the sensory systems, and therefore the need for a suitable mechanism that is able to integrate and display adaptive responses. Later in this thesis, the implications of such sensory processing in the presence of learning difficulties will be explained.

Research suggests that the 'neuro-typical' population present an estimation of sensory issues of about 5% to 10% of the population (Ahn, Miller, Milberger, & Mcintosh, 2004), and 10% to 55% of children with and without conditions, such as some neurodevelopmental disorder, are affected by challenges in processing and integrating sensory stimuli (Pfeiffer, May-Benson, & Bodison, 2018). The rate of difficulties in sensory processing increases to 40% to 90% for children who present comorbidity with other neurodevelopmental disorders (Ahn et al., 2004; Cheung & Siu, 2009; Fox, Snow, & Holland, 2014; Talay-Ongan & Wood, 2000). Dunn, Little, Dean, Robertson, & Evans (2016) conducted a scoping review of sensory factors, comprised of studies that compared sensory differences among children with and without conditions, including autism, dyspraxia, ADHD, and others. These studies showed that children with conditions were more likely to present sensory issues associated with their primary diagnosis (Dunn et al., 2016).

The research about the sensory issues that underlie the learning difficulties, in particular, the reading disorders, have been led by theories about auditory deficit processing (Tallal, 1980), visual impairment (Stein, 2001a), and motor/automatization difficulties (Fawcett & Nicolson, 2008; Nicolson & Fawcett, 1990). Also, despite the evidence towards a deficit in basic auditory and visual skills associated with learning difficulties (Talcott, Hansen, Assoku, & Stein, 2000; Talcott, Witton, et al., 2000; Witton et al., 1998), there is no consensus on the role of the sensory processing in learning difficulties (Goswami, 2014). Thus, it is proposed to examine children, adolescents and adults with learning difficulties concerning their sensory profile across the different modalities, including both mono-sensory and multi-sensory processing (Dunn, 1997b).

To explore the characteristics of the sensory processing profile of children, adolescents and adults with specific learning difficulties, four cross-sectional studies were designed, with convenience samples of children, adolescents and adults with and without specific learning difficulties.

The first aim of this thesis was to provide a revision of the sensory profile across three developmental stages: childhood, adolescence, and adulthood. The review of the sensory processing profile at different age stages addresses to the idea that while the sensory preferences have been described as person's stable traits (Kientz & Dunn, 1997), it is also known that sensory integrative functioning is age dependent (Johnson-Ecker & Parham, 2000). The second aim was to assess whether or not the sensory profile has an association with reading skills. The identification and understanding of specific learning difficulties has been a great concern due to their high prevalence and their relevance to academic achievements; however the heterogeneity of their nature, and variety of their manifestation has made this goal hard to achieve (Hallahan et al., 2007; Hallahan & Mercer, 2001; Ramus, 2004). The characterisation of sensory needs regarding reading difficulties would widen the range of the underlying phenomena that might maintain the problem.

The four studies that comprise the empirical work of this thesis include measures of learning difficulties in the academic context, that is, difficulties in reading and mathematics skills, and sensory processing of children and adults to test three main hypotheses. Throughout Chapter 2 will be highlighted the influence of sensory processing abilities on the neurodevelopmental disorders (Miller, Nielsen, Schoen, & Brett-Green, 2009; Schaaf et al., 2015; Wallace & Stevenson, 2014). Although research has shown robust evidence of sensory issues in conditions such as ASD (Baker, Lane, Angley, & Young, 2008; Gonthier, Longuépée, & Bouvard, 2016; Martínez-Sanchis, 2014; Tomchek, Huebner, & Dunn, 2014), and ADHD (Dunn & Bennett, 2002; Parush, Sohmer, Steinberg, & Kaitz, 1997), the evidence is not yet clear in terms of the sensory processing characteristics related to LD. Information on the sensory processing profile of people with LD would provide a better comprehension of the phenomena. Thus, for the empirical work presented here, it was predicted that the sensory processing profile would discriminate between children, adolescents and adults with and without learning difficulties. Accordingly, those with LD would present an atypical sensory processing profile, that is, the scores will differ from the mean of the normative data and will differ with scores of typically learning groups (Hypothesis 1). Previous studies have reported a high frequency of sensory behaviours in autism (Kern et al., 2007), ADHD (Dunn & Bennett, 2002), and children with learning difficulties with and without ADHD (Dove & Dunn, 2008). Thus, it was expected that the direction of the differences would indicate that subjects with learning difficulties engaged in the behaviours described in the sensory profile measures more frequently than typically learning groups.

Regarding the second hypothesis, in section 2.6.3 of Chapter 2, will be explained that sensory processing is age-dependent (Johnson-Ecker & Parham, 2000; Nardini et al., 2014; Wallace & Stevenson, 2014). Therefore, it was expected that differences in the sensory processing profile would be observed among the studies with children, adolescents and adults with LD (Hypothesis 2). Given the characteristics of the measures and design of the studies, it was not possible to make a direct comparison across the ages. However, a profile of high frequency of sensory-related behaviours for children, to a less frequent and most adaptive profile in adults was expected. The last hypothesis was built based on the evidence of audio-visual deficiencies linked to reading difficulties. Studies have shown that auditory processing deficits are associated with dyslexia (Tallal, 1980; Tallal, Miller, & Fitch, 1993), impairment on the visual magnocellular path (Stein, 2001), and reduced audio-visual integration in poor readers compared to typical readers (Harrar et al., 2014). Accordingly, an association was predicted between the level of learning difficulties, in particular for reading, and the sensory processing profile of participants (Hypothesis 3).

CHAPTER 2

LEARNING DIFFICULTIES

This chapter presents a description of the specific learning difficulties, in particular, reading difficulties. The chapter will describe relevant research of reading difficulties and the growing body of evidence that links neurodevelopmental disorders with sensory features. It will also illustrate the relevance of the study of the sensory profile in people with learning difficulties as a complement to understand this condition, highlighting the association with reading difficulties.

Specific learning disabilities or difficulties are a highly prevalent group of neurodevelopmental disorders that affect children and continue during adulthood. An estimate of the proportion of children with special educational needs in the UK was 14%, based on a schools census in January 2017 (Department for Education, 2017). Among them, the most prevalent type of primary need identified was learning difficulties (manifested at three levels, moderate, specific and severe) that accounted for two-fifths of the children. Children with learning difficulties can be incorporated into Special Educational Needs programme (SEN), which means that these students will received additional or different educational or training provision (Part 3, sections 20-21 of the Act 2014, the website for the "UK Government Legislation," can be found at http://www.legislation.gov.uk). SEN are more prevalent in boys than in girls: a sixth of 10-year-old boys had SEN support, but only half this proportion for girls of the same age.

People with specific learning difficulties have specific deficits in their ability to perceive or process information efficiently and accurately. They make forceful efforts to achieve one or more academic areas, such as reading, mathematics, or writing, despite adequate intelligence and educational opportunity (American Psychiatric Association, 2013; Hallahan, Pullen, & Ward, 2013). The Diagnostic and Statistical Manual of Mental Disorders 5th ed. (DSM-V) (American Psychiatric Association, 2013) lists the main problems to learning and academic skills that might be manifested as difficulties in at least one of the following: word reading, reading comprehension, spelling, written expression, mastering number sense, number facts, or calculation, and mathematical reasoning.

The ability-achievement discrepancy criterion and exclusion of other related conditions have been the traditional and most accepted procedure to identify students with specific learning difficulties (American Psychiatric Association, 2013). However, the LD group includes a range of heterogeneous problems with diverse characteristics resulting from a variety of biological and environmental causes (Goldstein & Schwebach, 2009). According to Fletcher, Stuebing, Morris, and Lyon, (2014) the discrepancy and exclusion criterion may be too simplistic to cover all of the characteristics of LD, because this method does not produce a conceptual model that include the heterogeneity of the construct. Hence, a method for classifying LD that includes cognitive discrepancy, achievement assessment, and evaluating of response to instruction would make a better estimation (Fletcher et al., 2014).

The current comprehension of specific learning disorders, and reading difficulties as a neurodevelopmental disorder (Gilger & Kaplan, 2001; Pennington, 1999), is the result of a cumulative body of research that includes interdisciplinary knowledge to provide an inclusive understanding of the phenomenon. The group of neurodevelopmental disorders is characterised by been manifested early in the development and provokes deficits in the personal, social, academic or occupational functioning (American Psychiatric Association, 2013). They can also be defined as conditions of abnormal central nervous system functioning that affect the child's adaptation to the environment (Vargo, 2015). The neurodevelopmental disorders can be specific limitations in certain areas of the development, to global impairments that adversely affect the whole functioning of the individual (American Psychiatric Association, 2013; Reed

& Warner-Rogers, 2008). The 5th Edition of the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013) classified as neurodevelopmental disorders the intellectual disabilities, communication disorders, autism spectrum disorder, attention-deficit/hyperactivity disorder, specific learning disorder and motor disorders, these conditions often co-exist in the same individual (Gilger & Kaplan, 2001; Kaplan, Dewey, Crawford, & Wilson, 2001).

Although the category of LD includes abilities such as mathematics, and writing, the field has been marked for the study of the reading difficulties. In the early history of the study of reading problems, also known as dyslexia, the neurologist Samuel T. Orton (cited in Wolf & Ashby, 2007) identified a group of students with a particular difficulty related to learning to read. He used the terms "strephosymbolia" or "twisted symbols" to explain a group of alterations in literacy that he linked with visual problems. Later, in a meeting of the World Federation of Neurologists in 1968 an updated definition of these problems was given. During the Conference, it was stated that severe reading problems, now recognise as dyslexia, are disorders manifested by a difficulty in learning to read despite conventional instruction, adequate intelligence, and socio-cultural opportunity (Critchely, 1970).

Reading problems are the most prevalent learning difficulties, affecting 5-12% among school-age children (Peterson & Pennington, 2015). Difficulties in reading commonly result from an underlying deficit in the phonological component of language, which includes problems with accurate or fluent word recognition, poor decoding, reading comprehension, and poor spelling abilities (American Psychiatric Association, 2013; Reed & Warner-Rogers, 2008; Shaywitz & Shaywitz, 2005; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990). The difficulties in reading are not expected when compared with the child's general abilities (e.g. IQ), and with their access to adequate educational opportunities (Herbert, 2003; Swanson et al., 2013).

The International Dyslexia Association (International Dyslexia Association [IDA], 2018) and the British Dyslexia Association (British Dyslexia Association [BDA], 2018) have highlighted some points of consensus in their definitions. Both accept that the main symptom of the problem is in the literacy domain, with a special focus on the phonological awareness component. Both associations recognize that there may be secondary symptoms associated with this, such as processing speed, automatization, and working memory issues. In addition, Vellutino et al., (2004) proposed that difficulties with reading may or may not go together with problems with language comprehension.

The variety in the manifestation of reading difficulties, and the recognition of reading skills in a continuum involves the conjunction of several concepts to refer to subjects with problems in the reading domain (Siegel & Mazabel, 2014; Stanovich, 1988). In particular, developmental dyslexia, a concept that is used to describe those with severe difficulties in reading (Shaywitz & Shaywitz, 2005; Vellutino et al., 2004). While some authors suggests that the terms dyslexia and reading disability are synonymous (Siegel & Mazabel, 2014), other argued that the concepts are part of a continuum of reading skills (Stanovich, 1988). Likewise, it has been established (Gilger, Pennington, & DeFries, 1991; Stanovich, 1988; Shaywitz & Shaywitz, 2005) that reading ability is distributed normally in the population, thus reading abilities occur along a continuum from poor to good readers, and dyslexia would be located at the extreme left of the normal curve. In addition, some studies have debated whether dyslexia exists as a particular entity (Elliott & Grigorenko, 2014; Stanovich, 1994). De Gelder and Vroomen, (1998) described the term 'poor readers' to refer to the manifestation of problems in the phonological domain in people with average or above IQ, without giving detailed information of the intensity and severity of the problem. However, 'poor readers' is also used as a generic concept to refer to the variety of manifestations within the reading difficulties domain (Dykman & Ackerman, 1991; Georgiou, Protopapas, Papadopoulos, Skaloumbakas, &

Parrila, 2010; Stoodley & Stein, 2006; Van Zuijen, Plakas, Maassen, Maurits, & Van der Leij, 2013). Besides, the term 'garden variety-poor readers' is used to describe subjects with deficits in literacy due to poor vocabulary and below average cognitive abilities (Gough & Tunmer, 1986; Stanovich, 1988; Swan & Goswami, 1997). When the difficulties are characterised by problems with accurate or fluent word recognition, poor decoding, and poor spelling abilities, the DSM-V suggests the diagnosis of developmental dyslexia (American Psychiatric Association, 2013). In addition, there are other difficulties outside the phonological domain that have been associated with dyslexia such as poor motor coordination, left-right confusion, and problems with sequencing (Nicolson & Fawcett, 1995; Stein, 2001). Accordingly, the concepts of reading difficulties and dyslexia may be used interchangeably (Vellutino, Fletcher, Snowling, & Scanlon, 2004), and the variety of symptoms should be taking into account in order to have a better characterisation of the problem. Thus, in this thesis, the classification of reading difficulties will include dyslexia as part of the continuum of reading failures. Also, theories and research on dyslexia will be included (see pages 18 to 32) to support the comprehension of the broad phenomenon of the reading difficulties.

Although there is some consensus about the manifestation of reading difficulties, as was exposed previously according to the definition of both the IDA and the BDA (IDA, 2018; BDA, 2018). The review of the current bibliography showed that not all poor readers struggle with reading in the same way, nor do they show a similar pattern of difficulties (Cumming, Wilson, & Goswami, 2015; Frith, 1999; Harrar et al., 2014; Nicolson, Fawcett, Brookes, & Needle, 2010; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Wolf & Ashby, 2007). Some studies even suggest the existence of subtypes of reading difficulties (Heim et al., 2008; Willems, Jansma, Blomert, & Vaessen, 2016). For example, Heim et al (2008) observed three clusters of children with reading difficulties who differed regarding the involvement of phonological awareness, attention, auditory and magnocellular tasks. In spite of this diversity, the major consensus is that phonological awareness issues represent the core cognitive skills that are manifested with several difficulties: counting syllables, detecting rhymes, deciding whether words share phonemes, and substituting one phoneme for another (Melby-Lervåg, Lyster, & Hulme, 2012; Siegel & Mazabel, 2014; Ziegler & Goswami, 2005).

2.1 Comorbidity

The apparent variety within the learning difficulties described above may be associated with other conditions that often co-occur. Although, for reading difficulties the main symptoms are linked with phonological issues, the profiles are characterized by a range of impairments in the language field (such as speech problems) and in different cognitive domains, like attention, executive function, and motor skills (Reid, 2009; Vellutino et al., 2004). Mathematics problems often co-occur with reading problems in a high rate (Lewis, Hitch, & Walker, 1994; Sigmundsson, Anholt, & Talcott, 2010). This variety of characteristics reflects wider problems underlying LD and brings challenges to its understanding and in the design of tailored interventions that can contribute to the development of children across the board.

The most common co-occurring difficulties of reading difficulties are Specific Language Impairment (SLI) (Brookman, McDonald, McDonald, & Bishop, 2013). Both dyslexia and SLI showed similar profiles in working memory and intelligence coefficient (Alloway, Tewolde, Skipper, & Hijar, 2017). Great comorbidity has been reported with Attention Deficit and Hyperactivity Disorder (ADHD), particularly inattentive signs (Kaplan, Dewey, Crawford, & Wilson, 2001; Martin, Levy, Pieka, & Hay, 2006). The overlap between SLI and ADHD with LD, including dyslexia, has been reported in 10% to over 50% of cases (Bental & Tirosh, 2007; Dykman & Ackerman, 1991; McArthur, Hogben, Edwards, Heath, & Mengler, 2000; Semrud-Cllikeman et al., 1992; Snowling, 2012; Willcutt & Pennington, 2000).

Some researchers have examined reading difficulties in relation to developmental coordination disorders (also known as dyspraxia). Kirby, Sugden, Beveridge, Edwards, and Edwards (2008) estimated an overlap in between 35% and 50% of cases. A relation between impairments in reading and gross motor skills in both locomotor skills (like run, gallop) and object-control skills (two-hand strike, catch, kick) has also been suggested (Westendorp, Hartman, Houwen, Smith, & Visscher, 2011). Reading problems may coexist with handwriting problems. One of the problems is the slow speed writing and the low quality showed by poor readers, which interferes with their schoolwork. Also, the writing is described as messy and illegible, without an apparent order (Fawcett & Nicolson, 1999; Nicolson et al., 2001). In addition, associations between more than one diagnostic entity are recognised. Research has shown a high prevalence of reading disorders, ADHD symptomatology, and motor issues (Kooistra, Crawford, Dewey, Cantell, & Kaplan, 2005).

The presence of symptoms on the motor domain and failures in cognitive skills for people with reading problems is controversial. Studies that support the presence of motor problems have arisen from the early work of Rutter & Yule in 1970 (cited in Brookman, McDonald, McDonald, & Bishop, 2013). Rutter & Yule (1970) found an excess of motor impairments in children who were poor readers relative to their IQ; these results have been used as evidence that literacy problems have a neurological basis. Fawcett and Nicolson, (1999; 1994) have conducted studies that show impairments in speed motor tasks, such as naming words and non-words, peg-moving, bead threading, finger tapping, sequencing and body balance. Impairments in implicit motor learning have been found in adults with reading disorders (Stoodley & Stein, 2006), and a delay in the development of motor skills in children with learning difficulties compared with typically developing peers (Gaysina, Maughan, & Richards, 2010; Westendorp et al., 2014). In contrast, other studies (Irannejad & Savage, 2012; Savage & Frederickson, 2006; White et al., 2006) have found mixed and opposite results, arguing that not all children with reading difficulties perform differently from their peers on motor tasks. Indeed, regression analyses have indicated that motor skills do not predict reading proficiency (Ramus et al., 2003; White et al., 2006). Moreover, studies argued that poor performance in motor tasks is attributed to a comorbidity with other syndromes, such as Specific Language Impairment (SLI) (Brookman et al., 2013) or Attention Deficit Hyperactivity Disorder –ADHD (Wimmer et al., 1999). Due to the large occurrence of comorbidity, critics argue that some research on reading difficulties has used non-pure samples, which has led to biased results (although the concept of "pure" is highly controversial, as will be discussed in Chapter 7) (Hallahan et al., 2007; Kaplan et al., 2001).

Regarding other cognitive skills, and morphological differences in dyslexia, Galaburda and colleagues (Galaburda, Menard, & Rosen, 1994; Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985) used autopsy technique to study dyslexic brains. The researchers found an asymmetry between the two hemispheres, and abnormal development in the left hemisphere. They suggested a vulnerability of the left hemisphere that is widely associated with language skills. Evidence has been published that links the cerebellum with reading. Nicolson, Fawcett and colleagues (Fawcett & Nicolson, 1999, 2008; Nicolson, Fawcett, & Dean, 2001) discovered behavioural signs of cerebellar abnormality in dyslexic children, and abnormal cerebellar function in dyslexic adults. A Brazilian study (Cruz-Rodrigues, Barbosa, Toledo-Piza, Miranda, & Bueno, 2014) assessed dyslexic and non-dyslexic children with neuropsychological batteries. The findings of Cruz-Rodriguez et al. showed significant differences between the children in their intellectual level, phonological working memory, semantic memory and right-left discrimination. Also, the group of children with dyslexia showed poorer school performance in terms of their reading, writing and mathematics skills.

2.2 Evaluation of specific learning difficulties

The effective characterization of LD is fundamental to identify individuals' needs at the earliest possible stage of the academic path (Tomalin & Saunders, 2017). The variety of assessments of learning difficulties/disabilities is linked with the heterogeneity of their conceptualization, which can also be observed in the diversity of the assessment tools available nowadays (Fletcher et al., 2014; Swanson et al., 2013). In this revision, the focus will be on screening tests and questionnaires of self and parents' report used for research purposes.

Screening tests originated from the medical sciences, where the objective is to assess in a cost-effective way the likelihood of having a particular disorder (Maxim, Niebo, & Utell, 2014). Fawcett and Nicolson (Fawcett & Nicolson, 2004; Fawcett, Pickering, & Nicolson, 1993; Nicolson & Fawcett, 1997) designed screening tests primarily to identify children at risk of having reading disorders, and then extended them to adults. These screening tools include a wide range of tasks and require a trained evaluator who is able to deliver the instructions and follow the specific procedures of the instrument (Nicolson & Fawcett, 1997).

While an assessment with screening test seems the most appropriate to capture a wide range of abilities and a direct measure of the participants' performance, they demand time and special training from the evaluator. Questionnaires have thus been a feasible method of assessing learning difficulties in a large population, although they also have some limitations. Questionnaires to assess LD are broadly used with parents or teachers as a source when assessing children, and as self-report in adults. Self-report tools have proved to be valid in measuring symptoms associated with LD (Daniels et al., 2012; Faraone, Biederman, & Milberger, 1995; Glascoe & Dworkin, 1995; Lefly & Pennington, 2000; Little, Dean, Tomchek, & Dunn, 2016; Snowling, Dawes, Nash, & Hulme, 2012). The Colorado learning difficulties questionnaire (Willcutt et al., 2011) is a report scale that is used to assess reading, social cognition, social anxiety, and spatial and maths characteristics of children. Further studies have demonstrated its validity and utility for identifying children at risk of LD (Hadley & Kimberlin, 2016; Patrick et al., 2013; Yailagh, 2014). The questionnaires for adults can address statements regarding their history of learning difficulties, and the current presence of the problems. The Adult reading history questionnaire (Lefly & Pennington, 2000) aims to capture information about past reading difficulty that would not be apparent on a measure of current reading ability. The factor structure of the scale has been shown to be reliable and is able to predict performance on reading (Welcome & Meza, 2018). Finally, the Adult self-report questionnaire (Snowling et al., 2012) explores dyslexia related symptoms in adults. The scale demonstrates a good correlation with actual measures of literacy (Leavett, Nash, & Snowling, 2014; Snowling et al., 2012).

The questionnaires require a reasonable awareness of their own -for self-reports- or others – for parents/teachers reports- learning difficulties, adequate reading comprehension, are subject to faking due to social desirability bias, and the scores evidence a specific moment of testing rather than a comprehensive process of assessment (Leavett et al., 2014; Reid, 2009). All these elements may affect results and their interpretation and may involve potential overestimation of the data, that require a critical approach for conclusions.

2.3 Reading difficulties

The process of sensory integration sets the ground for the acquisition of complex cognitive skills, such as reading (Dionne-Dostie, Paquette, Lassonde, & Gallagher, 2015). Reading is the outcome of a complex process that enables people to attain further academic knowledge (Vellutino et al., 2004), hence difficulties in reading acquisition can negatively affect the further development of more complex skills and knowledge (Huey, 1908). Thus, an effort has been made in developing theories to understand the underlying issues of poor readers, from the classical approach that focuses its attention on the development of the phonological skills involved in reading (Liberman, 1971), to theories that claim cerebellar abnormalities as the main cause of the problem (Nicolson et al., 1999).

Reading is a multidimensional and complex process that shapes our way of interacting with the environment and our possibilities as humans (Goswami, 2008). Learning to read influences, and is influenced by, human development and everyday experiences during a person's lifespan (Stein, 2001b). Generally speaking, individual differences in learning to read are influenced by both biological and environmental variables that set the path for the development of the brain systems related to reading skills (Pennington, 1999). Regarding the biological variables, genetic studies have consistently shown an association between parents' and children's literacy abilities (Bishop, 2015; Gilger et al., 1991; Scarborough, 1989). Likewise, environmental opportunities, in terms of access and quality of instruction, and the learning environment at home, are key elements of the cognitive development (Sénéchal & LeFevre, 2002; Törmänen & Roebers, 2017).

It has been well established that phonological skills are the foundations for learning to read (Bradley & Bryant, 1978; Vellutino, 1979). Strong correlation has been found between phonemic awareness and letter knowledge with word reading skills. Reading involves decoding the print letters with the associated sound into a coherent meaning, that is, effectively linked visual and auditory cues (Hulme & Snowling, 2013; Melby-Lervåg et al., 2012; Vellutino et al., 2004). The research on phonological awareness dating back to about 1970, due to its relevance for language and reading acquisition. It is considered a primarily metalinguistic ability that is fundamental for learning to read. Phonological awareness is the ability to identify the sound structure of a spoken word, thus having the knowledge of the general sound structure of words as comprising smaller, discernible units (phonemes, syllables). Also, having an awareness of the phonological structure of words, subjects are able to access and manipulate phonological structure (Hayward et al., 2017). Orthographic awareness (how letters in written words are organized) and syntactic awareness (grammatical knowledge) together with phonological awareness provide the learner with the foundations for accurate and fluent reading and spelling (Vellutino et al., 2004).

As reported in Melby-Lervåg et al. (2012) the development of reading skills is a process where the pre-existing phonological codes (spoken words) are combined with novel orthographic codes. These codes symbolize representations of spoken words, and spoken words represent real-life experiences. The first step of this process is called phonological decoding (or sounding out), which is characterized by learning the connection between letters and their sounds. Over time, decoding knowledge provides the foundations to further establish connections between orthography and oral language (Ziegler, Perry, & Zorzi, 2014). Vellutino et al. (2004) developed a model to organize and depict the relationship between the knowledge and skills involved in learning to read. According to Vellutino, both visual coding of written words and linguistic coding are the foundation to consolidate further associations between letter-sound, which in turn lead the literacy acquisition process. The model proposed by Vellutino et al., (2004) includes memory and working memory systems. These high-level control functions interact with each other by allowing phonological and semantic storage and retrieving the language and printer-word information to carry out processing operations.

A meta-analysis that included 235 studies assessed the relationship among three phonological skills: phonemic awareness, rime awareness, and verbal short-term memory with reading skills in children (Melby-Lervåg et al., 2012). The analysis revealed that phonemic awareness had the strongest correlation with individual differences in word reading ability. Rime awareness, and verbal short-term memory also showed an association with reading, but the correlation was weaker compared with phonemic awareness (Melby-Lervåg et al. 2012). The findings from this review supported the notion that general phonological skills, and phonemic awareness in particular, are directly related to the process of learning to read. Other relevant predictors of reading proficiency are letter knowledge (Melby-Lervåg et al., 2012) and rapid automatized naming (RAN) (Norton & Wolf, 2012). RAN is recognized as a prerequisite for reading ability by some authors (Denckla & Rudel, 1976; Denckla & Rudel, 1974; Wolf & Bowers, 2000). RAN tasks are a good measure of cognitive skills linked with literacy, they consist of asking subjects to name a series of familiar items (letters, words, colours or objects) that are presented randomly as quickly as possible (Denckla & Rudel, 1976; Denckla & Rudel, 1974; Wolf, Bowers, & Biddle, 2000). Performance on RAN tasks is significantly associated with later reading ability and is considered a universal predictor of reading fluency (Norton & Wolf, 2012). Similarly, Caravolas et al. (2012) showed that letter-sound as instruction method of letter knowledge had a strong relationship with reading, and letter knowledge, in general, had a correlation with reading skills, especially at the beginning of the instruction time.

Differences in reading and learning to read regarding different orthographies are another aspect that requires attention. Studies comparing consistent orthographies, also known as shallow orthographies (e.g. Finnish and Spanish), with inconsistent or deep orthographies (e.g. English), have demonstrated that children learn to read easier in the first condition than when faced with deeper orthographies (Seymour, Aro, & Erskine, 2003). A meta-analysis reviewed functional neuroimaging studies that compared dyslexic readers in deep orthography, English, with shallow orthographies, including German, Italian, and Swedish (Martin, Kronbichler, & Richlan, 2016). A total of 28 studies were included in the meta-analysis, which showed a universal under-activation in the left occipital cortex, but orthographic-specific brain functioning in other brain regions, such as under-activation of the left inferior frontal gyrus (IFG) pars triangularis for deeper orthography, and in the IFG pars orbitalis in shallow orthographies, among others.

2.3.1 Theories of reading difficulties.

Previously there was explained that reading disorders are the most prevalent type of LD, and so the research has been mainly focussed on this condition. Also, as part of the broad group of the neurodevelopmental disorders, the origins of reading difficulties emerge from a variety of genetic, organic, and environmental factors (Pennington, 1999). The current predominant theories of reading difficulties and dyslexia are described as follows organised by the suggestion of Frith (1999). Frith proposed a framework that allows for organising the theories into three levels of depth: behavioural, cognitive and biological. The theories can be compatible each other, because they explain the symptoms from different viewpoints that do not confine the phenomenon to just one level. Cognitive and biological theories will be presented first. The behavioural manifestations will be considered last, as a summary of the signs described by each framework.

2.3.1.1 Cognitive level (information processing).

Phonological deficit theory

The psycholinguistic-based theories were developed in the early 1970s with the exploration of the relation between speech and reading development, and marked the beginning of later research into phonological processing (Liberman, 1971; Liberman, Shankweiler, Fischer, & Carter, 1974).

The phonological deficit theory is the most studied (Stanovich, 1988). The theory posits that reading and spelling difficulties result from impairments in the ability to identify or manipulate the component sounds in speech, called phonological awareness. Failures in phonological awareness explained poor association of printed representations with the correct speech elements. Cognitive studies across languages demonstrate that children with developmental dyslexia have difficulties in basic phonological tasks such as manipulation of speech sounds (Goswami et al., 2010; Kim & Davis, 2004; Share & Levin, 1999; Heinz Wimmer, 1996; Ziegler & Goswami, 2005). Phonological awareness is a relevant metalinguistic skill concerning knowledge about the sounds that make up words. A phonological connection with reading impairments has been found in research in different languages, as demonstrated by Paulesu et al., (2001) in Italian, French, and English dyslexic children.

The phonological theory has received support from different researchers who have pointed a clear link between phonological deficits and the subsequent reading problems (Melby-Lervåg et al., 2012; Ramus et al., 2003; Vellutino et al., 2004) as the main explanation for reading difficulties in dyslexia. For example, Hayward et al. (2017) studied the common phonological awareness errors in first grade children. Their results showed that those children with poor reading performance were more prone to exhibit insertion and omission of letters, phonemic segmentation and substitution.

However, the theory fails to explain the other symptoms associated with reading disorders. That is, extensive evaluation of problems beyond the phonological domain have reported poor motor skills, slow processing speed, a lack of automatization, problem in executive functions, maths difficulties, auditory processing deficit, and visual problems that may be manifested along with the reading problems (Dionne-Dostie et al., 2015; Fostick & Revah, 2018; Kruger, Kruger, Hugo, & Campbell, 2001; Nicolson & Fawcett, 1990; Stein, 2012; Viana, Razuk, de Freitas, & Barela, 2013).

Auditory processing deficit theory

Perceptual strength and weaknesses in different sensory modalities have been found during assessments of dyslexic children. Focusing on one of these modalities, Tallal, (1980) tested the relation between auditory temporal perception and reading disabilities. Tallal presented four auditory perceptual tasks with non-verbal auditory stimuli only, and a nonsense word-reading task to reading disabled children. The children showed an impairment on tasks involving serial pattern perception when the rate of presentation of the stimulus increased. Tallal suggested that the children's deficit was linked with the perception of auditory stimuli that arrived rapidly and sequentially, and that this perceptual deficit may be a characteristic of people with dyslexic. Accordingly, a deficit in the basic auditory level would affect the integration of rapid sensory information, which would lead to an incorrect analysis of speech, and thus phonological issues (Tallal, 1980; Tallal, Miller, & Fitch, 1993).

Reading development requires high-level speech processing that may be impaired due to difficulties in the processing of sensory input (Tallal, 1980). If this is the case, the phonological impairment would be a secondary issue to a more basic auditory deficit. Likewise, Hari and Kiesila, (1996) observed deficit in the processing of rapid sound sequences in dyslexic adults, and Fostick and Revah, (2018) supported the view of dyslexia as a multi-deficit and remarked the relevance of an auditory temporal processing deficit in its manifestation. In the same way, children with dyslexia presented an impaired auditory neural processing that reflect a general auditory impairment (Stefanics et al., 2011).

The auditory processing deficit theory has detractors who argue that the auditory perception may vary between different languages associated with orthography consistency, which would be a flaw on the explicative power of this theory (Goswami, 2014). In addition, other studies (Breier, Fletcher, Foorman, Klass, & Gray, 2003; Landerl & Willburger, 2010; Share, Jorm, Maclean, & Matthews, 2002) have reported no clear relationship between temporal auditory processing and the phonological deficit observed in participant with reading difficulties. For example, Landerl and Willburger (2010) reported correlations between temporal processing tasks with reading and spelling ranged between −.11 and −.33, which do not allow to conclude a definite effect of temporal processing deficit in literacy skills.

Some aspects of the Auditory processing deficit theory have been further studied emerging the Temporal Sampling Theory (Goswami, 2011). This framework posits phonological problems as the primary risk factor for dyslexia, but recognises a general difficulty to identify the frequencies range of speech reflected in impairments in rise time discrimination (Goswami, 2011). Sensitivity to identify the rise time of speech was found as a significant predictor of phonological awareness on three different orthographies (English, Spanish, and Chinese) (Goswami et al., 2010), and impairment in the discrimination of amplitude temporal sampling ability was also observed in children with specific language difficulties (Goswami et al., 2016). Two EEG studies (Colling, Noble, & Goswami, 2017; Power, Colling, Mead, Barnes, & Goswami, 2016) provided neurophysiological evidence of poor ability on the neurological representation of a given stimulus of low-frequency amplitude (neural encoding), and an atypical auditory rhythmic perception in children diagnosed with dyslexia. Casini, Pech-Georgel, and Ziegler, (2017) studied implicit and explicit temporal processing in both auditory and visual modalities. Their results are consistent with the theory of auditory temporal deficits in children with dyslexia, including deficits in the visual domain.

Automatization deficit hypothesis

The Automatization Deficit Hypothesis addresses the definition of dyslexia as a learning disability (Nicolson & Fawcett, 1990; Nicolson et al., 2010). The Automatization Deficit Hypothesis claims that dyslexics may have difficulties performing any task that requires the automatization of skills. Nicolson and Fawcett (1990) observed the performance of dyslexic children in a dual-task – a task of motor balance and a second task that involved the distraction of conscious attention. The results showed effortful performance in reading and writing in the dyslexic sample; also, the dyslexic sample was more prone to error, and more easily disrupted than a typically developed group. In a further study, (Fawcett & Nicolson, 1994) the reaction time of the dyslexic children was measured in three different tasks - simple reaction, selective choice reaction, and lexical decision. In the last two tasks the dyslexic group had longer reaction times compared with a chronological age control group and a reading age control group. Another study (Moores, Nicolson, & Fawcett, 2003) confirmed a general impairment to automatized skills in adolescents and young adults. Later, Bucci, Bui-Quoc, and Gerard, (2013) tested the postural control of dyslexic children while solving a cognitive task. The results of this study showed worse performance in the dyslexic group than the control group, supporting the hypothesis of a deficit in the automatic integration of visual input and postural control. Orban, Lungu, & Doyon (2008) reviewed studies that linked automaticity with an impairment in motor sequence learning. Orban et al concluded that the deficit represents a mixture of implicit and explicit processing and found that all of the studies reviewed revealed a motor sequence learning impairment in dyslexics.

The results shown above by Bucci et al. (2013) and Nicolson et al. (2010) suggest that dyslexics need to consciously lead their attention to compensate even in routine tasks that should be done without having to think or concentrate consciously. Problems in skill automatization are attributable to impaired cerebellar function, and automaticity is the final product of procedural learning (Fawcett & Nicolson, 2008; Nicolson & Fawcett, 2011).

Critics of the automatization theory, such as Raberger and Wimmer (2003), examined the relation between reading disability and ADHD with a balancing task. The balancing task has been used previously by Nicolson and Fawcett (Nicolson & Fawcett, 1990, 1995), consisting of the participant standing on a platform on different positions (e.g. two feet together) along a specific time. Raberger and Wimmer results showed poor balancing only in the ADHD group and poor rapid naming only in the reading disabled group. Based on these results, Raberger and Wimmer argued that the automatization difficulties previously found by Nicolson and Fawcett, (1990) may have been biased by comorbidity in the sample, given the high frequency of other conditions (especially ADHD) in poor readers, as was explained previously in this Chapter (see section 2.1). It is important to note, however, that Nicolson and Fawcett explicitly screened out clinical levels of ADHD in their sampling procedures, thereby this criticism appears misplaced. Nonetheless, a subsequent review (Rochelle, Witton, & Talcott, 2009) argues that sub-clinical levels of attention deficit might well characterise those poor readers who have comorbid motor issues. It is established that not all dyslexic children show motor difficulties, with perhaps 15%-50% showing balance issues (Ramus et al., 2003; Sprenger-Charolles, Colé, & Serniclaes, 2006; Stoodley, Fawcett, Nicolson, & Stein, 2005). One theoretical approach that attempts to integrate these findings is the ‘procedural learning difficulties framework’ (Nicolson & Fawcett, 2007), which attributes the comorbidities to deficits in function of the many brain networks involved in procedural learning. Within this framework, sensory processing issues could also be incorporated (but were not by the authors), leading to framework of scope and function similar to that claimed by Stein and his colleagues in terms of magnocellular processing (Stein, 2019; Stein, Talcott, & Walsh, 2000; Stein & Walsh, 1997) discussed below.

Rapid Naming deficit and Double deficit hypotheses.

Denckla and Rudel (1974, 1976) based upon the work of Geschwind, (1965), designed a set of naming tasks called a Rapid Automatized Naming (RAN) test. Denckla and Rudel demonstrated that the speed of naming letters and numbers in serial naming provides a cue to differentiate dyslexic children from those with other learning disabilities. A number of subsequent researchers reported similar results, demonstrating that dyslexic and language-impaired children are slower at every age in terms of naming speed, especially for letters and numbers (Bexkens, Van Den Wildenberg, & Tijms, 2015; Katz, Curtiss, & Tallal, 1992; Tallal, 1980). Additionally, rapid automatized naming and verbal memory span have been found consistently as predictor of reading difficulties in English (Caravolas et al., 2012). RAN is composed of attentional, visual, temporal, and lexical recognition sub-processes, which all contribute to performance in naming speed tasks (Wolf et al., 2000).

Wolf and Bowers, (1999, 2000) argued that dyslexics people may have either phonological problems or processing speed problems independently, calling it the Double-deficit Hypothesis. The double deficit hypothesis (DDH) described dyslexic children that exhibit two major central deficits of reading disorders: phonological decoding and naming speed. Wolf and Bowers, (1999, 2000) described the possibility of three subtypes of reading impairment from the combination of these two skills: a phonological deficit with poor phonological awareness, intact naming speed; rate deficit, with naming speed deficits, intact phonological awareness skills; and the double deficit, with an impairment in both naming speed and phonological skills. Further research on the Double-deficit hypothesis have found that children who present deficits in both, phonological awareness and naming speed, have significantly lower scores on reading tasks than children with a deficit in only one of these skills (Wolf & Bowers, 2000). Schatschneider and colleagues (Schatschneider et al., 2002) demonstrated that impairments in phonological awareness and naming speed affect reading acquisition and future performance. Other studies (Lovett, Steinbach, & Frijters, 2015; Waber, Forbes, Wolff, & Weiler, 2004) have also recognized the contribution of the double deficit hypothesis in identifying different profile of children with reading difficulties.

Although the DDH hypothesis has expanded the understanding of dyslexia, including disorders in automaticity, processing speed and fluency as well as phonology, Pennington, Cardoso-Martins, Green, and Lefly, (2001) argued that the phonological theory is able to give a broader explanation that embraced the deficits that characterised dyslexia, including naming speed. Similarly, other studies (Nelson, 2015; Schatschneider et al., 2002; Vukovic & Siegel, 2006; Heinz Wimmer, Mayringer, Landerl, & Landed, 2000) that reported evidence for an independent rapid naming deficit in dyslexia are not clear, and the DDH is weak in predicting the dyslexia symptoms.

2.3.1.2 Biological level (genetics and neurology)

The magnocellular deficit theory

The theory was developed by Stein (2001a) who proposed that the visual magnocellular system is impaired in dyslexia, supported by the evidence that most reading problems have a primary sensorimotor cause. The magnocellular system is involved in the synchronization of visual information during the reading process (Stein, 2001a, 2001b). Therefore, an impairment in this system affects motion sensitivity binocular fixation, and is considered responsible for timing visual events when reading leaving oral and non-verbal reasoning skills intact (Stein, 2018).

Stein, (2001a) proposed that dyslexic people have different brains, which affects their reading, writing and spelling skills, but extends to their coordination, laterality and sequence ability. Post-mortem studies on the brains of dyslexic people have shown disorders in the magnocellular layers of the lateral geniculate nucleus and smaller magno-cells compared with controls, which may abnormally reduce their motion (Galaburda & Livingstone, 1993). The magnocellular visual processing is relevant on giving a respond to fast changes in the visual system (Skottun, 2000). Failures in the functioning of the magnocellular system may cause an inadequate reaction to visual input, for example the appearance that letters move around and cross over each other when individuals attempt to read written texts (Stein, 2001a). Dysfunction in the magnocellular system would include deficit in visual, auditory, and tactile systems (Stein, 2014; Stein & Walsh, 1997). The magnocellular system, which main structure would be the cerebellum (Stein 2001a), is involved in the generation of responds to rapidly changing stimuli, so impairments in this system may result in temporal processing deficits in both visual and auditory modalities (Livingstone, Rosen, Drislane, & Galaburda, 1991).

As noted above, the magnocellular deficit framework has considerable power in explanatory terms and does have much in common with Nicolson and Fawcett's procedural learning deficit framework, but it is very much more specific, arguing that all the problems arise from magnocellular processing difficulties (rather than differences in neural plasticity). The adequacy of the magnocellular theory as complete explanation for reading difficulties is problematic due to the lack of evidence about other cognitive processes that are related to the magnocellular function, for instance spatial orientation, and in other modalities like auditory (Goswami, 2014; Ramus et al., 2003; Skottun, 2000). A review of the visual deficit in dyslexic children found that the deficit was only significant in 20% of the 22 studies reviewed (Skottun, 2000) which questions the reliability of the magnocellular theory. Additionally, other theories explain the visual problems observed in the dyslexic population. For example, the Visual Stress theory (Wilkins, 1995; Wilkins, Huang, & Cao, 2004) posits that the reading process can provoke a negative result in vision due to the effect of the successive lines printed in a text. Visual stress negatively affects the reading speed and in the long term can influence children's willingness to read (Wilkins et al., 2004).

The cerebellar deficit hypothesis.

Frank and Levinson (1973) were the first to suggest cerebellar impairment in developmental dyslexia. They described deficient muscle tone, posture, balance, binocular coordination and spatial orientation in the dyslexic population. All of those skills are associated with the vestibular system, proprioception and the cerebellum. Further study of Fawcett and Nicolson, (1999) on the cerebellar deficit hypothesis maintain that dyslexic people exhibit a range of symptoms due to a cerebellar impairment like a lack of automatization and motor skills deficits. Data from several sources have identified the link between cerebellar functioning, learning, and reading difficulties (Koziol, Budding, & Chidekel, 2011; Magallón, Crespo-Eguílaz, & Narbona, 2015; Mariën et al., 2014; Nicolson & Fawcett, 2000; Nicolson, Daum, Schugens, Fawcett, & Schulz, 2002; Nicolson & Fawcett, 1994). Also, a number of studies reporting poor performance of children and adults with reading difficulties on tasks that include both cognitive and balance demands, provide support for a cerebellar commitment in dyslexia (Brookes, Tinkler, Nicolson, & Fawcett, 2010; Stoodley, Fawcett, Nicolson, & Stein, 2006; Vieira, Quercia, Michel, Pozzo, & Bonnetblanc, 2009; Wimmer et al., 1999). Likewise, Barela, Dias, Godoi, Viana, and de Freitas (2011) reported that dyslexic children swayed significant more than not dyslexic in a balance experiment, and concluded that the cerebellum hypothesis might provide a valid explanation for the weak motor-action processing of dyslexic children.

Neuroanatomical and neuroimaging findings provide support for atypical cerebellar functioning in dyslexia (Alvarez & Fiez, 2018; Finch, Nicolson, & Fawcett, 2002; Jenkins, Brooks, Nixon, Frackowiak, & Passingham, 1994; Laycock et al., 2008; Nicolson et al., 1999). Pernet, Poline, Demonet, & Rousselet, (2009) found evidence of different brain phenotypes among dyslexic people, and Feng et al., (2017) observed atypical cerebellar activation in dyslexic children during a reading task. Similarly, Rae et al. (2002) reported alteration in the organization of the cerebellum that may be associated with the phonological and motor skills difficulties observed in dyslexic participants. In addition, neuroimaging techniques have revealed a reduction in cerebellar activity when performing tasks that involve motor processes (Brunswick, McCrory, Price, Frith, & Frith, 1999; McCrory, Frith, Brunswick, & Price, 2000; Nicolson et al., 1999).

By contrast, other studies (van Daal & van der Leij, 1999; White et al., 2006; Yap & van der Leij, 1994) with dyslexic children have found inconsistent outcomes in aspects such as speed of processing and motor tasks in dyslexic children, which would refute the cerebellum hypothesis. It is important to note that these critiques miss the point made by Nicolson et al. (Nicolson et al., 2001a; Nicolson, Fawcett, & Dean, 2001b) that the cerebellum function need to be impaired in all aspects of processing.

Genetic causes

The genetic variables interact with environmental influences to build the further reading skills (Hulme & Snowling, 2013). Genes have proved significant effects in LDs (Paracchini, 2011) with strong evidence for genetic underlying causes. Gilger et al., (1991) indicated that approximately 40% to 50% of the first-degree relatives (siblings and parents) of a subject with dyslexia are prone to have reading problems, and Scarborough, (1989) proposed that familial risk for reading difficulties is a good predictor of further occurrence of difficulties in this skills. In spite of the clear genetic component of dyslexia, so far there is no consensus about specific genes involved (Fisher & Defries, 2002; Paracchini, 2011; Vellutino et al., 2004).

The theories reviewed here, from the classical phonological theory (Liberman, 1971; Liberman, Shankweiler, Fischer, & Carter, 1974) to the broadest explanation like the magnocellular theory (Stein, 2001a), contribute to the understanding of all or some of the symptoms observed in reading difficulties. Although phonological skills are the key for reading acquisition, the development of sensory abilities is a common point in all the aforementioned theories. Such approaches, however, have failed to address the sensory profile of people with reading difficulties beyond an audio-visual domain despite the importance of other senses in development. The above literature review is an attempt to expand the view of the reading difficulties, including all the dimensions that have been mentioned in different studies. Nonetheless, the theories and hypotheses are not free of the critiques that have been made previously. In spite of these critiques, the phonological theory is broadly accepted as the main cause for the reading problems (Goswami, 2014; Irannejad & Savage, 2012; White et al., 2006), and considers other symptoms to be the consequence of or due to comorbidity with other disorders, rather than related to reading skills.

New emerging hypotheses

In line with the acknowledge of the limitations of the phonological theory as the sole explanation of reading disorders, there are new theoretical approaches that try to embrace the variability of the symptoms. Two hypotheses will be briefly reviewed, the 'Neural Noise Hypothesis', and the 'Delayed Neural Commitment' framework. These theories require further evidence to demonstrate their relevance and validity, but they provide a fresh explanation to understand the foundations of reading disorders.

The Neural Noise Hypothesis (Hancock, Pugh, & Hoeft, 2017) attempts to link some of the key neural and behavioural deficits associated with reading deficits to basic neural processes. Neural noise refers to sources of random variability in the firing neurological activity and is linked to the balance between excitatory/inhibitory activity within a neural network. Hence, a rise in cortical excitability will provoke a rise in neural noise. Hancock et al. (2017) proposed reading-related consequences of neural noise: a malfunctioning of sensory processing, limited noise exclusion in visual and auditory domains, poor phonological awareness skill, and negative effects in multisensory integration so impacting the phoneme-grapheme mapping.

The Delayed Neural Commitment framework (Nicolson & Fawcett, 2019) assumes that dyslexia is associated with minimal brain differences, that in turn lead to learning deficits. In particular, for dyslexic children, such differences would influence a slower skill acquisition process and the need for more time for the building of neural networks that support the acquisition of reading.

2.3.1.3 Behavioural level (primary characteristics)

More than an explanation of the causes of dyslexia, the behavioural level, that is, the compilation of the behavioural manifestations of reading difficulties, recognises that the manifestation of dyslexia may vary between subjects, and gives a first clue to find a correct intervention method (Frith, 1999).

Below is a summary of the main characteristics mentioned in the theories presented in the point 2.3.1 as well as in the previous definition of developmental dyslexia (e.g. American Psychiatric Association, 2013).

- Reading problems: characterised by inaccuracy, slowness, and the mixing up of sounds and graphemes. Also, slow fluency reading words and non-words and naming pictures (Reed & Warner-Rogers, 2008; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990; Shaywitz & Shaywitz, 2005; Vellutino et al., 2004).

- Poor handwriting, in terms of quality and speed (Fawcett & Nicolson, 1999; Nicolson et al., 2001).
- Lack of automaticity in any skill that should become automatic through practice (Nicolson & Fawcett, 1990; Nicolson et al., 2010).
- Executive function issues, especially in working memory (Reid, 2009; Vellutino et al., 2004).
- Motor problems: gross and fine motor issues, for example, poor performance in peg-moving, bead threading, finger tapping, sequencing and body balance (Heim et al., 2010; Stoodley et al., 2006; Westendorp et al., 2011).
- Problems in processing auditory information and in visual-spatial and motion perception (Dionne-Dostie et al., 2015; Fostick & Revah, 2018; Kruger, Kruger, Hugo, & Campbell, 2001; Nicolson & Fawcett, 1990; Stein, 2012; Viana, Razuk, de Freitas, & Barela, 2013).
- General sensory problems. Auditory processing difficulties, particularly in the temporal component. Visual difficulties regarding the motion sensitivity system (Stein, 2001; Tallal, 1980), and visual stress sensitivity (Wilkins, 1995; Wilkins et al., 2004).
- Finally, a new wave of research called Positive Dyslexia (Nicolson, 2015) focuses on the strengths of people with dyslexia rather than the difficulties. Thereby, Nicolson described unconventional thinking strengths on dyslexia characterised by special cognitive abilities, such as good visuo-spatial skills, and creativity; three social abilities, empathy, teamwork, and communication; and specific skills related to the work environment, determination, proactivity and flexible coping.

The behavioural manifestations of reading difficulties described above illustrate the relevance of the sensory aspects within the signs of reading disorders. That is, auditory, visual, and motor deficits are commonly reported in studies on reading (Dionne-Dostie et al., 2015; Fostick & Revah, 2018b; Heim et al., 2010; Kruger et al., 2001; Nicolson & Fawcett, 1990; Stein, 2001a, 2012; Stoodley et al., 2006b; Tallal, 1980; Viana et al., 2013; Westendorp et al., 2011; Wilkins, 1995; Wilkins et al., 2004). The next section presents research that connects sensory processing difficulties with learning difficulties.

2.4 Learning difficulties and sensory processing

A description of reading difficulties and the most accepted theories has been given in section 2.3, as an attempt to characterise the most common and most studied type of LD. Within a cognitive level, the phonological issues have received support as the main cause of reading difficulties, including developmental dyslexia. However, as already stated (see section 2.3.1.3), there is strong evidence of outlier symptoms in the motor, procedural, and sensory fields (Dionne-Dostie et al., 2015; Fostick & Revah, 2018; Kruger, Kruger, Hugo, & Campbell, 2001; Nicolson & Fawcett, 1990; Stein, 2012; Viana, Razuk, de Freitas, & Barela, 2013). Even the very early reports of Orton in 1925 (cited in Henry, 1998) recognized the relevance of the motor skills for literacy. Further research (Koziol et al., 2011; Kruger et al., 2001; Magallón et al., 2015; Nicolson & Fawcett, 1994) have found evidence of difficulties integrating auditory, visual, somato-sensory, motor, and language skills in the dyslexic population. The magnocellular (Stein, 2001) and auditory processing deficit theories (Tallal, 1980) focus their analysis on the sensory issues that underlie the reading difficulties, but they still have a narrow view in terms of understanding the heterogeneity of their manifestation. Neurobiological evidence confirms a basic phonological deficit which may co-occur with sensorimotor issues (Ramus, 2004). Thus, research has consistently shown that sensory-related behaviours are a relevant component within the manifestation of learning difficulties, although the expression and prevalence seem to vary among populations.

Approaches from the field of the sensory integration, sensory processing, and multi-sensory functioning have provided relevant insights for the understanding of neurodevelopmental conditions (Miller, Nielsen, Schoen, & Brett-Green, 2009; Schaaf et al., 2015; Wallace & Stevenson, 2014). The estimated rate of sensory issues within neurodevelopmental disorders has ranged from about 40% to almost 90%, which is significantly higher than in the 'neuro-typical' population with an estimation of about 5% to 10% (Ahn et al., 2004; Fox et al., 2014; Talay-Ongan & Wood, 2000). A review of Dunn et al., (2016) showed that children with neurodevelopmental disorders process sensory inputs differently from their peers with no conditions, which may suggest that sensory processing is associated with cognitive processes and brain activity.

Children with a diagnosis of ADHD and ASD present the most documented and high prevalence of sensory impairments (Dunn & Bennett, 2002; Dunn et al., 2016; Tomchek & Dunn, 2007). The underlying sensory problems in Autism Spectrum Disorders (ASD) have been studied in both children and adults (Baker, Lane, Angley, & Young, 2008; Gonthier, Longuépée, & Bouvard, 2016; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011; Martinez-Sanchis, 2014; Tomchek, Huebner, & Dunn, 2014). About 95% of people with ASD present associated sensory issues (Baker et al., 2008; Gonthier et al., 2016; Kern et al., 2007; Kientz & Dunn, 1997; Tomchek & Dunn, 2007; Tomchek et al., 2014). Sensory processing dysfunction seems to predict the severity of the symptomatology of ASD (Sanz-Cervera, Pastor-Cerezuela, Fernández-Andrés, & Tárraga-Mínguez, 2015). ASD has consistently shown sensory processing patterns that are far away from the expectations when compared with typically developing groups, for example over focused attention to sensory details (Baker et al., 2008; Gonthier et al., 2016; Kern et al., 2007; Tomchek et al., 2014). These patterns represent sensory processing deficits that may affect learning processes (Tomchek et al., 2014). Also, a delayed multisensory temporal processing has been reported in children with ASD (Kwakye et al., 2011).

There is also evidence of sensory processing differences in people with attention deficit and hyperactivity disorder (ADHD) (Dunn & Bennett, 2002; Panagiotidi, Overton, & Stafford, 2017b; Parush et al., 1997). Children with ADHD present lower visual perception when sensory processing difficulties are associated (Jung, Woo, Kang, Choi, & Kim, 2014) and studies have found difficulties in tactile processing and impaired balance performance (Ghanizadeh, 2011). Likewise, sensory issues have been reported in specific language disorders (SLI) (McArthur & Bishop, 2005; Taal, Rietman, Meulen, Schipper, & Dejonckere, 2013). Researchers have suggested that the grammatical difficulties in SLI may be linked with impaired auditory discrimination of amplitude rise time (Cumming et al., 2015; Goswami et al., 2016). Van der Linde, Franzsen, & Barnard-Ashton, (2013) found that more than 80% of children with SLI presented sensory processing difficulties in all areas assessed, and more than 50% of them presented difficulties in auditory, vestibular, touch and oral areas.

Some investigations have demonstrated the potential role of sensory processing as part of the characteristics of LD (Dove & Dunn, 2008; Dunn, 2014; Keller, 2001; Kruger et al., 2001; Padankatti, 2005). Dove and Dunn (2008) compared the sensory processing profile of students with and without specific learning difficulties and ADHD. The study showed a sensory profile of high frequency of behaviours in response to sensations in students with specific learning difficulties that may create more difficulties (Dove & Dunn, 2008). Dunn (2014) reported significant differences in the sensory profile of children with and without LD, characterized by the challenging processing of auditory, visual, and movement systems and a sensory profile that differed from the norms. Padankatti, (2005) examined the sensory profile of children with and without learning disabilities. Based on a frequency criterion, Padankatti showed that children with LD differed of the typical group regarding their sensory profile, particularly in the sensory systems of movement, touch, and body position. Kruger et al. (2001) conducted a phylogenetic study on children with learning difficulties. The results of Kruger et al. showed an interrelation between auditory, visual, somato-sensory, motor and language skills, implying that is not possible to observe learning difficulties without the presence of sensory involvement. This finding highlights the close association between cognitive skills and sensory processing and their mutual influence for the acquiring of learning goals. Finally, poor handwriting, a common behavioural manifestation in learning difficulties (Fawcett & Nicolson, 1999; Nicolson et al., 2001) is associated with an inadequate sensory integration process, and so demonstrates an additional link between LD and sensory issues (Keller, 2001).

Researchers have proposed that children with reading problems have difficulties linking verbal labels to the corresponding visual stimuli, which affects the establishment of appropriate associations between a word and its spelling (Blau et al., 2010; Wimmer et al., 2000; Windfuhr & Snowling, 2001). Similarly, the integration of auditory and visual sensory inputs has been noted as relevant for the development of cognitive skills such as reading (Chen, Zhang, Ai, Xie, & Meng, 2016; Francisco, Jesse, Groen, & McQueen, 2017; Froyen, Van Atteveldt, Bonte, & Blomert, 2008; Froyen, Willems, & Blomert, 2011; Kronschnabel, Brem, Maurer, & Brandeis, 2014; Nash et al., 2017). Thus, the literature on LD and sensory deficits has focused particularly on the study of auditory and visual processing. In the early 1980s, Tallal (1980) tested the relation between auditory temporal perception and reading disabilities. Tallal's results showed an impairment on tasks involving serial pattern perception when the rate of presentation of the stimuli increased, suggesting a deficit in the perception of auditory stimuli that arrive rapidly and sequentially (Tallal, 1980; Tallal, Miller, & Fitch, 1993). Rose, Feldman, Jankowski, and Futterweit (1999) included audio-visual stimuli to test the performance of poor versus typical readers. Rose et al., (1999) found that poor readers struggled more in matching temporal patterns of tones and lights in both intra-modal and cross-modal conditions, especially in the latter modality. Harrar et al. (2014) showed that a group of dyslexic adults struggled more than typical readers in integrating audio-visual sensory modalities, especially when the auditory stimuli were presented first. Similar results have been found when dyslexic readers, both children (Dionne-Dostie et al., 2015; Fischer, Hartnegg, & Mokler, 2000) and adults (Conlon, Wright, Norris, & Chekaluk, 2011; Francisco et al., 2017; Hairston, Burdette, Flowers, Wood, & Wallace, 2005) are exposed to audio-visual temporal processing tasks. Overall, these studies have shown that dyslexics perform below the level of control groups in audio-visual tasks, although significant individual differences are commonly found, which confirm high variability in the manifestation of this condition (Fischer et al., 2000; Ridder, Borsting, & Banton, 2001).

Studies on multisensory processing (Laasonen, Service, & Virsu, 2001, 2002) have found an impairment in temporal input processing in dyslexics when visual, auditory and tactile stimuli were presented rapidly, and a positive correlation between temporal acuity and phonological awareness in dyslexic participants. Hahn et al. (2014) found multi-sensory integration deficits in dyslexic people that may be a consequence of impairments in phonological and graphemic representation connectivity. Likewise, studies have demonstrated that adults and children with dyslexia are less sensitive to detecting visual motion signals, or low rates of auditory frequency modulation (Talcott, Hansen, et al., 2000; Talcott, Witton, et al., 2000; Witton et al., 1998). Such apparent ‘hyposensitivity’ in dyslexics might be linked with their literacy proficiency (Talcott, Witton, et al., 2000) and suggested an expanded temporal window of integration manifested by high sensory threshold, in particular for visual and auditory stimuli (Hairston et al., 2005). Children with dyslexia showed a delayed and smaller neurological reaction (in the N2b component) under incongruent non-linguistic audio-visual stimuli (Widmann, Schröger, Tervaniemi, Pakarinen, & Kujala, 2012).

Despite the evidence of sensory issues accompanying learning difficulties, in particular in the field of reading disorders, the specific processes involved are not clear. There is no consensus about the relevance and prevalence of sensory difficulties within the variability of the LD manifestation, and they may reflect other non-sensory developmental variables (Goswami, 2014). For example, Hulslander and colleagues (2004) assessed children and young adults with a range of reading ability. The assessment included measures of IQ, reading, and sensory processing (frequency and amplitude modulation detection of auditory stimuli, and motion and form detection of visual stimuli). The results showed correlation between reading skills and sensory processing threshold, however when controlled by IQ such association was lost. These findings do not exclude the possibility that sensory processing might have an effect on reading skills in a more general way, but evidence that such association might be not easily detected. Thus, requiring the incorporation of a new approach to test learning difficulties and their sensory characteristics.

2.4.1 Sensory Processing. Definition of concepts

Sensory processing is a non-specific concept that is used to describe the way in which sensation is detected, transduced and transmitted through the nervous system. It refers to the ability to register and modulate sensory information and to organize this sensory input to respond to situational demands (Humphry, 2002). Additionally, sensory processing refers to the way in which sensory information is managed by the nervous system. Its function is to enable adaptive responses to the environment and facilitate engagement in significant daily life activities (Johnson-Ecker & Parham, 2000). The operationalization of the concept of sensory processing is problematic due to the lack of a consistently-agreed upon definition, and its variety that depend on the development of neural connections (Koziol et al., 2011).

The concept of Sensory Integration (S.I.) emerged as a way to explain atypical responses to normal stimulation observed in both children and adults, as well as a related theory, assessment, and treatment method to approach to these dysfunctions. Ayres (1963) developed the S.I. theory based on clinical observations. Ayres suggested that some brainstem mechanisms are disorganized in some learning-disabled children. The S.I. theory refers to the organization of sensations from the senses for use, a primary function of the central nervous system. The brain uses the information to form perceptions, behaviours and learning in an unconscious process (Ayres, 2005). The central nervous system organizes and interprets incoming information captured by all of the sensory systems (visual, vestibular, proprioceptive, tactile, auditory, gustatory and olfactory). Thus, the individual's response to sensory experiences impacts on their interaction with the environment, their social relations and their academic learning (Bundy, Lane, & Murray, 2002; Dunn, 1997). The outcome of the interaction between the sensory systems and the environment is crucial for perception, cognitive processing and control of actions. Also, the combination of the information coming from different sensory channels improves and influence behaviour and perception (van Leeuwen, Trautmann-Lengsfeld, Wallace, Engel, & Murray, 2016).

Sensory integration requires internal cognitive processes to be developed, in which attention abilities are strongly associated (Talsma, 2015; Talsma & Woldorff, 2005). The implication of attention in multisensory processing for school-age children was demonstrated by Barutchu et al., (2019) who studied the attention skills and two multisensory processes through verbal and non-verbal illusions tasks in children. The results showed a correlation between attention and multisensory processes, but such association is dependent on the attention type required by the task.

Neuroscience principles are the foundation for the S.I. concept of sensory integration and multisensory integration is used in neuroscience to describe the neural process that occurs when combining signals from two or more senses in the central nervous system (Miller et al., 2009). Miller et al., (2009) suggested that both viewpoints, clinical (the observations from atypically developed children) and neuroscience (evidence from the brain system), are complementary in terms of understanding the complex process of sensory processing. Dunn's Model of Sensory Processing (1997) emerged from the Ayres' theory (1963) and the interaction of neuroscience principles. Sensory processing is defined as a construct that describes the interaction between a person's neurological function and the environment (Dunn, 1997b). This model will be explained with more detail in Chapter 3.

Identifiable patterns of sensory processing are manifested at different developmental ages across the lifespan (Padankatti, 2005). Also, challenging patterns have been associated with some neurodevelopmental disorders, especially autism and ADHD (Dunn, 2007), in pre-term born children (Bröring et al., 2018; Cabral, da Silva, Tudella, & Simões Martinez, 2015; Crozier et al., 2016; Niutanen, Harra, Lano, & Metsäranta, 2020), and in children with behavioural problems (Critz, Blake, & Nogueira, 2015; Gourley, Wind, Henninger, & Chinitz, 2013). A reduction of white matter has been reported in children with sensory processing disorders (Owen et al., 2013), which provides evidence of differences in brain structures associated with sensory issues. It has been proposed that sensory processing issues may be part of the difficulties of several disorders, but may also be identified as particular problems related to the senses in terms of inappropriate responses to sensory stimuli (modulation), difficulties in the interpretation of the stimuli, and motor problems as a result of sensory issues (Ahn, Miller, Milberger, & Mcintosh, 2004; Fox, Snow, & Holland, 2014; Miller, Anzalone, Lane, Cermak, & Osten, 2007).

Davies and colleagues (Davies, Chang, & Gavin, 2010; Davies & Gavin, 2007), used electroencephalography (EEG) measures to examine children with and without sensory processing disorders (SPD). They found less auditory sensory gating (process in which the brain responds to stimuli and filters out irrelevant information) in SPD children and 86% accuracy in the sensitivity of EEG measures to distinguish SPD children from those with typical development. In addition, the differences observed between children with and without SPD suggest a failures in the maturation of the sensory systems for the SPD children, which affect the ability to habituate to stimuli, and as a consequence, these children would need an extended period for processing of such stimuli (Davies et al., 2010).

In another study, Davies, Chang, and Gavin, (2009) explored maturational change by comparing the sensory gating between typical and SPD children and typical adults. The results demonstrated that adults presented an enhanced sensory gating as compared with either child group, and children with SPD were deficient in their ability to supress and modulate their response to sensory stimuli. Chang et al., (2016) found strong correlation between the white matter and sensory functioning in children.

2.4.2 Neural mechanisms of sensory processing

As expressed at the beginning of the introduction (see page 1), all human behaviours, encompassing those related to learning processes, are based on the sensorimotor system, which includes a sensory input and its motor output (Cisek & Kalaska, 2010; Koziol et al., 2011). Consequently, it is reasonable to posit that cognitive processes cannot occur in isolation from the sensorimotor system (Koziol et al., 2011). The association between the sensorimotor system and cognitive skills is suggested to be mediated by the neocortex, the basal ganglia, and the cerebellum (Cisek & Kalaska, 2010; Dionne-Dostie et al., 2015; Kruger et al., 2001).

The neocortex plays an executive role in processing sensory information and planning motor responses (Koziol et al., 2011). The basal ganglia has several roles; among them it is involved in learning motor sequences and is connected with the prefrontal region, suggesting a mediator role in cognitive functions (Cisek & Kalaska, 2010; Middleton & Strick, 2002).

Finally, the cerebellum is recognised for its role in motor processes and sensory integration (Herzfeld & Shadmehr, 2014; Manzoni, 2005), but research has also demonstrated a role in cognitive processes (Alvarez & Fiez, 2018; Justus & Ivry, 2001; Middleton & Strick, 2002). These neural structures creates a system that serves adaptation: the first stages of development require high cognitive control for the acquisition of new behaviours; then a switch is expected to occur to an automatic process that releases cognitive effort to be used in further and more complex tasks (Bargh, 1997; Bargh & Chartrand, 1999; Hikosaka & Isoda, 2010). This switching mechanisms goes in both directions, from cognitive control to automatic and vice versa, in regard to environmental demands and the novelty of the tasks (Hikosaka & Isoda, 2010). Difficulties in the automatization of tasks may impact on individuals' reading skills, as proposed by the Automatization deficit hypothesis (Nicolson & Fawcett, 1990; Nicolson et al., 2010) explained in section 2.3.1.1.

The concept of sensory processing has been heavily influenced by studies on the superior colliculus, a subcortical convergence zone for sensory information (Stein & Meredith, 1993). One of the features of the superior colliculus (SC) is that it integrates the information from multiple senses, creating an enhancement of the multisensory process in the brain (Yu, Rowland, & Stein, 2010). Also, the thalamus plays a role as an early sensory integrator (Cappe, Rouiller, & Barone, 2012).

Modulation is a central mechanism that makes adaptive communication possible among the sensory processing input, motor responses, and cognitive functions, that is, the system composed by the neocortex, basal ganglia and cerebellum (Cisek & Kalaska, 2010). The ability to modulate sensory processing involves receiving, focusing, monitoring and adjusting the sensory inputs (Dionne-Dostie et al., 2015). A concept review (Brown, Tse, Fortune, & Tse, 2019) proposed that sensory modulation is a twofold process that originates in the central nervous system as the neurological ability to regulate and process sensory stimuli, and subsequently involves a behavioural response to the stimulus.

Difficulties in the modulation of sensory information may manifest as an over-response, under-response, or sensory seeking (searching behaviour to strong stimulation) response to stimuli (Dunn, 2001; Miller et al., 2009). For instance, Mcintosh, Miller, Shyu, and Hagerman, (1999) observed atypical physiological responses characterised by an over-response to stimuli, which suggest modulation issues. Kern (2002) proposed that a failure in the cerebellum may be involved in inconsistent sensory modulation, and an unfittingly sensory integration process, which would explain the particular sensory profile observed in autism and other neurodevelopmental disorders.

Regarding the organisation and modulation of sensory information, studies have found differences in the threshold of sensory integration in children with learning difficulties when compared with typically developed children. Sperling, Lu, Manis, and Seidenberg (2005) found that children who were poor readers presented a lower threshold in high-noise conditions compared with children who were good readers, which affected their ability to focus on relevant, over irrelevant information. Richardson, Thomson, Scott, and Goswami (2004) observed a high threshold in dyslexic children for integration auditory temporal information. A successful balance of neurological thresholds and the display of adaptive responses to specific demands depends on the maturation of the nervous systems as well as having adequate learning experiences (Jorquera-Cabrera, Romero-Ayuso, Rodriguez-Gil, & Triviño-Juárez, 2017). Thus, maladaptive neurological responses may be associated with problems in modulation, as proposed by Dionne-Dostie et al. (2015).

2.4.3 The development of sensory processing.

The human brain experiences intense changes in its structures and functions that set the foundations to an improvement of abilities throughout development (Casey, Tottenham, Liston, & Durston, 2005). The multisensory temporal processing abilities depend on the maturation of different senses, and on the maturation of the nervous system throughout the developmental stages (Nardini, Dekker, & Petrini, 2014; Wallace & Stevenson, 2014). Studies on mammals showed a late maturation of multisensory systems needed for high-order functions, and dependant of gaining cross-modal experiences (Wallace, Carriere, Perrault, Vaughan, & Stein, 2006; Wallace & Stein, 2001). Therefore, as infants gain more experience interacting with the sensory world, their inter-sensory matching abilities and strategies are adjusted and enhanced (Wallace & Stevenson, 2014; Wallace & Stein, 2007; Williams, 2017). For example, it has been suggested that the groundwork for reading skills lay in the audio-visual system (Hahn et al., 2014; Hairston et al., 2005). Children need maturation of both the basic sensory systems and the sensory integration areas before more complex cognitive functions, such as literacy, can appear. Peiffer, Mozolic, Hugenschmidt, and Laurienti, (2007) demonstrated a constant enhancement of the multisensory ability by observing faster response in older adults compared with their younger counterparts. Wallace and Stein (2007) proposed that early cross-modal experiences are crucial to improve the temporal synchronization of stimuli, which is needed to reach the maturation of multisensory ability. Thereby, adults are able to integrate diverse information in a statistically optimal fashion; that is, the single inputs to be integrated are weighted proportionally according to their reliability (Ernst, 2008; Hartcher-O’Brien, Di Luca, & Ernst, 2014). The establishment of maturational milestones in multisensory development could be crucial in predicting certain developmental disabilities that have been associated with abnormal multisensory processing, such as dyslexia and autism (Hillock, Powers, & Wallace, 2011).

Multisensory processing is conceptualized as the influence of one sensory modality on the activity generated by another modality (Clemo, Keniston, & Meredith, 2012). This process involves the convergence of inputs from different sensory modalities onto individual neurons. Accordingly, the signals are received from multiple sensory channels that share similar spatial and temporal properties, and merge into an holistic representation of the environment (Barutchu, Crewther, & Crewther, 2009). The ability to integrate cues from multiple senses is a fundamental feature of brain function. Multisensory integration involves synthetizing information that contains different perspectives from the external world, creating an enhanced experience and adaptive response (Stein, Stanford, & Rowland, 2014). The process of multisensory integration is automatized, and to take place, a meaningful relationship is needed between all sensory inputs to allow the emerging of critical skills, such as cognitive skills (Engel, Senkowski, & Schneider, 2012; Wallace & Stevenson, 2014). Wallace and Stein, (2007) proposed that early cross-modal experiences are crucial to improve the temporal synchronization of stimuli, which is needed to reach the maturation of multisensory ability. Thereby, adults are able to integrate diverse information in a statistically optimal fashion; that is, the single inputs to be integrated are weighted proportionally according to their reliability (Ernst, 2008; Hartcher-O'Brien, Di Luca, & Ernst, 2014).

Researchers recognized that the first seven years of life are crucial in the development of multi-sensory functioning. Most of the activity in this period needs to be organized to build a strong background to support the acquisition of different skills that become the basis for more complex and mature behaviour (Ernst, 2008; Hillock et al., 2011; Robinson & Sloutsky, 2010). Multisensory functions improve significantly during the first year of life (Lewkowicz, 2012), and takes until late childhood to reach adult-level functioning (Mamassian, 2015). Also, multisensory functions depends on the gaining of cross-modal experiences (Stein, Stanford, & Rowland, 2014; Wallace & Stein, 2001). Gori, Del Viva, Sandini, and Burr (2008) measured sensory perception with visual and haptic spatial information. Gori et al. results showed that children start to optimally integrate both cues sometime between 8 and 10 years of age. Before 8-10 years old the perceptual systems are being recalibrated, and would not be ready for the integration of multisensory inputs. Nardini, Jones, Bedford, and Braddick, (2008) assessed the ability of children to navigate under visual cues. They found that children younger than 8 years old are unable to optimally integrate multisensory. A study on audio-visual integration (Nardini, Bales, & Mareschal, 2016) confirms that the speed and efficiency of multisensory integration improve with age.

2.4.3.1 The seven senses

As previously stated, during the first years of life the developing nervous system needs to organize the sensations in order to get meaningful information from both internal (from the body) and external (from the environment) inputs (Lewkowicz, 2012; Mamassian, 2015; Wallace & Stevenson, 2014; Williams, 2017). The activities in which children engage provide opportunities to gain more complex and mature associations among the senses (Ayres, 2005). Genetic and familial factors along with exposition to sensory experiences play a significant role in the progress to maturity of the whole sensory system (Bundy et al., 2002; Pedrosa, Caçola, & Carvalhal, 2015).

While all of the seven senses are highly relevant throughout the whole life span, they mature at different rates and have different developmental paths (Ayres, 2005). The sense of touch has an early maturation starting in the womb, thus providing the new-born with a repertoire of early responses to the environment, the reflexes. The vestibular – the sense of gravity and motion that comes from the inner ear- and proprioception – the relative position of one’s own body from joint and muscle receptors- senses are also observed from the first day of life. The average one month old child is able to respond to a sudden movement of his body (outward movement of limbs and the intent to grasp) (Ayres, 2005; Bundy et al., 2002).

The senses of smell and taste are also well organized at birth and are involved in the vital function of feeding through sucking. The senses of sight and hearing are present in the new-born; however their maturation relies on gaining experiences in order to reach better organization and control (Ayres, 2005; Herbert, 2003). Motor skills, such as motor control, depend on the maturation of the senses and the combination of vision, vestibular, tactile, and proprioception senses into an unified-meaning signal (Stapel, Rosander, & Von Hofsten, 2017). New motor skills require practice to become fluid and coordinated, and some of them turn into automatic behaviour, that is, they do not require conscious attention to be performed (Kurtz, 2008).

CHAPTER 3

DUNN'S FRAMEWORK OF SENSORY PROCESSING

Dunn's framework of sensory processing (1997b) arises from the occupational therapy field as an approach to observe and interpret the role of sensory processing in the performance of children. This framework is an attempt to understand the interaction between neuroscience and behavioural concepts by providing measures for children as young as toddlers up to adults over 65 years old (Dunn, 1997a). The rationale behind Dunn's model (1997b) posits that all of the senses need to work together in harmony. In other words, the senses of touch, smell, taste, sight and sound, as well as physical movement and body awareness, are expected to have a balanced response to enable the adequate and adaptive functioning of brain mechanisms.

Dunn's (1997b) framework is depicted in a four-quadrant conceptual model that characterizes the behaviours that people exhibit in their daily lives as a result of the interaction between two dimensions. The first dimension corresponds to 'self-regulation strategies' or 'behavioural response', understood as the individual's capacity to respond to situations by adjusting their actions to achieve the desired results. The self-regulation strategies range from passive, when a person allows the events in the environment to occur around them; to active that characterises a person who seeks to control the amount of stimulation he/she receives (Dunn, 2007). The second dimension refers to 'neurological thresholds', defined as the point at which there is sufficient sensory input to cause the nervous system to activate (Dunn, 1997b). The neurological threshold continuum is based on nervous system principles: excitation, when the neuron is activated, and inhibition, when the likelihood of responding is decreased, or responses are blocked (Dunn, 1997a, 1997b). The high end of the neurological threshold continuum represents hyposensitivity or the process of habituation, which is the way of recognizing the stimulus as familiar and thereby decreasing attention, so the person requires a more salient stimulus to react. He/she would not notice things as easily as others because of the need for much greater intensity. At the extreme low end occurs the process of sensitization or hypersensitivity, which is the way of recognizing all of the stimuli as relevant and thereby maintaining attention. The sensory receptors are easily activated by the sensory events, so a person would be much more responsive even to low intensity stimuli (Dunn, 1997b, 2014). Dunn claimed a combination of these two dimensions reflects individuals' variability in processing sensory information, conceptualized as a stable trait from which are derived four sensory quadrants named Registration, Seeking, Avoiding, and Sensitivity (Dunn, 1997, 2014; Tomchek et al., 2014). These sensory quadrants will be explained with more detail in section 3.1.

According to Dunn (1997a, 1997b, 2001) the brain regulates the incoming messages and the consequent responses by a modulation process that provides a balance between the excitation and inhibition mechanisms regarding the available stimuli. An adequate sensory integration of the inputs ensure an adaptive behaviour and functional performance, thus deficits in sensory processing would affect the behaviour, including attention and learning processes (White et al., 2007). Cognitive mechanisms like attention and memory, needed in the learning processes, operate with information from the sensory systems. An adequate processing would occur only when internal (sensations of the body) and external (sensations of the environment) information are in a balanced state (Dunn, 2001)

Approaches from different disciplines have studied particular sensory response to stimuli that contribute to the understanding of some sensory quadrants of Dunn's model (Dunn, 1997b). For example, Aaron and colleagues (Aron & Aron, 1997; Aron, Aron, & Jagiellowicz, 2012) described sensory processing sensitivity as a personality trait characterised by low sensory threshold and high sensitivity to stimuli. The sensory processing sensitivity would be associated with a deep cognitive processing of stimuli, behavioural inhibition and high emotional reactivity. Sensation seeking has been linked with the adolescence period, in its understanding of the desire to achieve new experiences and take risks, as well as a lack of self-regulation in terms of thoughts, feelings, or actions (Foulkes & Blakemore, 2018; Spear, 2000; Steinberg et al., 2017). Also, there is evidence of physiological phenomenon in humans linked to sensation seeking traits, such as a reduction in heart rate in people with high sensation seeking traits (Carton, Morand, Bungenera, & Jouvent, 1995; Glicksohn & Abulafia, 1998; Zuckerman, 1994).

3.1. Sensory quadrants and sensory systems

As noted above, Dunn's model of sensory processing is based on the combination of two constructs, behavioural self-regulation strategies and neurological thresholds, which emerge from the responses of basic sensory systems. These two constructs serve as axes that cross to form four theoretical sensory quadrants (Dunn, 1997b, 2001). Such quadrants, Registration, Seeking, Avoiding and Sensitivity, would reflect a person's characteristics to respond to sensory stimulation regarding the particular situation and demands (Dunn, 1997b). The sensory quadrants draw a profile of the most likely actions concerning the ability to modulate behavioural responses over sensory demands. As explained in section 2.4.2, the ability to modulate sensory processing involves receiving, focusing, monitoring and adjusting the sensory inputs to maintain a balance of the neurological thresholds and to exhibit adaptive behaviours (Dionne-Dostie et al., 2015; Jorquera-Cabrera et al., 2017; Miller et al., 2009; Taal et al., 2013). This behavioural modulation mechanism would act to monitor and regulate the habituation and sensitization responses to allow an adequate learning process by maintaining a balance between the neurological threshold and the self-regulation strategies (Dunn, 1997a).

In practical terms, Dunn's four-quadrant model is based on the preferences of people along six sensory systems, which depict their sensory characteristics regarding the neurological threshold and self-regulation strategies (Brown & Dunn, 2002; Dunn, 2014). The figure 3.1 shows the interaction among the concepts of the Dunn's framework.

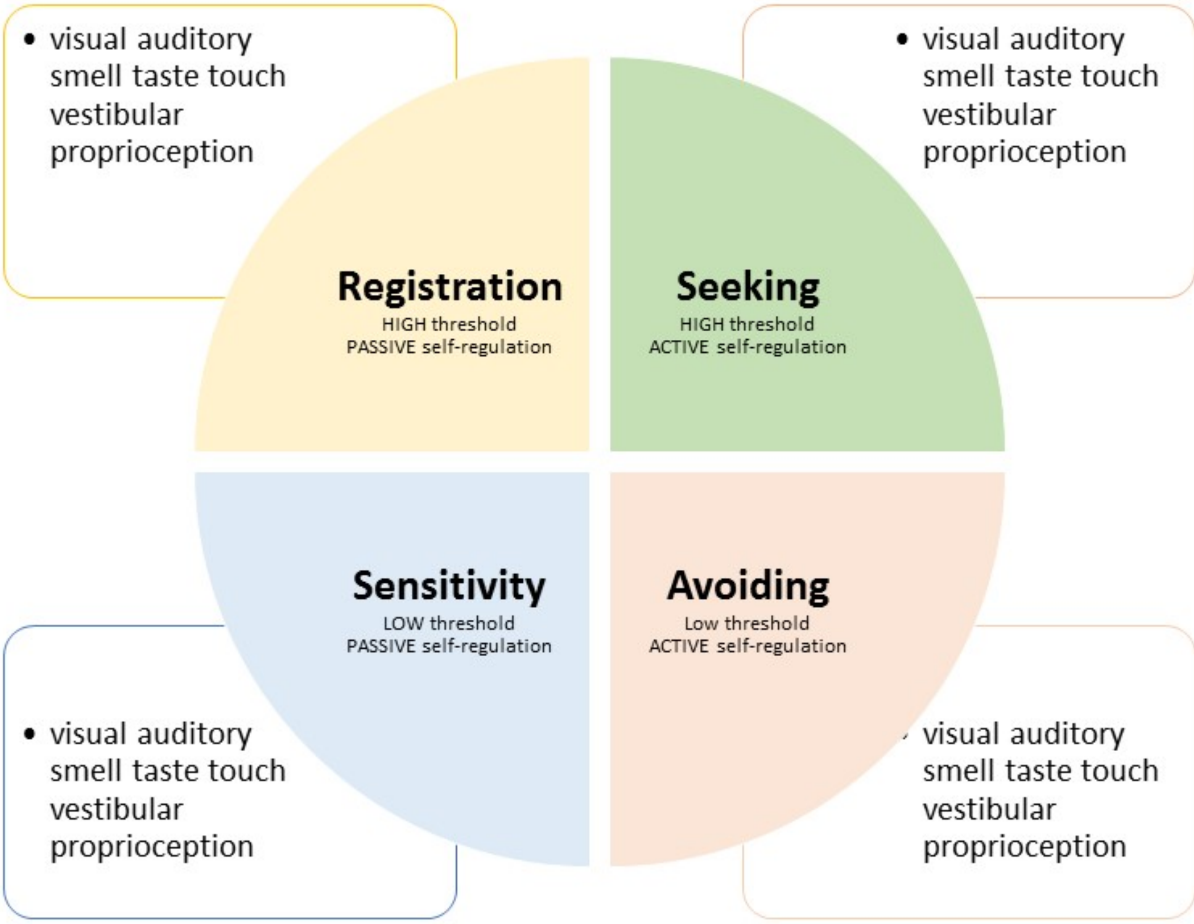

Figure 3.1 Dunn's sensory processing framework. Organization of sensory quadrants and sensory systems, adapted from Dunn, 1997.

3.1.1. Sensory quadrants

The quadrants that represent the high neurological thresholds are related to individuals lack of response or need for more intense sensory stimuli, that is hyposensitivity (Brown & Dunn, 2002; Dunn, 1997b). These quadrants are:

- Registration, which measures passive behavioural responses associated with missing stimuli or responding slowly. People with high scores in this quadrant are bystanders, they may have trouble reacting to rapidly presented or low-intensity stimuli. Thus, bystanders would beneficiate of strategies that slow down the rate of presentation of stimuli, so that the individual has time to detect and process the information.
- Seeking, which measures active behavioural responses associated with enjoyment, creativity, and the pursuit of sensory stimuli. People with high scores in this quadrant may create additional stimuli or look for environments that provide sensory stimuli and regard sensory experiences as pleasurable. However, those who present an excess of seeking behaviours may become easily bored and may find low-stimulus environments intolerable.

The low neurological threshold is characterized by a person's notice of or annoyance with sensory stimuli, that is hypersensitivity (Brown & Dunn, 2002; Dunn, 1997b). The quadrants that represent this threshold are:

- Avoiding, which measures active behavioural responses such as deliberate acts to reduce or prevent exposure to sensory stimuli, and efforts to make exposure more predictable. People with high Avoiding scores would be overwhelmed or bothered by sensory stimuli, consequently they actively engage with their environments to reduce sensory stimuli. Avoiders may use rituals to increase the predictability of their sensory environment.
- Sensitivity, which measures passive behavioural responses associated with responses such as noticing behaviours, distractibility and discomfort with sensory stimuli. Individuals with high scores in this quadrant may have a tendency to notice each stimulus as it presents itself, with high awareness of the environment. This over-attention to stimuli may interfere with the focus on performing activities of interest.

The quadrants can be organized regarding the normative expected behaviour ('Just like the majority') and by that means, the behaviours that would be characteristics for those who engage more than others ('More than others'), and people who engage less than other ('Less than others') (Dunn, 2014). Table 3.1 shows a summary of the general concepts for interpretation of the sensory quadrants on the sensory profile questionnaire of Dunn.

Table 3.1. Example of behaviours associated to the sensory quadrants.

A person with scores on….	**Less than others** (below the mean)	**Just like the majority** (mean)	**More than others** (above the mean)
Seeking	May not seek enough sensory input to sustain successful participation	Uses sensory input to gather information necessary for participation	May seek sensory input in ways so excessive or disruptive that it interferes with participation
Avoiding	May fail to notice the sensory input needed for participation	Manages sensory input to get just the amount needed for participation	May become so overwhelmed by sensory input that it interferes with participation
Sensitivity	May fail to detect the particular sensory input needed to sustain participation	Detects the sensory input that enables participation	May be so distracted by sensory input that it interferes with participation.
Registration	May notice sensory input that is note helpful for participation	Notices enough sensory input to support participation	May miss sensory input needed for participation

Extracted from Sensory profile 2, *User's Manua*l, page 54 (Dunn, 2014).

3.1.2 Sensory systems

The sensory systems included in Dunn's model (1997) correspond to Auditory, Visual, Touch, and Movement, plus Body Position and Oral for the children scale (Dunn, 2014), and

Taste/Smell, and Activity Level for the Adolescent/Adult scale (Brown & Dunn, 2002). The sensory systems are responsible for bringing information from the environment to the nervous system for processing. The sensory systems, through the components of arousal/alerting and discrimination/mapping, among others, allows the individual to interact with the environment and gather information for discrimination and mapping such input (Dunn, 1997a).

The table 3.2 shows a summary of the description for each sensory system and an example of the statements for both the Children scale and the Adolescent/Adult scale designed by Dunn (Brown & Dunn, 2002; Dunn, 2014).

Table 3.2 Description of sensory systems for the Children and Adolescent/Adult scales.

Sensory system	Description	Example of statements for children[a]	Example of statements for Adolescent/Adult[b]
Auditory	Measures the person's responses to things heard.	My child struggles to complete tasks when music or TV is on.	I hum, whistle, sing, or make other noises. I like to attend events with a lot of music.
Visual	Measures the person's responses to things seen.	My child need help to find objects that are obvious to others.	I like to wear colourful clothing. I do not notice when people come into the room.
Touch	Measure the person's responses to stimuli that touch the skin.	My child touches people or objects to the point of annoying others.	I like how it feels to get my hair cut. I move away when others get too close to me.
Movement	Measures the person's responses to movement.	My child takes movement or climbing risks that are unsafe.	I am afraid of heights. I choose to engage in physical activities.
Body position	Measure the person's responses to changes in joint and muscle positions.	My child walks loudly as if feet are heavy	-
Oral	Measure the person's responses to touch and taste in the mouth.	My child is a picky eater, especially about food textures.	-
Taste / Smell	Includes items that measure the individual's responses to odours and tastes.	-	I add spice to my food. I go over to smell fresh flowers when I see them.
Activity level	Measure the individual's disposition toward involvement in daily activities.	-	I work on two or more tasks at the same time. I stay away from crowds.

[a] Extracted from manual of Sensory Profile-2 (Dunn, 2014). [b] Extracted from manual of Adolescent/Adult sensory profile (Brown and Dunn, 2002).

3.2 Dunn's questionnaires to assess sensory processing

Sensory processing has been measured with different approaches that include questionnaires, standardized batteries of tests, laboratory tasks, and clinical observations. A systematic review of the available tools for the assessment of sensory processing in children (Jorquera-Cabrera et al., 2017) identified eleven standardized test that varied in the scope of the abilities measured. For example, the Touch Inventory for elementary school-aged children (Royeen, 1986) and the Motor planning maze assessment (Ivey, Lane, & May-Benson, 2014) assess tactile characteristics and motor performance respectively. There are other batteries of test that include a broader range of measures, such as attention, social and sensory responses, posture, perception, and language in order to obtain a picture of the individual across the board (Miller, 1988).

The laboratory sensory processing tasks have been designed to explore specific elements of sensory processing such as timing and integration of information from more than one channel. For example, a well-known paradigm is the temporal order judgement (TOJ), which investigates information processing in different modalities like visual and auditory (Hendrich, Strobach, Buss, Müller, & Schubert, 2012). In a TOJ task, the participant is asked to indicate the order of appearance of two stimuli coming from different channels. The TOJ has been used to investigate sensory abilities in people with learning difficulties (Hairston et al., 2005; Laasonen et al., 2001, 2002; Richardson et al., 2004). The similar judgement task (SJ) is another task that is used to elicit a different neural mechanism than the TOJ (Matthews, Welch, Achtman, Fenton, & Fitzgerald, 2016). The SJ consists of asking the participant to judge if two stimuli, usually auditory and visual, were presented at the same or different times. It has been used to assess multisensory integration abilities in people with learning difficulties like dyslexia (Hillock et al., 2011; Stevenson & Wallace, 2013). Electrophysiology techniques are also used to investigate sensory processing. For example, electroencephalogram studies of the mismatch negativity (MMN) have identified the brain mechanisms of auditory functioning and the influence of audio-visual conditions on the integration and prediction of sensory cues (Näätänen, 1995; Schroger, 1998; Winkler, 2007).

Sensory processing can also be assessed through questionnaires, and four scales have been used frequently. These scales are the Sensory Experiences Questionnaire (Ausderau et al., 2014; Baranek, David, Poe, Stone, & Watson, 2006; Little et al., 2011) which is used to characterise children with autism and other developmental disorders; the Evaluation of Sensory Processing (Johnson-Ecker & Parham, 2000; Su & Parham, 2014) which assesses the sensory processing of children in the context of school and home; the Short Sensory Profile (Baker et al., 2008; Fox et al., 2014; Lane, Molloy, & Bishop, 2014) which measures behaviours associated with abnormal responses to sensory stimuli in children, and the Sensory Profile questionnaires designed by Dunn, which were designed to characterize the sensory profile of children (Cheung & Siu, 2009; Dove & Dunn, 2008; Hilton, Graver, & LaVesser, 2007; Kern et al., 2007; Little, Dean, Tomchek, & Dunn, 2016; Padankatti, 2005; Taal et al., 2013; van der Linde, Franzsen, & Barnard-Ashton, 2013; Watling, Deitz, & White, 2001; White, Mulligan, Merrill, & Wright, 2007) and adults (Brown, Tollefson, Dunn, Cromwell, & Filion, 2000; Engel-Yeger et al., 2016; Engel-Yeger, Hus, & Rosenblum, 2012; Engel-Yeger & Dunn, 2011; Gonthier et al., 2016; Lowe et al., 2016).

The tests and questionnaires mentioned previously can be used to make a diagnosis of sensory-based processing disorders that affect socio-emotional, motor, and cognitive development (Jorquera-Cabrera et al., 2017; Miller. et al., 2007). The questionnaires can also identify sensory processing issues that may accompany both typical development and some neurodevelopmental disorders (Jorquera-Cabrera et al., 2017). The objective of this thesis was to measure sensory characteristics from childhood to adulthood in people with and without learning difficulties, thus Dunn's Model of Sensory Processing (1997b) was chosen given that it covers all the developmental stages and has been broadly used in research.

The questionnaires derived from Dunn's framework of sensory processing (Dunn, 1997b) provide information to understand the sensory processing of an individual which may impact his/her daily performance. These standardized tools assess sensory processing patterns in the context of the everyday life of individuals and give information about how such sensory pattern may contribute or interfere with the performance of children and adults. The statements in the questionnaires are described in terms of sensory-related behaviours, that is, behaviours that involve a response regarding some sensory situation. For example 'My child becomes irritated by wearing shoes or socks', 'My child enjoys looking at visual details in objects' (Dunn, 2014).

The sensory profile questionnaires provide cut off scores for each of the four sensory quadrants, which have a normal distribution and provide a classification system to categorize people's tendency for distinct behaviours (Dunn, 2014). The classifications range from 'Much less than most people' (-2SD), 'Less than most people' (-1SD), 'Just like the majority' (mean scores), 'More than most people (+1SD), and 'Much more than most people' (+2SD) (Brown & Dunn, 2002; Dunn, 2014). The categories reflect a continuum from less engagement in the behaviours described by the items on the questionnaire and, therefore, less intense response to them, to much more frequency and intense response compared with the expectation for the age group. Responses that fall into the 'Just like the majority' classification represent an expected performance, that is to say, the person react to sensory stimulation in a typical way (Dunn, 1997). A misbalanced profile, as indicated by scores either above or below the mean, will imply problems in the behavioural modulation of the stimuli, and therefore failure to display responses that match the demands and expectations of the environment (Bundy et al., 2002).

It is important to note that the quadrants do not exclude each other, so a person may have a profile characterised by high scores (or low scores) in more than one of the quadrants. Therefore, the objective of the questionnaires is not to classify individuals regarding one quadrant only, but to characterized them considering their sensory profile in all the four quadrants. Likewise, as Dunn and Brown (1997) indicated, the sensory patterns are observed in both typical and atypical populations, thus the difficulties in sensory processing observed in individuals with disabilities represents a different place on a continuum of sensory responsivity related to intensity or duration of response.

3.2.1 Children Sensory Profile

The Children Sensory Profile scale (Dunn, 2014) is a parental report instrument designed to assess sensory processing characteristics in children and their most frequent reactions to sensory experiences.

The second version of the Children Sensory Profile (CSP-2) was published by Dunn (2014). The CSP-2 is a standardised assessment that measures sensory processing or modulation abilities and its effect on functional performance in daily life in children aged 3:00 to 14:11 years old (see questionnaire sample in Appendix A). The CSP-2 questionnaire elicits information about six sensory systems - auditory, visual, touch, movement, body position, and oral- that in combination create the four sensory quadrants that characterise the sensory processing profile of children (Dunn, 2014). The items for the CSP-2 were developed through a process that included experts, teacher, therapists and families in order to define the suitability of each statement. A pilot study of the questionnaire was launched in 2012 that showed good understanding of the items and an adequate discrimination ability. The final standardization sample consisted of 1791 participants of both genders, with English as primary language, and 10% of children with conditions (Dunn, 2014).

The scale demonstrated strong internal consistency (Cronbach's $\alpha = .88 - .92$) and test-retest reliability ($r = .96 - .97$) (Dunn, 2014). There are no further reports of the properties of the scale, but Ermer and Dunn, (1997) examined the first version of the children Sensory Profile published in 1995, to test whether it could discriminate between children with and without disabilities. The results of Ermer and Dunn demonstrated that the questionnaire was able to differentiate at about 90% of the children tested (from a sample of 796 cases) on the basis of the frequency or intensity of certain behaviours that differentiated the groups. The quadrant of Seeking was one of the main predictors of disabilities, where children without conditions showed higher scores than children with conditions.

The CSP-2 is administered to parents who are asked to report the behaviours of their children regarding the sensory systems. The administration can be a paper questionnaire or online. The statements on the CSP-2 elicit information about the child's ways of responding to sensory experiences in everyday life. The questionnaire contains 86 statements that are Likert-style five-point items, ranging from (1) almost never, occasionally (2), half the time (3), frequently (4), to almost always (5), including a does not apply option (0). The total scores for the sensory systems are used to calculate the four quadrants: Registration, Seeking, Avoiding, and Sensitivity. The questionnaire also includes a classification method for both quadrants and sensory systems, consisting of five categories that reflect groups of scores along a bell curve, from 'Much less than others' (-SD), 'Just like the majority' (mean scores) to 'Much more than others' (+SD) (Dunn, 2014). The normative data for the sensory quadrants of the children scale is in Table 3.3.

Table 3.3 CSP-2 normative range of raw scores categories per quadrant

Quadrant	Much less than others -2SD	Less than others -1SD	Just like the majority *M*	More than others +1SD	Much more than others +2SD
Sensory quadrants					
Registration	0 – 6	7 – 18	19 – 43	44 – 55	56 – 110
Seeking	0 – 6	7 – 19	20 – 47	48 – 60	61 – 95
Avoiding	0 – 7	7 – 20	21 – 46	47 – 59	60 – 100
Sensitivity	0 – 6	7 – 17	18 – 42	43 – 53	54 – 95
Sensory systems					
Auditory	0 – 2	3 – 9	10 – 24	25 – 31	32 – 40
Visual	0 – 4	5 – 8	9 – 17	18 – 21	22 – 30
Touch	0	1 – 7	8 – 21	22 – 28	29 – 55
Movement	0 – 1	2 – 6	7 – 18	19 – 24	25 – 40
Body position	0	1 – 4	5 – 15	16 – 19	20 – 40
Oral	..	0 – 7	8 – 24	25 - 32	33 – 50

Extracted from manual of Sensory Profile-2 (Dunn, 2014)

3.2.2 Adolescent/Adult sensory profile

The Adolescent/Adult sensory profile (AASP) aims to characterize the behaviour of adolescents and adults in relation to their sensory processing. The AASP is a 60-item self-evaluation of behaviours regarding everyday sensory experiences (Brown & Dunn, 2002). The questionnaire contains questions regarding how he or she generally responds to sensations to capture the more stable and enduring sensory processing preferences of an individual. The AASP was designed to be used with adolescents from 11 years old, to adults (see questionnaire sample in Appendix B).

The validity and reliability of the AASP questionnaire were examined through an expert panel, item reliability and factor analysis, and construct validity, showing adequate psychometric properties and confirmation of the existence of a four quadrant model (Brown, Tollefson, Dunn, Cromwell, & Filion, 2000). The internal consistency (Cronbach's alpha) of quadrants was reported between .66 and .82 (Brown & Dunn, 2002). Significant correlation has been reported between the AASD and other questionnaires that measure sensory features (Horder, Wilson, Mendez, & Murphy, 2014). The AASP has proved to be useful in research. For instance, the AASP was used to examine the relationship between emotional disorders and sensory reactivity, showing significant association for the extreme sensory patterns expressed in hyper- or hyposensitivity (Engel-Yeger & Dunn, 2011; Engel-Yeger et al., 2016). Similar results were observed by Serafini et al. (2017) who suggested that lower ability to register sensory input may be an important factor involved in determining depression.

Normative cut scores of the AASP can be used to classify participants into five categories that reflect groups of scores along a bell curve. The range of raw scores categories per quadrant for adolescents aged 11-17 years, and adults aged 18 and more are shown in Table 3.4 (note that the AASP scale does not provide independent scores for the sensory systems).

Table 3.4 AASP normative raw scores categories per quadrants

	Categories				
Quadrant	Much less than others -2SD	Less than others -1SD	Just like the majority *mean*	More than others +1SD	Much more than others +2SD
Norms for 11 - 17 years old					
Registration	0 – 18	19 – 26	27 – 40	41 – 51	52 – 75
Seeking	0 – 27	28 – 41	42 – 58	59 – 65	66 – 75
Avoiding	0 – 18	19 – 25	26 – 40	41 – 48	49 – 75
Sensitivity	0 – 19	20 – 25	26 – 40	41 – 48	49 – 75
Norms for 18 - 64 years old					
Registration	0 – 18	19 – 23	24 – 35	36 – 44	45 – 75
Seeking	0 – 35	36 – 42	43 – 56	57 – 62	63 – 75
Avoiding	0 – 19	20 – 26	27 – 41	42 – 49	50 – 75
Sensitivity	0 – 18	19 – 25	26 – 41	42 – 48	49 – 75

Extracted from the manual of Adolescent/Adults sensory profile (Brown & Dunn, 2002).

3.3 Critical evaluation

The advantage of Dunn's questionnaires is that they offer a description of the sensory processing patterns of participants across all of the sensory modalities and they can be easily administered on paper and online. The psychometric properties of the questionnaires have been reported for both the children and adult versions (Brown & Dunn, 2002; Dunn, 2014). Hence, Dunn's questionnaires are a cost-effective method for acquiring a detailed profile of the sensory processing characteristics across the board, and for different age groups.

The inclusion of different sensory processing strategies in terms of self-regulation presents a valuable dimension not used by other theories (Dunn, 1997b), since on the one hand it provides a line of converging evidence in terms of the underlying processing differences, but also offers the opportunity to help support children by identifying and alleviating counter-productive behavioural habits.

Furthermore, there is extensive evidence that [some] children with disabilities exhibit patterns of behaviour that are distinguishable from children without disabilities (Cheung & Siu, 2009; Dunn & Brown, 1997; Ermer & Dunn, 1997), in particular, for people with ASD and ADHD (Dunn & Bennett, 2002; Kern et al., 2007; Watling et al., 2001). For instance, children with ADHD presented difficulties in adaptive responses to sensory events and differences with a control group in almost 80% of the sensory measures (Shimizu, Bueno, & Miranda, 2014). Another study (Little, Dean, Tomchek, & Dunn, 2018) showed patterns of high frequency of sensory behaviour for ASD and ADHD compared to a control group.

Comparisons between children with learning difficulties and typically learning children (Dove & Dunn, 2008; Padankatti, 2005) have shown significant differences in sensory processing in the quadrants of Seeking, Avoiding, and Registration, and high frequency of behaviours in response to sensory patterns for children with LD, which was uncommon for typically learning children. Then, Dunn (2014) compared the teachers' scores on the children sensory profile questionnaire of student with and without LD. The scores showed significant differences, children with LD presented significantly higher scores in the quadrants of Seeking and Registration, and auditory, visual and movement sensory systems, compared with their peers without LD (Dunn, 2014). Also, some authors have identified subgroups of sensory patterns derived from Dunn's scales that may be useful to classify a typical population and those with specific developmental and behavioural conditions (Gonthier et al., 2016; Little et al., 2016).

Although the Dunn’s questionnaires are a valuable tool to capture sensory characteristics, they include statements about other factors that may influence the patterns of sensory processing. Tavassoli, Hoekstra, and Baron-Cohen, (2014) pointed out that the Dunn’s questionnaires are useful since they produce clear group differences among those with and without conditions, however, the scales also measure a broad set of perceptual processes and affective responses, which do not correspond to sensory function exclusively. The discriminatory power of the Dunn’s questionnaires is debatable given that, as Little et al. (2018) reported, conditions as ADHD and ASD may present similar sensory profile and only differ by the intensity or frequency of the behaviours exhibited in each condition. This issue raises the concern of how frequent or infrequent a behaviour must be in order to be considered outside the expected ranges, taking into account the age group and social and cultural particularities. There is also the issue of how such frequency is defined. While Dunn (Brown & Dunn, 2002; Dunn, 2014) provided cut off scores and a classification system to identify a response as above or below the norms, these ranges may be too broad, which demands rigorous procedures to safely classify an individual as having sensory issues. In addition, data from parents’ reports and self-reports of sensory processing have a limited validity due to possible bias and due to the lack of measures of actual behaviour and performance (Schoen, Miller, & Sullivan, 2014). These issues request a careful interpretation of the data by the researchers.

There is great variability in sensory processing behaviours across children with and without conditions (Engel-Yeger, 2008; Lane et al., 2014) and data show that 15% of the general population responds to sensory events differently than expected (Dunn, 2014). Sensory characteristics are individuals' stable traits (Dunn, 1997b) and are not necessarily associated with a diagnostic condition (Van Hulle, Schmidt, & Goldsmith, 2012). Thus, the sole manifestation of sensory issues in an individual cannot be an undeniable indicator of failures in this dimension, and a particular sensory profile does not unequivocally set up a definite diagnosis.

Unfortunately, there has been little research attempting to relate sensory profile research to underlying cognitive or cognitive neuroscience research. One recent study (Metz et al., 2019) studied the validity of the Dunn's four quadrant model by examining the variation of the scores of the adolescent/adult version (Brown & Dunn, 2002) with external measures (personality test and brain stimulation). Metz et al. (2019) failed to find linkage between Dunn's hypothetical threshold measure and event-related potentials, and so there is a need to probe the relationship between Dunn's well-established clinically relevant behavioural tests and established literacy and cognitive measures. Yet, Metz et al. research was done with healthy adults, thus it is not known whether its interpretations can extend to children or individuals with special needs. Therefore, since the sensory quadrants are described in terms of observed behaviours (Brown & Dunn, 2002; Dunn, 2014), and there is not a clear link with neurological functioning (Metz et al., 2019), Dunn's model reflects the behavioural modulation characteristics that a person may display over environmental and internal demands.

Moreover, Dunn's scales have been little used in theoretical approaches to developmental differences. It is likely that this occurs for two reasons: first, for researchers from an experimental psychology background, Dunn's approach appears to be counter to the major explanatory theoretical frameworks for any of the developmental disorders. If we consider dyslexia, the leading framework, phonological deficit (Liberman, 1971; Liberman et al., 1974), would suggest that there was a deficit (a high threshold) specifically within the phonological component of the auditory modality. The magnocellular deficit framework (Stein, 2001a) would suggest high threshold for magnocellular stimuli within the visual modality. The cerebellar deficit framework (Nicolson & Fawcett, 1999) might well be unique in suggesting weaknesses in vestibular proprioception. Averaging scores across modalities goes against the aim of identifying specific structures or capabilities involved.

The second major concern arises from the collapse of the six modalities of sensory data (the sensory systems) into the four quadrants, and their interpretation in terms of 'low, medium or high' on the (different) dimensions of threshold and self-regulation (Brown & Dunn, 2002; Dunn, 2014). If there are indeed only these two fundamental dimensions, it is logically impossible to get high scores on all four quadrants, but previous research appears to suggest that this may be the case. Putting it bluntly, it is not clear what theoretical justification there is for the conceptual leap between the analysis in terms of thresholds and self-regulation on six sensory modalities, to the four quadrants analysis. Nor is particularly clear to see how this data reduction helps with the development of support strategies.

3.4 Thesis scope and summary

The present thesis aims to explore the sensory processing characteristics of people with specific learning difficulties from childhood to adulthood. The empirical work presented in the following Chapters - 4 to 7 - describes the studies that were designed to examine the sensory profile of groups of children, adolescents and adults, as well as to test the possible association between these sensory features and learning skills. Chapter 8 contains a general discussion of the thesis, and the results of the empirical work are also contrasted with the literature review, providing further discussion of the issues presented above regarding Dunn's framework.

Chapter 8 also includes the theoretical contribution, limitations and practical implications of the principal findings.

A summary of the measures that were used in this thesis is presented below in table 3.5, as well as the studies that were designed to reach the research aims.

Table 3.5. Summary of the measures used along the thesis.

Measure name	Number of items	Completed by	How the measure contributed to answering the study aims
Study 1. Children sensory processing and literacy skills (7 to 11 years old)			
Child Sensory Profile, 2nd edition (CSP-2). Designed by Dunn, 2014 (Appendix A)	86	Parents	Provided a parental measures of the child's sensory processing characteristics regarding 6 sensory systems that account for 4 sensory quadrants.
Dyslexia screening test, Junior version, 2nd edition. Designed by Fawcett and Nicolson, 2004	6	Children	Provided information regarding the performance of children among a wide range of skills associated with reading difficulties.
Multi-sensory task. Designed by the researcher	3	Children	Provided information of the performance of children on a multisensory task that included visual, auditory, and balance stimuli.
Study 2. Sensory processing in adolescents and their association with academic skills (13 to 16 years old)			
Questionnaire. Designed by the researcher	8	Adolescents	Provided a characterisation of the participants regarding age, gender, academic qualifications and the presence of any learning problem.
Adolescent / Adult Sensory Profile (AASP). Designed by Brown and Dunn, 2002 (Appendix B).	60	Adolescents	Provided a measure of the adolescents' sensory processing characteristics regarding 6 sensory systems that account for 4 sensory quadrants.
Colorado Learning Difficulties Questionnaire (CLDQ), short version. Original designed by Willcutt et al., 2011; short version published by Patrick et al., 2013.	11	Adolescents	Provided information regarding learning difficulties in reading and maths.
Study 3A. Sensory processing in adults (18 to 64 years old)			
Questionnaire. Designed by the researcher	8	Adults	Provided a characterisation of the participants regarding age, gender, academic qualifications and the presence of any learning problem.
Adolescent / Adult Sensory Profile (AASP). Designed by Brown and Dunn, 2002.	60	Adults	Provided a measure of the adults' sensory processing characteristics regarding 6 sensory systems that account for 4 sensory quadrants.

Measure name	Number of items	Completed by	How the measure contributed to answering the study aims
Study 3B. Sensory processing in adults and their association with academic skills (18-56 years old)			
Questionnaire. Designed by the researcher	5	Adults	Provided a characterisation of the participants regarding age, gender, and academic qualifications.
Adolescent / Adult Sensory Profile (AASP). Registration scale. Designed by Brown and Dunn, 2002.	15	Adults	Provided a measure of the adults' sensory processing characteristics regarding the registration quadrant.
Adult Reading Questionnaire (ARQ). Designed by Snowling, Dawes, Nash, and Hulme, 2012.	15	Adults	Provided information of the participants regarding their reading, word finding, attention, and hyperactivity characteristics.
Reading task. Designed by the researcher based on the application Assess for Success of Nicolson, Fawcett & Jones, 2018.	54	Adults	Report of accuracy and time in reading a list of single words.
Study 4. Comparison of sensory processing profile of children with and without neurodevelopmental conditions (8 to 10 years old).			
Questionnaire. Designed by the researcher	8	Parents	Provided a characterisation of the children regarding age, gender, academic qualifications and the presence of any neurodevelopmental problem.
Child Sensory Profile, 2nd edition (CSP-2). Designed by Dunn, 2014	86	Parents	Provided a parental measures of the child's sensory processing characteristics regarding 6 sensory systems that account for 4 sensory quadrants.
Colorado Learning Difficulties Questionnaire (CLDQ), short version. Original designed by Willcutt et al., 2011; short version published by Patrick et al., 2013.	11	Parents	Provided information regarding learning difficulties in reading and maths.

CHAPTER 4

STUDY 1: CHILDREN´S SENSORY PROCESSING AND LITERACY SKILLS

4.1 Introduction

This chapter presents the first empirical study aimed at exploring the sensory processing profile of children that present learning difficulties. Through the assessment of children with three different measures, sensory processing profile questionnaire, literacy skills test, and a multisensory task, it aimed to draw a general picture of the abilities and deficits of the participants.

4.1.1 Children with specific learning difficulties.

Learning is a natural and ongoing process that continues throughout life. Specific academic subjects such as reading, writing and arithmetic are usually training in formal education. While it is expected that every child achieve those knowledge and abilities at different pace, some of them fail in an unexpected way in spite of experiencing the same conditions than their peers (Frank, 2014).

Reading disorders are the most prevalent learning difficulties, affecting 5-12% among school-age children (Peterson & Pennington, 2015). Kuppen and Goswami, (2016) analysed the trajectory of children with dyslexia concluding the presence of an atypical phonological awareness skill, and delay in rapid automatized naming and phonological short-term memory. In the same way, phonemic awareness demonstrated strong association with children's word reading skills, while variables like rime awareness and verbal short-term memory present weaker correlation (Melby-Lervåg et al., 2012).

Although the phonological difficulties theory as the main and common cause for reading disorders has robust evidence that support it, the frequent associated sensorimotor issues requires a wider approach able to encompass such variety of symptoms (Ramus, 2003). Therefore, theories like the magnocellular (Stein, 2001) and the auditory temporal processing (Tallal, 1980) (see Chapter 2, section 2.3.1 for further explanation) provide guidelines to explore the characteristics of children with learning difficulties across the board. However, the implications are still not clear and more studies on sensory processing is required to unveil its association with learning difficulties (Goswami, 2014).

4.1.2. Sensory processing of children with learning difficulties.

Sensory processing abilities have been widely studied in a range of neurodevelopmental conditions. For example, the underlying sensory problems in Autism Spectrum Disorders have been studied in both children and adults (Baker, Lane, Angley, & Young, 2008; Gonthier, Longuépée, & Bouvard, 2016; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011; Martínez-Sanchis, 2014; Tomchek, Huebner, & Dunn, 2014). There is also evidence of sensory processing differences in people with attention deficit and hyperactivity disorder (Dunn & Bennett, 2002; Panagiotidi et al., 2017b; Parush et al., 1997; Shimizu et al., 2014), and specific language disorders (McArthur & Bishop, 2005; Taal et al., 2013). In the case of specific reading disorder, also known as developmental dyslexia, phonological processing deficits are well established, and represent the leading theory (Liberman, 1971; Liberman et al., 1974). The phonological theory posits that reading and spelling difficulties result from impairments in the ability to identify or manipulate the component sounds in speech, called phonological awareness (Liberman, 1971; Liberman et al., 1974). Nonetheless, the underlying cause of the phonological problems remains unclear, and there are longstanding theories that claim that 'magnocellular' sensory problems are significantly involved (Stein, 2019).

The integration of auditory and visual sensory inputs has been noted as being relevant for the development of cognitive skills such as reading (e.g. Chen, Zhang, Ai, Xie, & Meng, 2016; Francisco, Jesse, Groen, & McQueen, 2017; Froyen, Van Atteveldt, Bonte, & Blomert, 2008; Froyen, Willems, & Blomert, 2011; Kronschnabel, Brem, Maurer, & Brandeis, 2014; Nash et al., 2017). It has been proposed that literacy acquisition requires the ability to create coherent associations between visual and auditory cues, or more specifically, to create an association between the script letters and the speech sound (Vellutino, Fletcher, Snowling, & Scanlon, 2004). A proficient reading process involves decoding these printed letters and their corresponding sounds into a meaningful percept, by effectively linking the visual and auditory cues (Blomert, 2011; Hulme & Snowling, 2013; Melby-Lervåg, Lyster, & Hulme, 2012). However, as discussed in Chapter 2 (section 2.4), children with reading deficiency have demonstrated difficulties linking auditory and visual sensory inputs (Dionne-Dostie et al., 2015; Fischer et al., 2000; Rose et al., 1999).

Differences in sensory processing - the ability to register and modulate sensory information and to organise this sensory input to respond to situational demands (Humphry, 2002) - have also been widely studied in the context of Occupational Therapy for children. In particular, Dunn's Model of Sensory Processing (Dunn, 1997b) has been extensively used in research as an instrument to depict the sensory processing profile of children (Baker et al., 2008; Cheung & Siu, 2009; Dove & Dunn, 2008; Engel-Yeger & Dunn, 2011; Kern et al., 2007; Lowe et al., 2016; Padankatti, 2005; Taal et al., 2013; White, Mulligan, Merrill, & Wright, 2007). Dunn's model (1997) posits that all of the senses, that is the senses of touch, smell, taste, sight and sound, as well as physical movement and body awareness, are expected to have a balanced response to enable the adequate and adaptive functioning of brain mechanisms. Dunn's (1997) framework is represented in a four-quadrant model that characterises the behaviours that people exhibit in their daily lives as a result of the interaction between two hypothetical constructs, neurological thresholds and self-regulation strategies. Dunn designed questionnaires for children and adults based on her model of sensory processing

(Brown & Dunn, 2002; Dunn, 1997, 2014). Those questionnaires provide a profile that characterises the sensory preferences of people to sensory stimulation (a detailed explanation of Dunn's framework can be found in Chapter 3). A 'misbalanced' sensory profile is interpreted as having problems in the modulation of the stimuli, and therefore failure to display responses that match the demands and expectations of the environment (Bundy et al., 2002).

In the present study, I investigated the sensory processing abilities of children who attend special educational needs programme, thus having a background of specific learning disorders, in particular, those related to reading problems. Although research has shown robust evidence of sensory issues in conditions such as ASD (Baker et al., 2008; Gonthier et al., 2016; Martinez-Sanchis, 2014; Tomchek et al., 2014), and ADHD (Dunn & Bennett, 2002; Parush et al., 1997). The studies of Dove and Dunn (2008) and Padankatti (2005) reported that children with learning difficulties presented a challenging profile of sensory processing, characterised by significant high scores in the quadrants of Seeking, Avoiding, and Registration. The present study incorporated an audio-visual task to test the performance of children in this multisensory setting. Nevertheless, the influence of sensory issues on learning disorders has been challenged by a strong emphasis in phonological theories demonstrating that more research is still needed.

As mentioned in Chapter 2 (see section 2.4) the evidence that children with learning disorders present failures in the integration of single (e.g. Fischer et al., 2000) and multiple (e.g. Laasonen et al., 2000) sensory information, together with a particular sensory processing profile (Dove & Dunn, 2008) as described above (section 2.4). However, there is a lack of evidence about the link between sensory profile research to underlying cognitive or cognitive neuroscience research, as shown in Metz et al., (2019). Hence, Study 1 explored the relationship between Dunn's sensory-related behaviours tests and established literacy and cognitive measures.

4.2 Design of the study.

4.2.1 Hypotheses

In accordance with the hypotheses discussed in Chapter 1, the main hypothesis of Study 1 was that children with learning difficulties would show significant differences in the sensory profile when compared with a group of children without LD. A secondary hypothesis of this study was that when comparing an audio-visual task, children with LD will show a poorer performance than children without LD. A third hypothesis was that literacy skills will present a significant association with the sensory processing profile and the performance in the audio-visual task of children.

The main hypothesis was based upon previous findings that referred differences in the sensory processing abilities of children with learning difficulties (Dove & Dunn, 2008; Dunn, 2014; Padankatti, 2005). Such studies have shown higher scores for children with LD compare to those without LD. However, due to the limited previous evidence, more research is needed to stablish the characteristics of such differences. The secondary hypothesis was based on literature that has demonstrated dysfunction in auditory and visual sensitivity in poor readers children (Rose et al., 1999; Tallal, 1980; Tallal et al., 1993). The third hypothesis was developed from the work of Stein (Stein, 2001a, 2001b) and the empirical studies presented in Chapter 2, section 2.4 that proposed a basic sensory involvement on phonological issues. Because sensory abilities are relevant for the cognitive development (see Chapter 2), linkages between the sensory domain and cognitive skills may be regarded for purposes of this study as potential indicators of an early identification of learning problems. Further details of the research that led to the rationale for the hypotheses of this study can be found in Chapter 2 and 3.

4.3. Methodology

4.3.1 Participants

Data collection was made through head-teachers and teachers of local primary schools. After the approval of the schools to help with the study, teachers were given envelopes with information sheet and consent forms for families of children in years 2 to 5 of primary that would be able to take part. Teachers were asked to send half of the envelopes to children from their regular classes, who did not receive any academic support and did not present learning difficulties, and half envelopes to children who participate to Special Educational Needs programme (SEN), with a special focus on those with reading difficulties. Two hundred invitations to take part in Study 1 were sent out. The return rate was of 13%. The final sample was composed by 26 children aged 7 to 11 years old (13 females), and their parents from two primary schools in Sheffield. Two groups were created based on the children selection criteria: children with specific learning difficulties (LD), composed by those who currently were receiving support from the SEN programme (15 students), and a typically achieving group (TA) of 11 students who were not receiving any academic support and nor having learning difficulties, as reported for their teachers. The Children and Families Act 2014 stipulates that children will be incorporated into SEN if they have a learning difficulty or disability, which means that these students will received additional or different educational or training provision (Part 3, sections 20-21 of the Act 2014, the website for the "UK Government Legislation," can be found at http://www.legislation.gov.uk). All children were given written parental consent to take part in the study.

Table 4.1 Characterisation of participants

Group	Learning characteristics	Age	Gender
Specific learning difficulties (LD) n = 15	Student who currently were receiving support from the SEN programme.	Range = 7-10 Mean = 8.18	Male = 5 Female = 6
Typically achieving group (TA) n = 11	Students who were not receiving any academic support and nor having learning difficulties.	Range = 7-11 Mean = 9.2	Male = 8 Female = 7

All the empirical studies from this thesis received ethical approval from the University Psychology Ethics Committee. To avoid unnecessary repetition, the first ethical application and its additional documentation (information sheet, consent form) is attached in Appendix C as an illustration.

4.3.2 Measures and procedures

The families who agreed to take part in the study were asked to complete the Child Sensory Profile-2 (Dunn, 2014) at home and then returned it to school to be collected by the researcher. Children were tested on the school premises. The children were given six tasks from the Dyslexia Screening test – Junior (Fawcett & Nicolson, 2004), and a multi-sensory task. The schools provided a quiet room for the testing, and full assessment was completed in about 30 minutes per child.

4.3.2.1 Dyslexia screening test, Junior 2nd edition (DST-J)

The DST-J was administrated in an individual one-test session during school-time. The DST-J (Fawcett & Nicolson, 2004) was designed to assess children between 6.6 and 11.6 years of age. The main objective of the test is to distinguish children who are at risk of reading failure (Fawcett & Nicolson, 2004). The DST-J can be administrated by school professionals and last about 30 minutes to be completed. It is also been used for research purposes showing to be a useful tool for assessing children (Fawcett, Nicolson, Moss, Nicolson, & Reason, 2001; Reynolds & Nicolson, 2007; Reynolds, Nicolson, & Hambly, 2003).

The DST-J comprises twelve subtests to cover different areas that have showed to be affected in reading disorders: literacy skills, phonological awareness, verbal memory, motor skills and balance, and memory retrieval fluency (Fawcett & Nicolson, 2004; Reynolds et al., 2003). The subtests organized by areas are:

i. Literacy skills. One-minute reading is a composite of single word reading accuracy and fluency; Nonsense passage reading, involves reading a paragraph mixing real words and pseudowords to test grapheme-phoneme knowledge; Two minutes spelling requires writing down words that are dictated in a accuracy and fluency way; One minute writing assess speed in coping a passage.

ii. Phonological awareness and verbal working memory. Phonemic segmentation is a measure of the ability to cut off parts of a dictated word; Backwards digit span involves the repetition of single digits presenting in a tape with increase number of elements (from two to eight); Rhyme the child is asked to identify whether two similar words (dictated) rhymes or not.

iii. Motor skills and balance. Bead threading is a simple task of threading as many beads as possible in 30 seconds; Postural stability measures the wobble of the child when pushed slowly in the back with a stability tester.

iv. Memory retrieval fluency. Rapid automatized naming assesses how quickly the child can name familiar pictures on a page; Semantic fluency ask the child how many animals can name in one minute.

The norms allow for converting each raw score per subtest into an ‘at risk index’, which organises the punctuation into five categories from very strong risk to above average (non-risk side) (Fawcett & Nicolson, 2004). Unpublished norm data provided by the author’s test and used in previous study (Reynolds et al., 2003), allows for deciles to be derived for each individual score regarding the age. Thus, deciles between 1 and 3 correspond to risk categories (1 = high risk, 2 moderate risk, 3 mild risk), and deciles over 4 correspond to normal or non-risk for having reading disabilities (Fawcett & Nicolson, 2004).

Six subtests of the DST-J second edition were used to assess specific-domain literacy skills. The tasks selected and the order of presentation were as follows:

(i) Rapid Naming: This is a test of general linguistic fluency. It involves the time taken to speak the names of pictures on a page full of common objects.

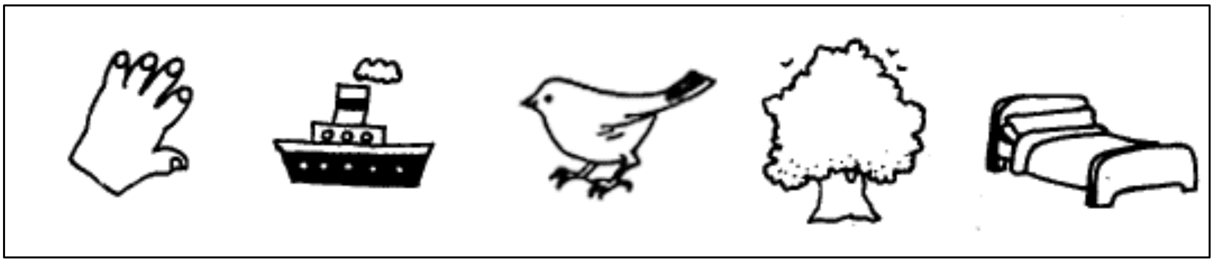

Figure 4.1 Rapid naming task, example of objects.

(ii) Bead threading: It measures fine motor skills. The test consists of seeing how many beads can be threaded in 30s.

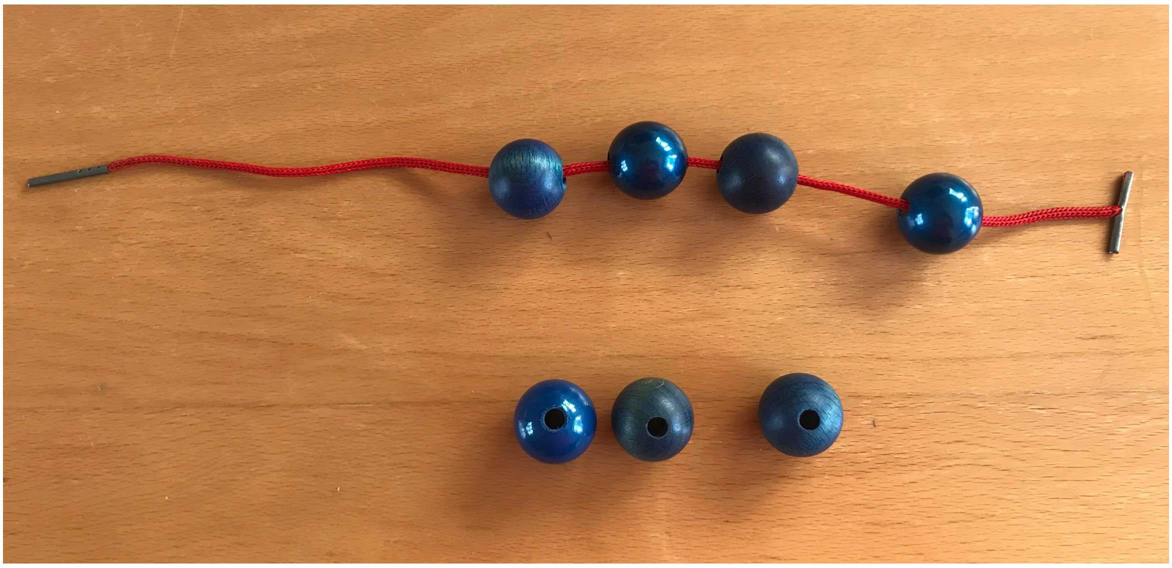

Figure 4.2 Bead threating example.

(iii) One-minute reading: Requires reading accuracy and fluency. The task measures the number of single words (in increasing difficulty) that can be read in one minute.

Example of words used during the practice.

cat	boat
ball	fox
hit	ship

(iv) Phonemic segmentation and Rhyming: Phonological awareness and verbal working memory. These tasks test the child's ability to play with the constituent sounds in words. In the phonemic segmentation task, the child is asked to repeat a word without a specific part of the same. The rhyming task consists of the child recognise whether two words rhymes or not.

Example of practice items of phonemic and rhyming tasks.

Phonemic segmentation	**Rhyming**
"Say football" "say it again, but without the ball"	cat bat cap mat

(v) Two minutes spelling: Literacy skill. This task assesses how many words the child can spell correctly in two minutes, while the tester dictates the words (in increasing difficulty). Examples of words from the practice section: bag, cow, pen.

4.3.2.2 Child Sensory Profile -2 (CSP-2)

The CSP-2 was explained in detail in Chapter 3, section 3.2.1. The questionnaire was used to collect information about the sensory processing profile of the participants. In the current study, the questionnaires in a paper format were completed by parents or carers of children who took part in the study.

4.3.2.3 Object Classification task

The Object classification task (OC) was designed by the author to test the influence of a multi-sensory setting on the performance of participants. The sensory modalities were visual and auditory stimuli. The core OC task was a simpler version of the Rapid Automatized Naming (RAN) task for classifying simple pictures. RAN tasks are a good measure of cognitive skills linked with literacy (Nicolson & Fawcett, 1994a; Nicolson et al., 2010; Tallal, 1980; Wolf & Bowers, 2000). RAN tasks consist of asking subjects to name a series of familiar items (letters, words, colours or objects) that are presented randomly as quickly as possible (Denckla & Rudel, 1976; Denckla & Rudel, 1974; Wolf, Bowers, & Biddle, 2000).

In Study 1, the OC task was displayed on an iPad (model MNV62B/A, 9 inches) placed in front of the participants during all of the trials, at an approximate distance of 35 cm from their eyes. The complete OC task was undertaken in two conditions of one minute each: the first condition was the visual OC test (uni-modal task), which involved timed classification of one of three types of object – cat, dog and tree - presented in a random order by the iPad. The pictures appeared in the centre of the iPad screen, and at the bottom, the three button-answers were shown (always in the same order: dog, cat, tree) organised in three parallel 4x4cm ‘buttons’.

The second condition was the audio-visual cross-modal OC task. This task was designed to probe sensory integration and sensory dissociation. It extended the unimodal OC tasks by presenting with the visual stimulus a sound associated with one of the target categories, creating a cross-modal situation. The sound appeared randomly at the same time as the picture, either as a non-conflict (e.g. an image of a dog and the sound of barking), or conflict (e.g. image of a dog and the sound of mewing) condition. For the picture of a tree, the accompanying sound was either mewing or barking. The sounds were played by the iPad’s speaker, which was set at the maximum volume. The performance on both conditions of the OC task was rated on accuracy (the percentage of correct responses) and speed (the mean response time for correct responses).

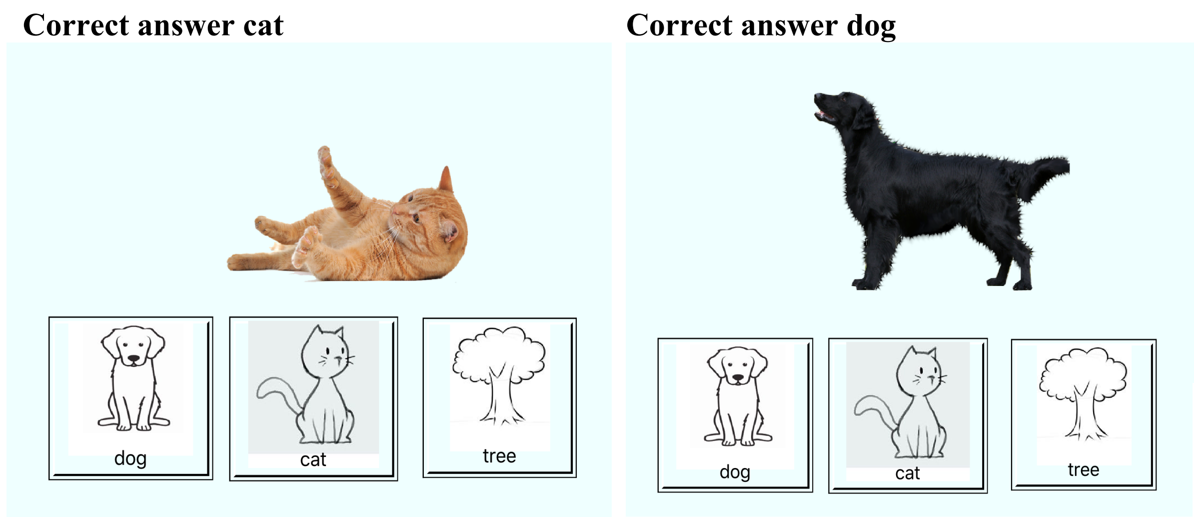

Figure 4.3 Object classification task example.

In addition to the main OC task, a vestibular component was included through a Nintendo ® Wii Balance Board (WBB). The WBB was a solid platform with a rough surface, which measure balance skills, that is, the ability to maintain the centre of gravity of the body within the base of support with minimal sway (Nichols, Glenn, & Hutchinson, 1995). The WBB had four sensors that stream information about the body-oscillation of participants along the medio-lateral centre of pressure (COPy) and anterior-posterior centre of pressure (COPx). The data was processed by a software, by merging the raw data into segments. Each segment represents the period during which the participant was standing over the WBB. The centre of pressure exerted by the feet over the surface of the WBB was streamed to computer software (Zing balance test) connected via Bluetooth, using a sampling frequency of 55 Hz (see specification of the WBB in figure 4.4).

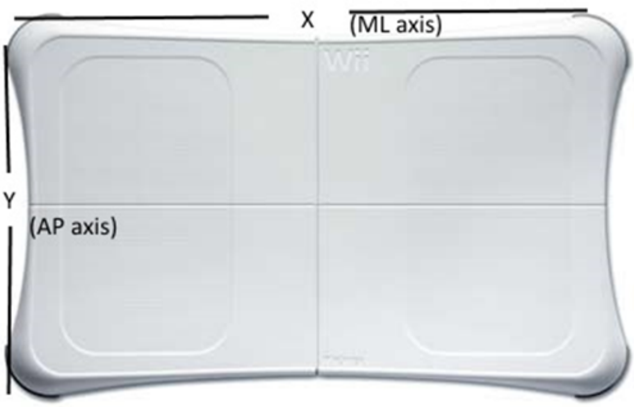

Figure 4.4 Surface of WII board. ML axis= medio-lateral, AP axis= anterior-posterior. Dimensions: height of 4cm, a width of 27cm and a length of 45cm.

In the current study, the WBB was used in a ‘single measure’: children stood on the WBB in five conditions; and ‘combined’ with the audio-visual task. This design was based on previous studies with WBB (Bower, McGinley, Miller, & Clark, 2014; Chang, Chang, Lee, & Feng, 2013; Clark et al., 2010; Huurnink, Fransz, Kingma, & van Dieën, 2013; Jeter et al., 2015; Larsen, Jørgensen, Junge, Juul-Kristensen, & Wedderkopp, 2014; Sgrò, Monteleone, Pavone, & Lipoma, 2014), and other force platforms (Bauer, Groger, Rupprecht, & Gabmann, 2008; Nichols et al., 1995; Salavati et al., 2009) that have shown a good validity of balance platforms for assessing balance skills. The procedure was as follows: participants were asked to remove their footwear and instructed to remain as stable as possible on the WBB in the following five conditions –single measures-: (i) open eyes two feet, one foot next to the other, feet separated by 15 cm approximately; (ii) open eyes right foot; (iii) closed eyes right foot; (iv) open eyes left foot; (v) closed eyes left foot. Then the WBB was used together with the Object Classification task –combined measure- in the open eyes two feet condition. The duration of each condition was 30 seconds. The whole task included six independent segments for each of the six conditions explained above. However, if during any of these conditions the child came off the platform, the computer would start a new segment. Figures 4.5, 4.6, and 4.7 provide more details of the WBB procedure and data recording.

WBB. Standing two feet together

WBB. Standing on right foot

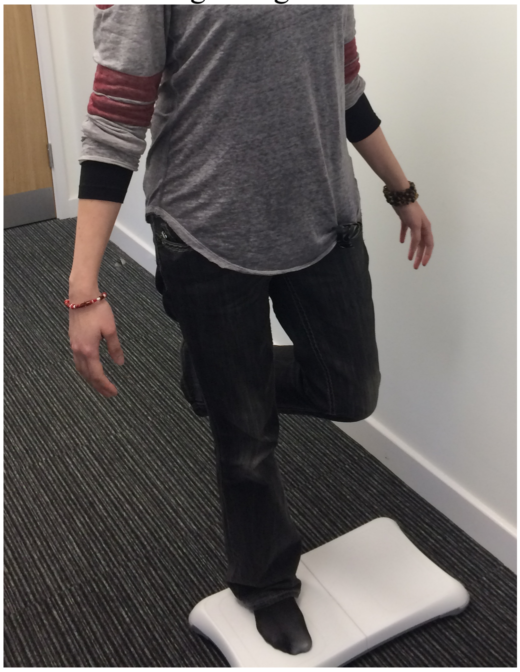

Figure 4.5 Example of position of participant on the WBB.

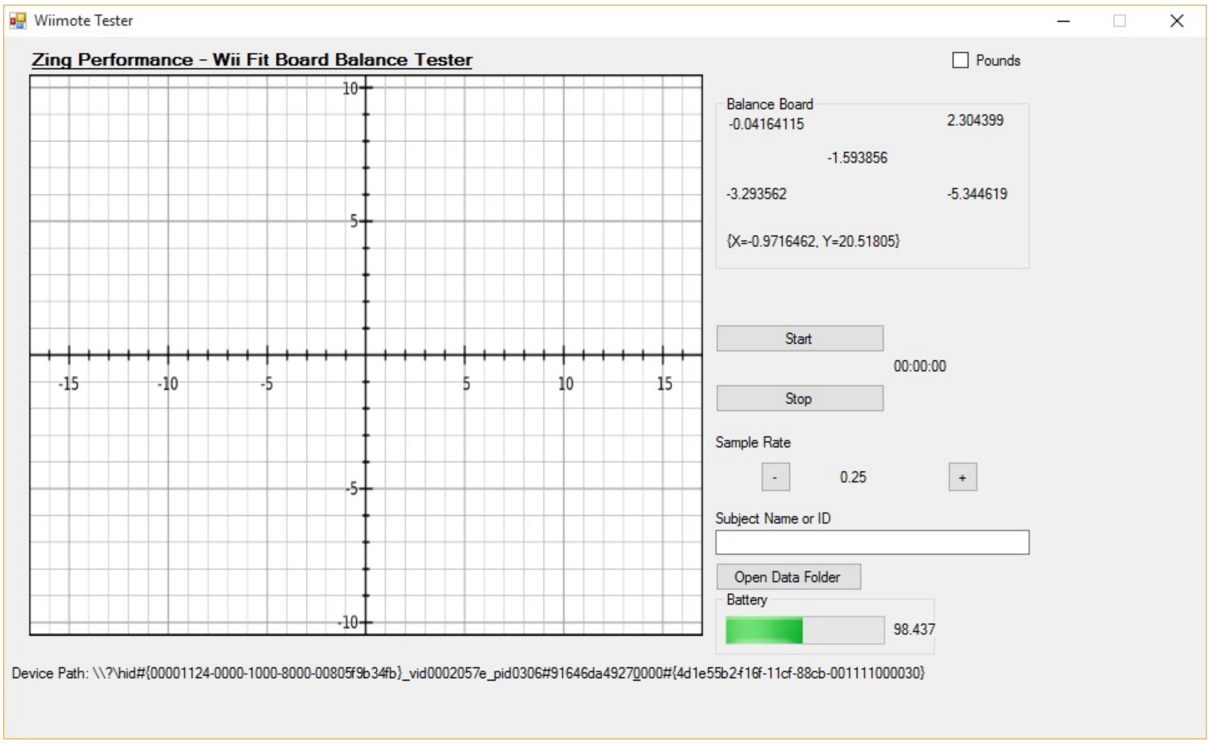

Figure 4.6 View of the WBB recording screen.

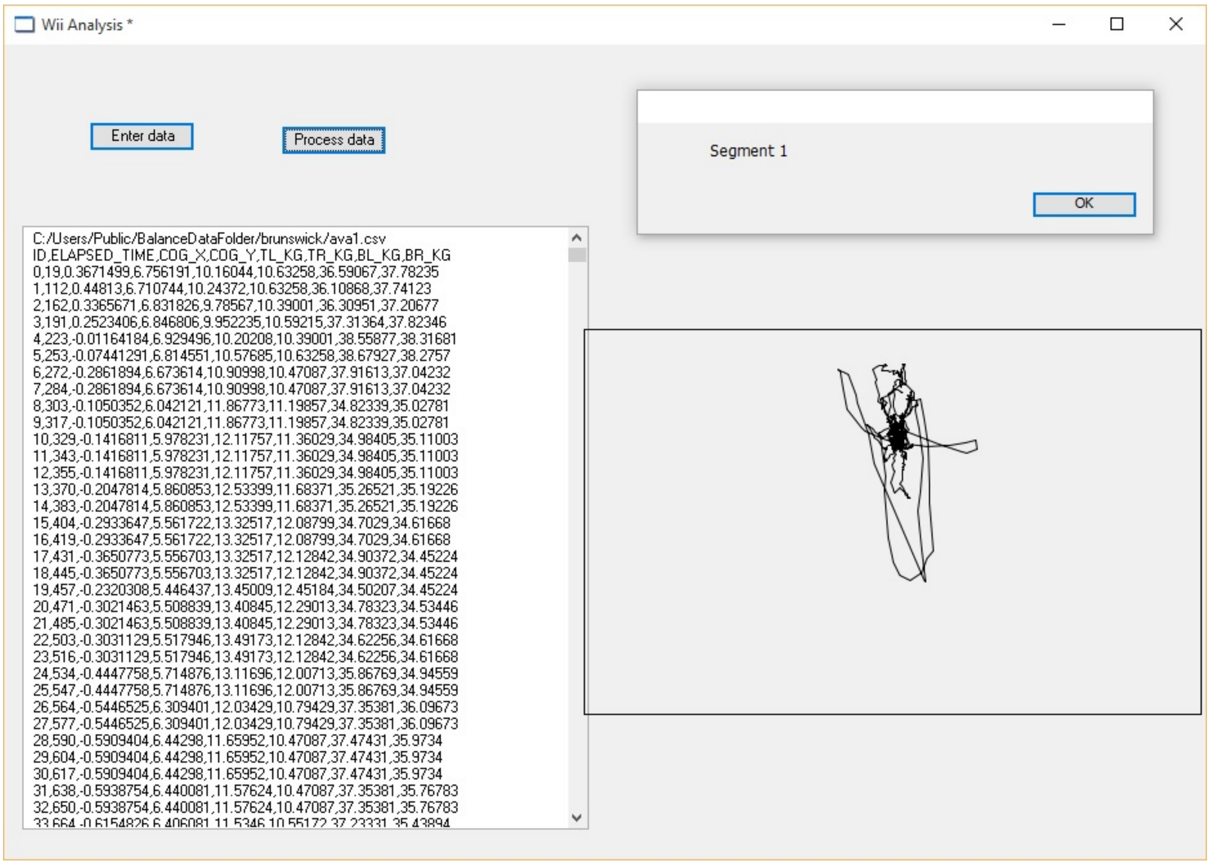

Figure 4.7. Example of the row data and segments of the WBB. The lines represent the trace of movement of the child over the WBB.

4.4 Results

4.4.1 Data check and descriptive statistics

The analysis was carried out using parametric or non-parametric tests as appropriate following examination of the response distributions. All statistical data analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp, 2016). In cases where age norms were not available, the data were screened for age effects, but none were found, and so age is not explicitly included as a factor in the analyses.

4.4.2 Literacy skills.

Performance on the DST-J sub-tasks (converted into age-normed decile scores) is shown in Figure 4.8. Cronbach's alphas for the DST-J was α =.716, which indicates an acceptable level of internal consistency for the scale with this specific sample. A Mann-

Whitney test showed significant differences between the groups in Reading (U = 18.5, p =.001), Rhymes (U = 42.0, p = .046) and Spelling (U = 16, p < .001). The TA group obtained significantly higher scores (i.e. better performance) than the group of children with SEN. No significant differences between the groups were found in the rapid naming, bead threading, and phonemic segmentation tasks.

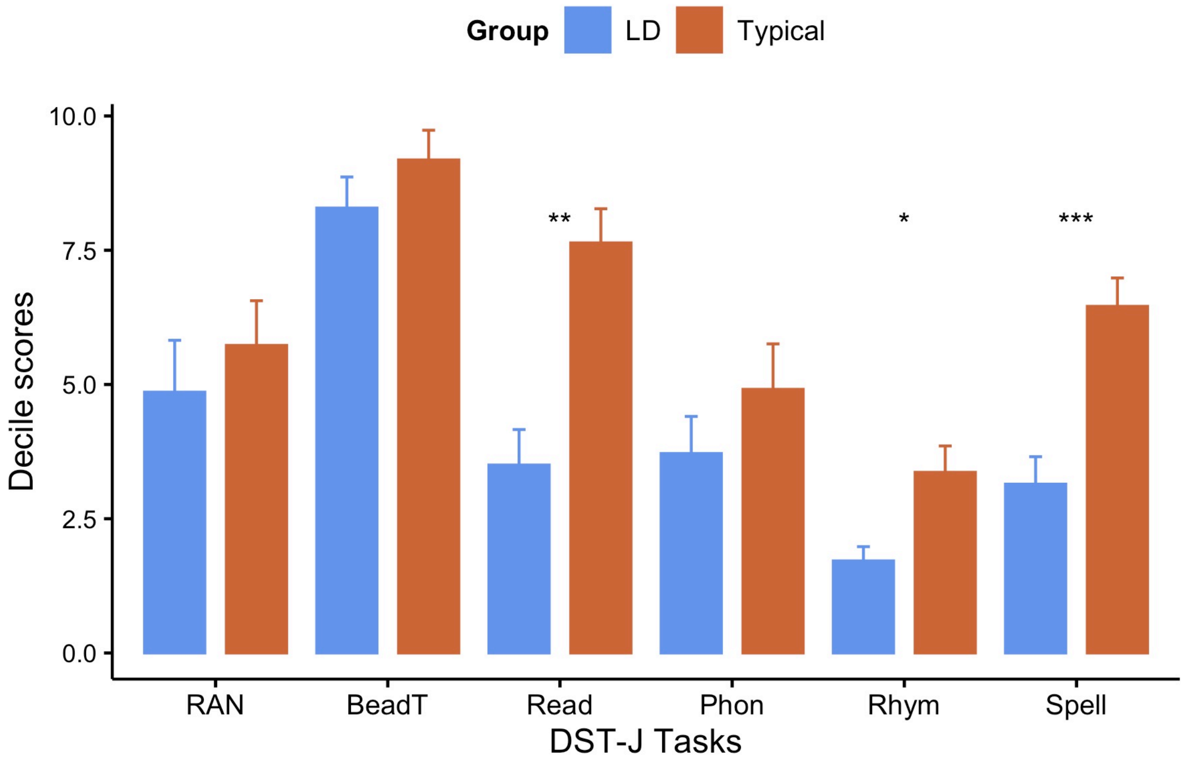

Figure 4.8 Dyslexia Screening test Junior. RAN, rapid naming; BEAD, bead threading; READ, reading; PHON, phonemic segmentation; RHYM, rhyming; SPELL, spelling. Typical: typically achieving; LD: learning difficulties. Significant differences between groups at ***< .001, **<.01, *<.05. Error bars represent standard error.

4.4.3 Sensory processing profile.

Cronbach's alphas for the CSP-2 consisted of 86 statements was α =.979, which indicates a high level of internal consistency for the scale with this specific sample.

4.4.3.1 Distribution of categorical scores along with the normative data.

CSP-2 data for each participant for each ‘quadrant’ were converted into an age-normed classification using Dunn’s CSP-2 norms (2014). Then the data was organized according to Dunn’s classification system of five categories. The graph below (Figure 4.9) showed that no child in the TA group provided a rating in the ‘More than Others’ category. By contrast, fewer children in the LD group had ratings in the ‘Less than Others’ category, with more (over 45%) in the ‘More than others’ category. Chi-square test of independence showed that there was significant association between group and the sensory profile classification for Registration X^2 (2) = 8.33, p = .040, and Avoiding X^2 (2) = 8.61, p = .035. LD children were more likely to show ‘More than others’ scores on those quadrants than the typical group.

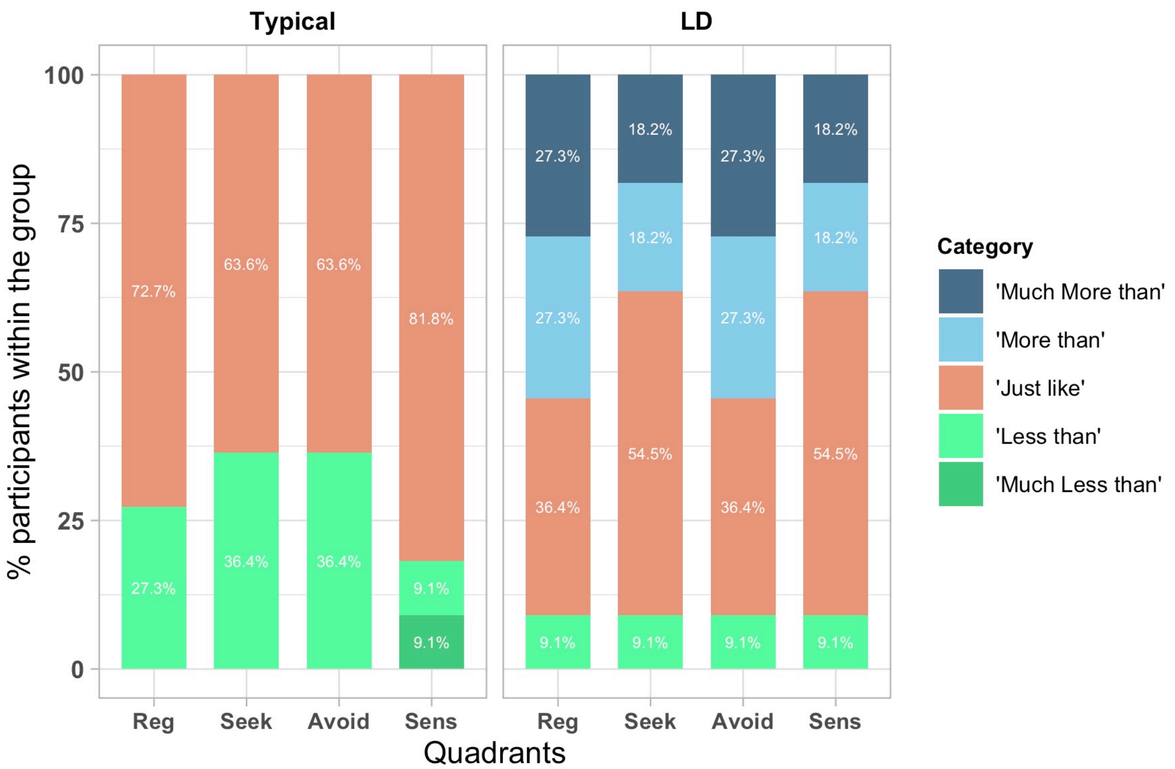

Figure 4.9 Representation of the groups on each of the four quadrants of Dunn’s model along the categorical ranges. Quadrants: Reg= Registration, Seek= Seeking, Avoid= Avoiding, Sens= Sensitivity.

4.4.3.2. Mean comparison between groups.

Mann-Whitney tests on the raw scores of the CSP-2 revealed significant between-group differences for the Registration, Avoiding and Sensitivity quadrants after Bonferroni correction at the level of $p<.0127$. Having compared with the Dunn's normative data (Dunn, 2014) Registration and Avoiding quadrants, but not the Sensitivity quadrant demonstrated 'clinical significance' according to Dunn's scoring procedure (with scores at least 1 SD above the mean).

The analysis of the sensory systems showed significant differences in auditory (U = 30.5, p= .028), movement (U = 54.5, p= .045), and body position (U = 19.0, p= .004). After Bonferroni correction at $p<.008$ level, only the sensory system of body position remains statistically significant, which also demonstrated 'clinical significance'. Statistical analyses and normative ranges are shown in table 4.2.

Table 4.2. Summary of the scores on the CSP-2 per groups

CSP-2	**TA Group** M (SD)	**SEN Group** M(SD)	**Norms** M(SD)	**Mann-Whitney** *p*	**Effect size** *d*
Sensory quadrants					
Registration	22.00 (8.98)	44.00 (17.81)	31.4 (11.7)	.004**	1.55
Seeking	22.45 (10.64)	38.27 (16.10)	35.9 (13.7)	.042*	1.15
Avoiding	23.36 (6.93)	48.27 (18.11)	33.9 (12.5)	.002**	1.81
Sensitivity	20.72 (8.22)	39.54 (20.18)	30.3 (11.0)	.006**	1.22
Sensory systems					
Auditory	11.91 (6.13)	22.00 (10.20)	17.7 (6.9)	.028*	1.19
Visual	8.91 (3.53)	11.83 (3.27)	13.6 (4.0)	.070	0.85
Touch	12.27 (7.32)	16.25 (10.13)	15.2 (6.9)	.477	0.45
Movement	7.82 (4.89)	14.83 (8.59)	13.7 (5.6)	.045*	1.00
Body Position	6.18 (4.14)	15.17 (8.40)	10.0 (4.5)	.004**	1.35
Oral	13.82 (9.91)	18.5 (14.00)	16.2 (7.4)	.518	0.38

Norms correspond to the mean raw score extracted from the CSP-2 user's manual (Dunn, 2014, page 219). Significant differences between groups at **<.01, *<.05. Effect size= Cohen's *d*.

4.4.4 Object classification task performance

Two type of scores were derived from the OC tasks: accuracy, which corresponded to the percentage of correct responses per trial; and reaction time, which was the average time of correct responses per trial in milliseconds.

Repeated measure ANOVA was used to test the influence of group and conditions for both measures accuracy and reaction time. Although the data of the accuracy scores had a non-normal distribution, parametric tests were chosen given that there was no non-parametric test available to assess interaction effect. Non-parametric tests provided equivalent findings for each condition.

4.4.4.1 OC Accuracy scores

A mixed 2x2 ANOVA was conducted with Group (TA, LD) as the between-subjects variable and Condition (visual, AV) as the within-subjects variable. With homogeneity of variance assumed (Levene´s test p>.05) there was a main effect of Condition of the multi-sensory OC task $F(1,22) = 6.19$, $p = .021$, $\eta_\rho^2 = .220$, but that of Group was not significant $F(1,22) = 3.72$, $p = .067$, $\eta_\rho^2 = .145$. There was a significant interaction effect between Condition and Group $F(2,44) = 8.30$, $p = .009$, $\eta_\rho^2 = .274$. This arose because in the AV condition, the LD group obtained a significantly lower percentage of correct responses (M = 88.39%, SD = 2.28) compared with the TA group (M = 97.24%, SD = 2.48, $p = 0.16$). By contrast both groups performed equivalently in the visual Condition. The results of the OC regarding accuracy scores are depicted in figure 4.10.

For the AV condition, the effect of conflict/non-conflict of the auditory stimulus were not significant (p>.05).

4.4.4.2 OC reaction time scores.

For the OC reaction time data, an equivalent mixed 2x2 ANOVA was also undertaken, with group (TA, LD) as the between-subjects variable and the two sensory conditions (visual, AV) as the within-subjects variable. With homogeneity of variance assumed (Levene´s test $p>.05$), there was a main effect of Condition on the reaction time of participants $F(1,22) = 46.06$, $p < .001$, $\eta_\rho^2 = .677$, due to the participants being slower in the AV condition (M = 1573.33 msec., SD = 45.3) than the visual only condition (M = 1323.40 msec., SD = 17.04). The Group variable did not show an effect on the reaction time $F(1,22) = 3.93$, $p = .060$, $\eta_\rho^2 = .152$. The interaction between the Group and Condition was also significant $F(1,22) = 5.36$, $p = .030$, $\eta_\rho^2 = .196$. Pairwise comparisons revealed that the significant effect was because the LD group was slower than the control group in the AV condition (mean difference = 199.94, $p = 0.38$). In addition, the interaction between conflict/non-conflict auditory stimulus on the AV condition and group variable showed a significant effect $F(1,22) = 6.76$, $p = .016$, $\eta_\rho^2 = .235$. The pairwise comparison showed that the interaction effect was due to the LD group (M = 1758.7 ms., SD = 71.2) being significantly slower on the conflict condition than the TA group (M = 1684.3 ms., SD = 70.4). Figure 4.10 depicts the reaction time scores on the OC.

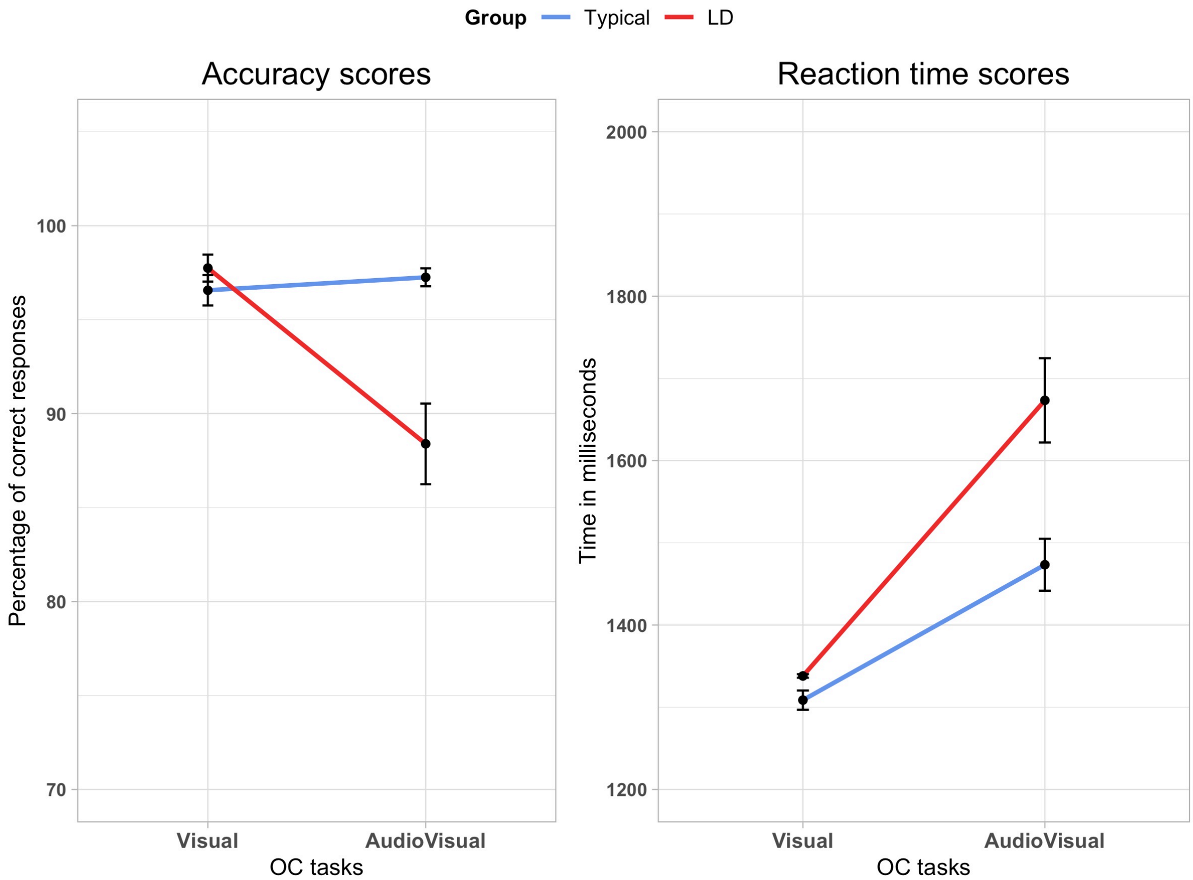

Figure 4.10 Line plots show the averaged Accuracy and Reaction time scores by both Visual and Audio-visual conditions. TA: Typically achieving; LD: Learning Difficulties. Error bars represent standard error.

4.4.4.3 Balance performance on the Wii Board

The WBB data were processed before the main statistical analyses following procedures from previous studies (Clark et al., 2010; Deans, 2011; Huurnink et al., 2013; Jeter et al., 2015). To summarize and standardize the scores, the standard deviation of axes x (COPx) and y (COPy) were weighted to obtain one average measure of the centre of pressure (COP) measurement. The average measure was determined as the distance between the weighted standard deviation of both axis x and axis y for each condition. The resulting scores represented the estimated sway of the participants over the WBB in the five conditions (open eyes two feet, open/closed eyes right foot, and open/closed eyes left foot).

Most of the participants obtained one segment for each of the five conditions; however, some participants tended to fall down from the WBB during the testing phase, creating several segments per condition. This situation seemed to be associated with the behaviour of children who were very excited over the WBB, they wanted to jump and move all the time despite the instructions of stand as still as possible. Thus, the COP data that represented the estimated sway over the WBB were extremely noisy and did not reveal between-group differences for any of the balance measures (F's < 1.6, p's > .31). See table 4.3 with details of the results.

Table 4.3 Distribution scores of the Balance task at the Wii Board per group

WBB Conditions	**TA Group**	**SEN Group**	**Mann-Whitney**	**Effect size**
Single measures	Mean (SD)	Mean (SD)	*U* / *p*	*d*
Open eyes double feet	1.30 (1.01)	1.70 (.97)	44.0 / .111	.403
Right foot	1.43 (.67)	1.84 (1.13)	51.0 / .379	.441
Left foot	1.35 (.52)	1.64 (.82)	56.0 / .392	.422
Closed eyes right foot	3.18 (2.33)	3.26 (1.56)	47.0 / .418	.040
Closed eyes left foot	3.41 (1.39)	3.61 (1.43)	66.0 / .776	.141
Double feet combined	1.90 (1.67)	2.97 (2.22)	48.0 / .268	0.544

Data correspond to CoP calculated as (SQRT((SDx^2)+(SDy^2))). Effect size= Cohen's *d*.

A Wilcoxon rank test was run to test for differences among the conditions separated by group. As expected, the results showed significant differences between the open eyes conditions and the blind conditions for both right and left feet (see paired test in Figure 4.11). However, these results were not relevant to the hypotheses of the present study.

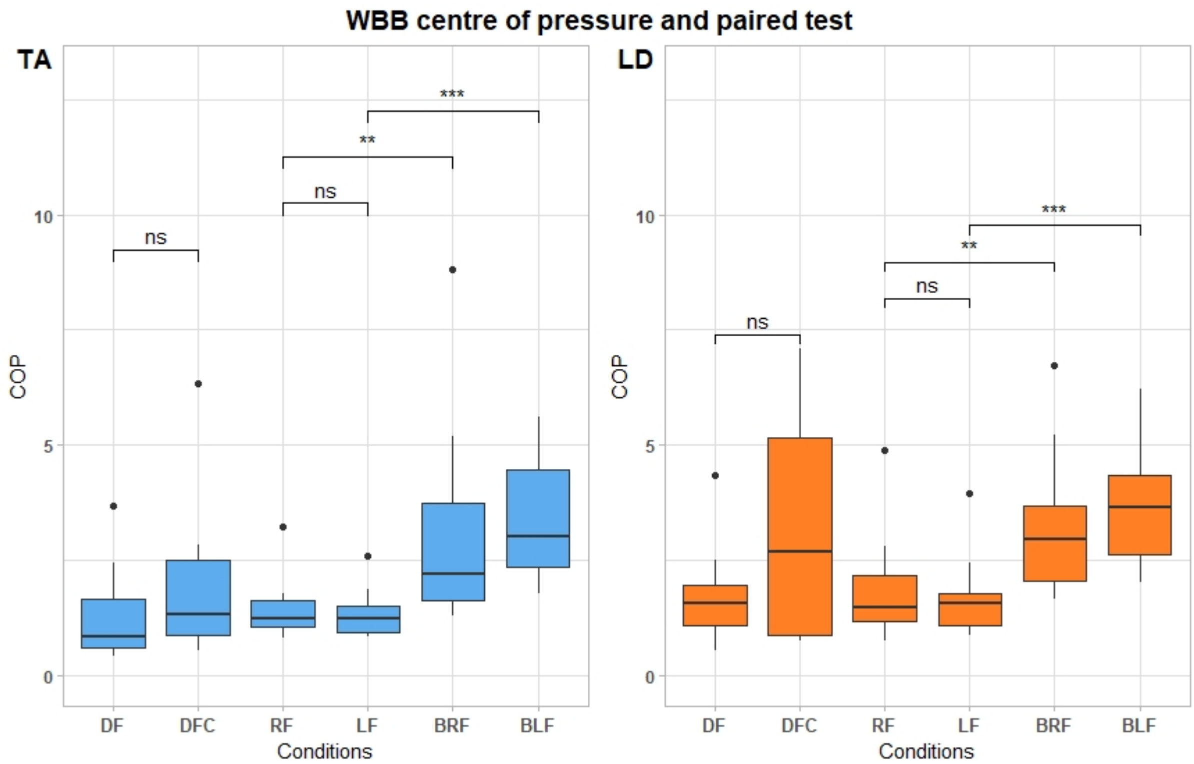

Figure 4.11. Boxplots of the centre of pressure (COP) over the WBB by group: Typically achieving (TA), and Learning difficulties (LD); and conditions: DF= open eyes double feet, DFC= open eyes two feet during the AV task, RF= open eyes right foot, LF= open eyes left foot, BRF= closed eyes right foot, BLF= closed eyes left foot. Significance was assessed with paired-Wilcoxon Test, significant levels at ***p<.001, **p< .01, *p< 0.05, ns>.05.

4.4.5 Association between literacy tasks, and sensory measures.

A Spearman correlation test was used to assess the relationship among literacy skills (DST-J), the performance on the OC task, and the scores of the sensory processing profile (CSP-2). All of these correlations were adjusted for multiple comparisons with Bonferroni (p value of 0.05 divided by the number of correlations).

For DST-J and OC there were some significant correlations among the scores, however, after Bonferroni correction, only the correlation between the accuracy score in the audio-visual condition of the OC task and the Spelling task were significant (see Table 4.4).

Table 4.4 Correlations between DST-J and OC task

	RAN	Bead T.	Reading	Phonemic	Rhymes	Spelling
OCV1	.567*	-.389	.080	.257	.112	.089
OCV2	-.231	.164	-.389	-.093	-.291	-.527*
OCAV1	.165	.059	.419*	.270	.444*	.671**
OCAV2	-.472	.088	-.505*	-.118	-.228	-.525*

DST-J: Dyslexia screening test; **OC**: Object classification task, OCV: Object classification visual only, OCAV: object classification audiovisual, 1: accuracy scores, 2: reaction time scores. Correlation significant at *p<.05; Bonferroni corrected at **p <.002

For DST-J and CSP-2 there were no significant correlations after the Bonferroni correction (see Table 4.5). These findings showed that there was no association between the literacy skills measures in the DST-J and the sensory processing profile.

Table 4.5 Correlations between DST-J and CSP-2 scores

	RAN	Bead T.	Reading	Phonemic	Rhymes	Spelling
CSP-2 Quadrants						
Registration	-.195	-.183	-.0351	-.319	-.131	-.232
Seeking	.021	-.075	-.070	-.350	-.073	-.254
Avoiding	-.209	-.079	-.459*	-.278	-.139	-.385
Sensitivity	-.123	-.057	-.218	-.287	-.239	-.283
CSP-2 Sensory systems						
Auditory	-.081	.093	-.161	-.078	-.437*	-.245
Visual	-.174	-.234	-.192	-.136	-.027	-.191
Touch	.009	.086	.061	-.035	-.073	.028
Movement	.005	-.007	-.079	-.274	-.077	-.263
Body posit.	-.208	-.324	-.422	-.154	.050	-.213
Oral	-.068	0	.014	-.344	-.008	-.172

DST-J: Dyslexia screening test; **CSP-2**: Child sensory profile-2. Correlation significant at *p<.05; Bonferroni corrected at **p <.0008

The analyses between the OC and CSP-2 measures showed significant negative correlations between the accuracy scores in the audio-visual condition and all the four sensory quadrants and the auditory and movement sensory systems (see Table 4.6). Nevertheless, after Bonferroni correction, the association with the Seeking quadrant was the only one that remained significant.

Table 4.6 Correlations between OC task and CSP-2 scores

	OCV1	OCV2	OCAV1	OCAV2
CSP-2 Quadrants				
Registration	-.014	-.249	-.575*	.139
Seeking	-.204	-.074	-.672**	.020
Avoiding	-.213	-.017	-.641*	.346
Sensitivity	-.066	-.228	-.636*	.111
CSP-2 Sensory systems				
Auditory	-.061	.149	-.542*	.123
Visual	-.071	-.207	-.317	-.106
Touch	-.107	-.296	-.346	-.013
Movement	-.113	-.083	-.579*	.017
Body position	.060	-.354	-.316	.023
Oral	-.378	-.169	-.404	.034

OC: Object classification task, OCV: Object classification visual only, OCAV: object classification audiovisual, 1: accuracy scores, 2: reaction time scores; **CSP-2**: Child sensory profile-2. Correlation significant at *p<.05; Bonferroni corrected at **p <.001

4.5 Discussion

Study 1 was designed to gather data on sensory processing in children with LD and to relate these findings to more traditional cognitive performance tests. The tests used were 6 subtests of the DST-J (Fawcett & Nicolson, 2004), the sensory profile questionnaire (Dunn, 2014), and a custom-designed object classification task to assess sensorimotor integration and dissociation.

On the DST-J, as expected, there were significant and substantial between-group differences on the literacy measures for Reading, Spelling and Rhyme, where the LD group obtained lower scores. Performance on Bead Threading, Rapid Naming and Phonological Processing were also lower, but not significantly so, for the LD group.

For the Sensory Processing Profile data, the LD group ratings were higher on all four quadrants, with significantly higher ratings for Registration, Avoiding, and Sensitivity, but only Registration and Avoiding reached Dunn's criterion for clinical significance (Dunn, 2014). For the sensory system ratings, the LD group had markedly higher ratings on Auditory, Movement and Body Position, but only the latter was still significant after the Bonferroni correction.

For the Object-Classification task, no between-group difference was found for the Visual-only condition. However, a significant interaction was found both for the accuracy and the response speed data. The LD group were markedly impaired on both speed and accuracy for the AV conflict condition, whereas the TA group showed only modest decrements.

The correlational analyses revealed few significant correlations among the OC task with DST-J and CSP-2 scores. No significant correlation was found between the DST-J and the CSP-2 scores.

4.5.1 Differences in the sensory processing profile between children with and without LD

The analysis of the CSP-2 showed differences in three quadrants, and the body position sensory system when compared children with and without LD associated with reading problems.

The high scores for the LD group on the CSP-2 ratings were consistent with previous studies (Dove & Dunn, 2008; Padankatti, 2005) that compared children with learning disorders with typically learning children. The manual of the CSP-2 (Dunn, 2014, pp. 47-55) states that high scores on Registration indicates that the child 'may miss sensory input needed for participation'; while high scores on Sensitivity indicate that the child 'may be so distracted by sensory input that it interferes with participation'; and high scores on Avoiding indicate that the child 'may become overwhelmed to stimuli, thus actively would try to avoid them'.

The results from Study 1 (in common with results of earlier studies like Metz et al., 2019) appear to present a challenge to Dunn's (1997) neurological threshold / self-regulation framework in that the LD group ratings were markedly higher on three quadrants whereas Dunn suggested that high scores on Registration, Sensitivity, and Avoiding represent high threshold

– passive self-regulation; high threshold – passive self-regulation; low threshold – active self-regulation; and low threshold - respectively, and so it appears not be logically possible to have high scores on opposite thresholds. Nevertheless, Dunn's neurological threshold / self-regulation framework (Dunn, 1997b) proposed that these apparently inconsistent quadrants can coexist in the same child, which showed much variability and individual differences within the LD children.

In terms of the Sensory Processing Profile, the major between-group difference was for Body Position, an index of proprioceptive sensitivity with representative probes being "Seems to have weak muscles", "Walks loudly as if feet are heavy". Movement Processing (e.g., "Loses balance unexpectedly when walking on an uneven surface", "Bumps into things, failing to notice objects or people in the way") and Auditory Processing (e.g., "Is distracted when there is a lot of noise around", "Tunes me out or seems to ignore me") also approached significance.

The Body Position index appears to be closely aligned with cerebellar function, in that low muscle tone and sub-optimal motor coordination are its classic signs (Holmes, 1939) as are the two Movement Processing questions noted here. The Auditory Processing questions appear contradictory, indicating both higher and lower thresholds, analogous to the present findings with the sensory quadrants.

4.5.2 Correlation between literacy skills and sensory measures

Contrary to expectations, the correlation analyses showed few associations between the literacy tasks and the sensory measures in both OC task and CSP-2 questionnaire. For the CSP-2 and the DST-J subtests, the results did not support the hypotheses that literacy skills were associated with the sensory processing profile of children. The few correlations observed did not meet the significance criterion after corrected with Bonferroni. It may be the case that the sensory profile reflects characteristics of children that have a particular development path and does not express a mutual relationship with literacy skills. Previous researchers (Cheung & Siu, 2009; Dove & Dunn, 2008; Taal et al., 2013) have not looked for correlations between these variables, but have looked instead for mean differences, which were also found in the present study. Thus, these findings do not necessarily preclude the proposed link between the sensory domain and cognitive skills (Dionne-Dostie et al., 2015; Stein, 2001b) since there was a correlation when testing for association between audio-visual performance task and literacy skills.

Concerning the results of the OC audio-visual task, there was a correlation with the Spelling subtest of the DST-J, and the Seeking quadrant of the CSP-2 questionnaire. These significant correlations suggest that the OC-AV task may tap an important underpinning skill for literacy. Consistent with the literature that the integration of auditory and visual sensory inputs are relevant for the development of cognitive skills like reading (Chen, Zhang, Ai, Xie, & Meng, 2016; Francisco, Jesse, Groen, & McQueen, 2017; Froyen, Van Atteveldt, Bonte, & Blomert, 2008; Froyen, Willems, & Blomert, 2011; Kronschnabel, Brem, Maurer, & Brandeis, 2014; Nash et al., 2017) the present findings indicate that the inclusion of the auditory-visual conflict does represent an important dimension of the processes of learning to read.

All the correlations had the significance p-value adjusted with the Bonferroni method. While this is a common approach in research, this method can lead to underestimation of the results, such as Type II errors (Cabin & Mitchell, 1999; Perneger, 1998).

4.5.3 Significant effect of audio-visual condition in the performance of children with LD

The data indicate that the LD group were less efficient at filtering out stimuli on a 'to-be-ignored' dimension, which is consistent with the "is distracted by noise" question of the Auditory sensory system (see section 4.5.2). By contrast, the TA group were able to filter out the conflicting auditory stimuli with little decrement to accuracy or speed. These results indicate that the TA group had an effective sensory filtering system and were, therefore, able to undertake the task 'automatically', but the LD group did not, and consequently had to undertake 'controlled processing' (Shiffrin & Schneider, 1977) to complete the task. The Automatization Deficit Hypothesis (Nicolson & Fawcett, 1990; Nicolson et al., 2010) may explain these results by suggesting that children with reading difficulties need to consciously lead their attention to compensate even in routine tasks that should be done without having to think or concentrate consciously. Problems in the automatization of skills reflect an involvement of cerebellar function as suggested by Nicolson and colleagues (Fawcett & Nicolson, 2008; Nicolson & Fawcett, 2011), but further research is needed to test this link.

One limitation of Study 1 was the small sample size both for TA and for LD children, compounded by the relatively wide age range involved. This limited the generality of the results obtained and highlighted the need for further attempted replications. It should be stressed, however, that the samples taken were the full set of those children (and parents) who agreed to participate using the ethics participation request, and those children were representative of the schools involved. A secondary limitation was that there was no information provided by the schools about the LD participants, except that they were in their SEN support systems. Indeed, the schools themselves had no externally validated diagnostic information available owing to the lengthy nature of SEN diagnosis in UK schools. The LD children might be diagnosable with any (or several) of a range of specific learning difficulties from dyslexia to ADHD to Language Disorder to Autism Spectrum Disorder. The robust nature of the differences found, especially given the relatively low numbers involved, is therefore noteworthy, and highlighted the value of avoiding premature specificity in participant selection given the major overlap between the symptoms of many learning disorders (Gilger & Kaplan, 2001; Kadesjo & Gillberg, 2001; Landerl & Moll, 2010; Nicolson & Fawcett, 2007). It should be acknowledged that the key measure of sensory profile is based on a parent-report questionnaire and therefore limited in this respect to their precision in identifying sensory deficits of their children (Leavett et al., 2014; Reid, 2009).

In summary, the assessment of the performance of children with LD on sensory profile questionnaires revealed highly significant differences in ‘behavioural sensory threshold’, especially for ‘Body Position’. Furthermore, performance on the newly developed Object Classification test revealed that the children with LD had impaired ability to filter out the auditory channel when undertaking a visual task. The results were interpreted in terms of impaired automatic sensory selection ability, leading to the need to consciously compensate to achieve adequate performance. This dual process explanation also provided a coherent explanation for the sensory profile findings. While the number of participants in this study was small, the use of the OC test can prove a fruitful methodology both for theoretical and applied approaches to understanding and supporting children with Special Educational Needs.

CHAPTER 5

STUDY 2: SENSORY PROCESSING IN ADOLESCENTS AND THEIR ASSOCIATION WITH ACADEMIC SKILLS.

5.1 Introduction

Study 1 was focused on primary children and provided insights regarding the impact of learning difficulties on their sensory processing abilities; the results of Study 1 showed a clear atypical sensory profile in children with LD compared to a group of typical learners. Given that sensory skills evolve across development, Study 2 examined the sensory processing profile in the next developmental stage, i.e. during adolescence.

The available studies about sensory processing in people under 18 are mainly focused on young children or they do not even distinguish between children and adolescents, providing general results of samples with participants from different age groups (e.g. Ausderau et al., 2014; Johnson-Ecker & Parham, 2000; Little, Dean, Tomchek, & Dunn, 2016; Padankatti, 2005). Therefore, information about the sensory profile on this precise developmental stage, the adolescence, may unveil relevant characteristics.

To explore how sensory processing is related to academic skills in adolescents with learning difficulties, Study 2 incorporated the assessment of the sensory processing profile through Dunn's model (Dunn, 1997) compared to the academic skills measured by the Colorado learning difficulties questionnaire, CLDQ (Willcutt et al., 2011). It was expected that differences would be found in the sensory profiles of students with and without learning difficulties. It was also expected that an association would be found between the sensory profile and the CLDQ scores.

5.1.1 Characteristics of the adolescence period.

Adolescence is the period before to adulthood with a recognizable starting point, puberty, but a more diffuse end, which is often associated with the attainment of personal independence (Fuhrmann, Knoll, & Blakemore, 2015). Recent studies (Fuhrmann et al., 2015; Larsen & Luna, 2018; Spear, 2000) have suggested that adolescence is a critical period for the maturation and plasticity of the nervous system, with particular characteristics that differ from the child and adult brain, which in turn highlights its importance in the developmental trajectory.

As people with typical development grow up, we expect to observe physical and cognitive changes, along with achieving new skills and engagement in more challenging activities (Herbert, 2003). In the same way that these developmental changes are expected, changes in their sensory processing characteristics are likely to occur (Ayres, 2005). Fuhrmann, Knoll, and Blakemore (2015) stated that the nervous system and the observed behaviour of adolescents are highly affected by sensory information, and accordingly, studies that examine the sensory needs at this stage and that compare sensory characteristics across children, adolescents, and adults would contribute with more insights on the field.

The transition from childhood to adolescence, and later to adulthood involves an enhancement of the nervous system's functioning, resulting in improvements in higher-order cognitive skills (Larsen & Luna, 2018). Taking into account individual differences in brain development, the enhancement of cognitive skills is due in part to an increase in the cortical white matter of the brain (Foulkes & Blakemore, 2018). Sensory abilities are experience-dependent, meaning that the more opportunities there are to interact with a multi-sensory environment and the more chances there are to react and receive feedback will all lead to the enhancement of the behaviour repertoire (Nardini, Dekker, & Petrini, 2014; Wallace & Stevenson, 2014). For instance, the ability to integrate stimuli coming from different sensory modalities is perfectible at about 8-10 years of age and continues to mature during the next years (Ernst, 2008; Gori et al., 2008; Hillock et al., 2011; Mamassian, 2015; Nardini et al., 2016; Robinson & Sloutsky, 2010). On the other hand, Engel-Yeger, Hus, & Rosenblum, (2012) reported a degenerative process in sensory processing abilities due to ageing. Pohl, Dunn, and Brown, (2003) observed a declined in sensory perception at 65 years old. Therefore, the enhancement of sensory skills may suffer a drop after reaching the peak of ability. Hence, adolescence is a special period of transition in the neurological maturation, where the nervous system has reached almost complete development that will continue to be enhanced (Spear, 2000).

Despite the importance of the adolescence period and the clear differences with younger children, there is a paucity of research on its sensory characteristics. Some of the few studies available (Mallau, Vaugoyeau, & Assaiante, 2010) have shown significant differences in the quality of the sensory abilities among children and adolescents. Padankatti (2005) conducted a study on children aged 5-12 years old with and without learning difficulties and found a different performance in terms of the sensory profile between younger and older children, mainly concerning to sensation seeking behaviours. Dahl (2004) and Spear (2000) found a trend of teenagers taking risks and experiencing highly intense emotions. While these behaviours may be normative and have a positive impact on the transition to adulthood, they can create vulnerability in the young as well.

Adolescence has been described as an emotionally intense epoch characterised by an increase in risk-taking, an emergence of psychiatric disorders, and a high rate of morbidity and mortality (Dahl, 2004; Spear, 2000). Depression has been associated with problems in the school performance in reading and writing, and general difficulties in concentration in adolescents (Frojd et al., 2008). Eissa, (2016) studied behavioural and emotional problems in adolescents (aged 12-18) with dyslexia. The results of Eissa revealed a negative effect of dyslexia on the self-esteem of adolescents along with emotional symptoms such as anxiety and depression. Similarly, Willcutt and Pennington, (2000) observed a significant association between reading disorders and psychiatric comorbidity in children aged 8 to 19 years old. The presence of reading and math problems in adolescents increase the likelihood of emotional and behavioural disorders and a sense of inadequacy (a measure of immature and odd behaviours) (Martinez & Semrud-Clikeman, 2004). In addition, there has been reported (Svetaz, Ireland, & Blum, 2000) that adolescents with learning disorders are two times more likely to present risk of emotional distress and attempting suicide than their typically learning peers; more risk-taking behaviours like early sexual experiences, fighting and bullying (Palfiova et al., 2016); and affective and anxiety disorders (Daniel, Erkanli, Nutter, Hickman, & Palmes, 2007).

5.1.2 Learning difficulties in adolescents

Regarding cognitive achievements, adolescence involves a significant enhancement of complex cognitive skills, like those associated with executive functions, and a gradual increment of cognitive control (Larsen & Luna, 2018). The 5th Edition of the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013) stated that adolescents who present specific learning difficulties may be able to compensate for some of those learning difficulties, however reading will remain slow and effortful, which will affect reading comprehension. Also, spelling mistakes are common on adolescents, and the difficulties extend to maths and problems solving (American Psychiatric Association, 2013).

A longitudinal study (Snowling, Muter, & Carroll, 2007) of children at family risk of dyslexia reported that at the early adolescence stage (8 to 13 years old), the participants showed good reading comprehension, but poor read fluency and orthographic deficits. The results of Snowling et al. (2007) suggested that reading disorders tend to persist into the adolescence and demonstrated a significant effect of gene-environment in maintaining the problems.

Students with LD who attend schools that provide special educational needs services may achieve academic progress on reading and math close to the average progress of students without LD (Cole, Waldron, & Majd, 2004). Wanzek, Wexler, Vaughn, and Ciullo, (2010) reviewed reading interventions for students with LD at an early adolescence stage (9-11 years old). The findings of Wanzek et al. (2010) exposed mixed results, with a significant effect on the improvement of reading comprehension, but mild results for fluency and vocabulary skills. A meta-analysis of mathematical intervention programs for secondary students with LD concluded that such programmes had a positive influence by increasing the mathematical results of the students (Jitendra et al., 2018). An opposite study posited that students with LD obtain higher academic achievement when they are included in general education classroom rather than when they attend special classes (Rea, McLaughlin, & Walther-Thomas, 2002). Mcleskey and Waldron, (2011) made a revision of the available literature on the effectiveness of educational programs for LD children, their conclusions revealed that those programmes are able to improve the reading and mathematical achievement of students, however, these results depend on the quality of such programmes. This revision (Mcleskey & Waldron, 2011) suggest that conclusions about the impact of special educational programmes on the academic results of students, have to be made with caution.

5.2 Design of the study

5.2.1 Hypotheses

In Study 2, the main hypothesis was that adolescents with LD would obtain scores above the mean on the sensory profile questionnaire, and would show significant differences with a group of adolescents without LD. A secondary hypothesis was that a significant correlation would be found between the level of learning difficulties, including reading and mathematics scales (CLDQ) and the sensory processing profile (AASP).

These hypotheses were based on evidence suggesting difficulties to integrate sensory information in children with a neurodevelopmental disorder (Dionne-Dostie et al., 2015), and on Dove and Dunn (2008) and Padankatti (2005), who found different performance on most of the categories of the sensory profile. The second hypothesis, as in the previous study with children, was based on Stein (Stein, 2001a, 2001b) who proposed a basic sensory involvement on phonological issues. Similarly, the studies on auditory and visual tasks provided evidence suggesting that learning difficulties, in particular reading disorders, may be associated with sensory issues (Rose et al., 1999; Tallal, 1980; Tallal et al., 1993; Widmann et al., 2012). Regarding mathematical skills and sensory issues, the work of Sigmundsson et al. (2010) found evidence of sensory deficit. Therefore, the second hypothesis of this study explores the possible association between difficulties in reading and mathematics as main learning skills and the sensory processing abilities in adolescents.

5.3 Methodology

5.3.1 Participants

One hundred and twenty-four adolescents participated in the study; the adolescents were aged between 13-16 years old (Mean age = 14.17, SD = .884) and comprised 80 females. Participants were recruited via local schools of South Yorkshire area (84 surveys) and social media via Facebook sponsored posts with a target audience of UK families, English-speakers (33 surveys). Eleven surveys were excluded: six of them due to participants referred having either hearing or visual non-treated problems, four due to incongruent learning needs report, that is, participants referred receiving SEN support at school, however, they did not refer any academic problem listed in the survey, and one participant had significant outlier scores. The final sample comprised 113 participants.

Two groups were created based on the information provided for the participants in the questionnaires. Regarding the learning skills of the adolescents, the survey showed that 40.7% referred to not having any academic difficulties at school (46 students). They were labelled the typically learning group. The other group comprised those who did refer to having learning difficulties (LD). Of the 67 students with LD, 53.7% mentioned difficulties related to literacy skills (teachers referred 35 of them as having a dyslexia diagnosis), 25.4% referred to difficulties with maths, and 20.9% referred to difficulties in both reading and maths skills. 28.4% of student with LD currently received additional educational support at school.

Table 5.1. Characterisation of participants

Group	Gender & Age	Language	Learning characteristics
Typically learning (TA) n: 46	13 Male 32 Female 1 missing Mean age: 14.09	English native speaker: 37 Other language: 9	Students who neither present an academic difficulty at school nor participate in SEN.
Learning difficulties (LD) n: 67	22 Male 45 Female Mean age: 14.19	English native speaker: 50 Other language: 17	Students who present an academic difficulty at school and some of them also participate in SEN (19 students). Literacy problems: 36 Maths problems: 17 Lit. & maths: 14
Surveys excluded	Sensory conditions: Untreated visual problems: 5 Untreated hearing problems: 1 Incongruent learning needs report: 4		

5.3.2 Measures and procedures

As the participants were under-18 years, they gave informed consent together with the approval of their parents. The data collection was based on adolescents' self-report. For those adolescents who agreed to take part, they were asked to complete six closed questions, five of this were further considered for the analyses. The demographic questions were regarding gender, and date of birth. Then specific questions were included: "Do you receive additional educational support at school, e.g. via an in-class teaching assistant, extra classes to support your learning, other Special Educational Needs support?"; "Which of the following skills have you experienced learning problems?" Among reading, writing, maths, and motor skills; and "Do you have any of the following conditions?" among orthopaedic abnormality, untreated visual problems and untreated hearing problems.

5.3.2.1 Colorado Learning Difficulties Questionnaire (CLDQ)

Study 2 had a group analysis approach and attempted to include data from a large sample of adolescents, thus the CLDQ questionnaire was selected to be a time-effective tool. The CLDQ was designed by Willcutt et al. (2011) to screen for learning difficulties, which Willcutt et al. defined as behaviours that are likely to indicate the possibility of LD. The questionnaire aimed to assess specific dimensions that are usually affected in children and adolescents with learning difficulties, including reading, maths, social cognition, spatial functioning, and memory scales. The validation of the CLDQ was carried out with a large sample of 8.004 participants from the community with and without conditions and was administered as a screening measure.

The full CLDQ contains 20 statements that showed good correlation with actual reading (overall r =.64) and mathematical achievement, and measures of social skills (Willcutt et al., 2011). Further studies (Hadley & Kimberlin, 2016; Patrick et al., 2013; Yailagh, 2014) have reported good reliability of the questionnaire and its validity for identifying children with learning difficulties, especially with the reading and maths scales. For the purposes of the present study of obtaining information about reading and mathematical achievement, the short version of the CLDQ adapted by Patrick et al. (2013) was used. The short version included 11 statements from the reading and maths scales only. The short version has been tested in previous studies and has been reported a good correlation between the scores and achievement measures (Hadley & Kimberlin, 2016; Patrick et al., 2013; Willcutt et al., 2011).

The reading scale (CLDQ-R) included six statements about spelling, learning to read and reading proficiency. The maths scale (CLDQ-M) includes five statements about general mathematical skills. The original maths scale of three items was improved by including two additional items (Patrick et al., 2013). Both the CLDQ-R and CLDQ-M scales have a Likert-style five-point statements, ranging from (1) “never/to at all” to (5) “always/a great deal”. Table 5.2 shows the short version of the CLDQ. Higher scores indicate greater levels of perceived academic difficulty in each area. A priori cut scores were set for the CLDQ-R (2.67), and CLDQ-M (2.60) scales based on the > 1SD above the validation sample mean as reported by Patrick et al. (2013). Scores greater than 1SD above the mean indicated a possible learning difficulty.

Table 5.2 Colorado learning difficulties questionnaire, short version

Below you will find some statements about your academic skills. Please select one option.					
Did you ever have...	Never/ Not at all	Rarely/ a Little	Sometimes	Frequently /Quite a lot	Always/ a Great Deal
1. Difficulty with spelling	1	2	3	4	5
2. Difficulty learning letter names	1	2	3	4	5
3. Difficulty learning phonics (sounding out words)	1	2	3	4	5
4. Reads slowly	1	2	3	4	5
5. Reads below grade or expectancy level	1	2	3	4	5
6. Required extra reading help in school because of problems with reading and spelling	1	2	3	4	5
7. Worse at math than at reading and spelling	1	2	3	4	5
8. Makes careless errors in math, such as adding when the sign indicates subtraction	1	2	3	4	5
9. Trouble learning new math concepts such as carrying or borrowing	1	2	3	4	5
10. Difficulty learning early math facts	1	2	3	4	5
11. Difficulty with math word problems	1	2	3	4	5

CLDQ-R: items 1 to 6; CLDQ-M: items 7 to 11. Note: the scores were not displayed to the participants

5.3.2.2 Adolescent / Adult Sensory Profile (AASP).

The Adolescent/Adult Sensory Profile (AASP; Brown & Dunn, 2002) is a standardised assessment that measures sensory processing or modulation abilities among adolescents and adults, aged 11 years and upwards (complete questionnaire in Appendix B). The AASP was designed based on Dunn's (1997) model of sensory processing, further explanation of the theoretical framework and questionnaires properties can be found in Chapter 3.

In Study 2, the questionnaire was conducted as a self-report using the Qualtrics online software, and the paper form. The paper questionnaire instructed participants to mark any statement that they were unable to answer because they had not experienced the situation. Thus, in the online version a "does not apply" option was included. The statements were organized according to the six sensory systems, taste/smell, movement, visual, touch and auditory, and a scale for activity level.

5.4 Results

5.4.1 Data check and descriptive statistics

The first step of the data analysis process was to screen all of the variables for outliers and normality. Kolmogorov-Smirnov and the visual inspection of histograms showed a normal distribution of the AASP scores so parametric tests were used. Non-parametric tests were used for the CLDQ given that the scores did not meet the normality criterion (Kolmogorov-Smirnov test $<.05$).

The survey type (online/paper) was checked through independent-sample t-tests, which showed non-significant differences in the dependent variables of interest ($p>.05$). The variable of age was checked through correlation analysis and did not show significant results either ($p>.05$). Thus, further analyses were made with all the surveys and all participants without making differences by age.

The CLDQ scores of both groups were checked to contrast them with the reports received from the participants on their academic skills. Cronbach's alphas for the CLDQ sum of scales consisted of 11 statements was $\alpha =.792$, which indicates an acceptable level of internal consistency for the scale with this specific sample. The typically learning group obtained a mean of 1.59 on the CLDQ-R and 1.74 on the CLDQ-M scale. These scores located the typical group on the mean for the CLDQ questionnaire, that is, there is unlikely that this group present LD. In the LD group, the participants obtained a mean of 2.31 for the Reading scale and 2.45 for the Maths scale. Although the scores of the LD group are below those of the 1SD from the mean, a Mann-Witney test showed significant differences between the groups in both the reading and Maths scales ($p< .001$), with higher scores for the LD group compared to the typical group.

Table 5.3 Descriptive scores and statistical results on the CDLQ.

CLDQ	**TA Group**	**SEN Group**	**Cut scores**	**Mann-Witney**		**Effect size**
	M (SD)	M(SD)	+1SD	*U*	*p*	*d*
Reading	1.59 (.39)	2.31 (.55)	2.67	2.639	<.001	1.50
Maths	1.74 (.60)	2.45 (.85)	2.60	2.309	<.001	.97
Sum of scales	17.58 (4.32)	25.49 (6.05)		2.639	<.001	1.49

Cut off scores for the reading and math scales based on the > 1SD above the validation sample mean (Patrick et al., 2013). Effect size= Cohen's *d*.

5.4.2 Sensory processing profile of Adolescents

Cronbach's alphas for the AASP sum of scales consisted of 60 statements was α =.893, which indicates a good level of internal consistency for the scale with this specific sample.

5.4.2.1 Distribution of categorical scores along with the normative data.

The distribution of participants from less to more engagement on sensory behaviours is shown based on the categorical data from the AASP. Below is shown a stacked graph (see Figure 5.1) to compare the distribution of scores on each of the four sensory quadrants per group. The graph shows than both the typical and LD groups presented more scores on the medium segment that represent the mean category ('Just like the majority'), and less on the extreme categories ('Less than others', and 'More than others').

Chi-square test of independence showed that there was a significant association between group and the sensory profile classification for Registration $X^2(4) = 12.37$, $p = .015$, and Sensitivity $X^2(4) = 12.19$, $p = .016$. LD adolescents were more likely to show 'More than others' scores on those quadrants than the typical group, conversely, typical children were more likely to obtained scores on the 'Less than other' and 'Just like the majority' categories.

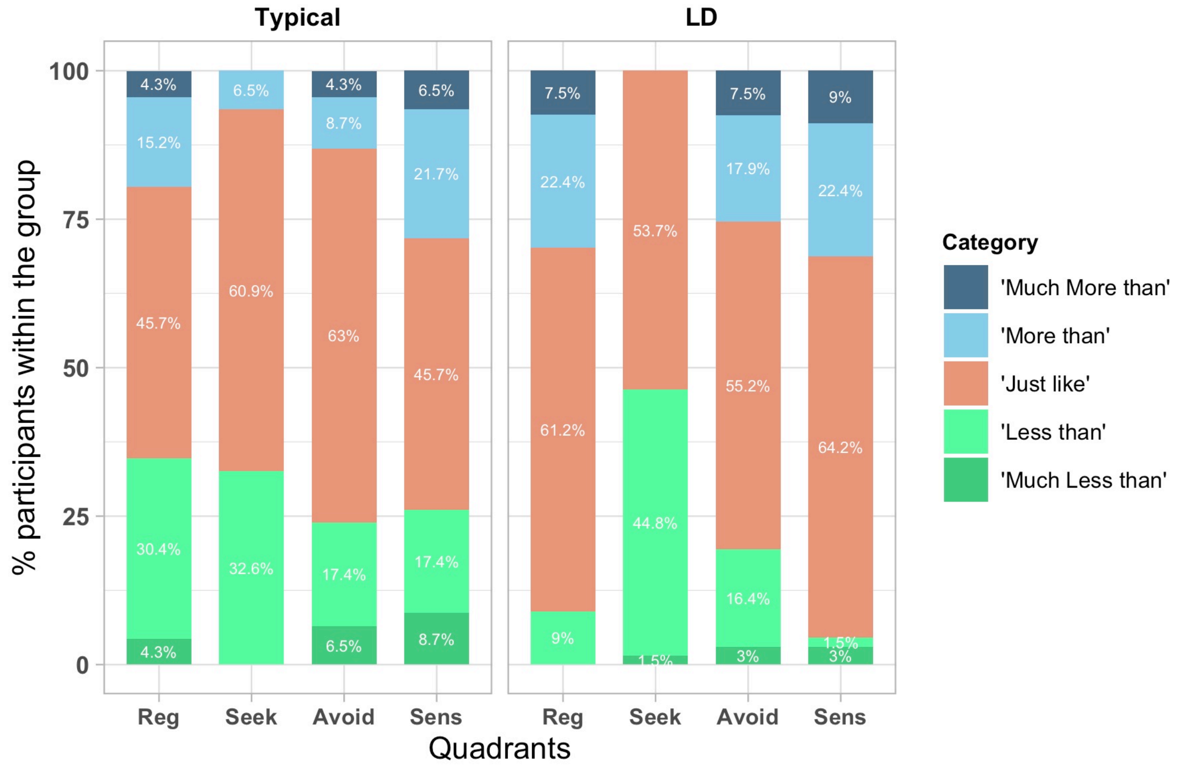

Figure 5.1 Representation of the groups on each of the four quadrants of Dunn's model along the categorical ranges. Quadrants: Reg= Registration, Seek= Seeking, Avoid= Avoiding, Sens= Sensitivity.

5.4.2.2 Mean comparison between groups.

Sensory quadrants.

To test the hypothesis that students with learning difficulties would obtain higher scores on the sensory profile compared with the typical learning group, a multivariate ANOVA was conducted. Box's test showed that the observed covariance matrices of the dependent variables (the four sensory quadrants) are equal across groups (p=.431). The multivariate test showed a significant effect for the sensory quadrants according to the groups $F(4, 108) = 2.638$, $p = .038$; Wilk's $\Lambda = .911$, partial $\eta^2 = .089$. Univariate tests indicated significant differences for the Registration ($F\,(1, 111) = 8.18$, p=.005; partial $\eta^2 = .069$) and Sensitive ($F\,(4, 111) = 4.89$, p= .029; partial $\eta^2 = .042$) quadrants. Examination of mean estimates indicated that students of the LD group obtained higher scores than students from the typical group on those quadrants.

Sensory Systems.

The six sensory system scores were compared for the two groups using a MANOVA test. Box's test showed that the observed covariance matrices of the dependent variables (the six sensory systems) are equal across groups (p=.233). The multivariate test indicated significant differences between the two groups of adolescents in their sensory systems, $F(6, 106) = 2.590$, $p = .022$; Wilk's $\Lambda = .872$, partial $\eta^2 = .128$. Univariate tests showed significant differences in three sensory systems, visual ($F (1, 111) = 6.65$, $p =.011$; partial $\eta^2 = .072$.), auditory ($F (1, 111) = 6.35$, $p =.013$; partial $\eta^2 = .054$), and activity level ($F (1, 111) = 6.74$, $p =.018$; partial $\eta^2 = .049$). The LD group had higher scores than the typical learning group in those sensory systems.

In summary, the multivariate analysis showed that the sensory profile questionnaire revealed significant differences between the typically learning adolescents and those with difficulties on some of the scales. The descriptive scores and statistical results for the two groups, typically learning and learning difficulties adolescents, on the AASP are shown on the table below (Table 5.4).

Table 5.4 Descriptive scores and statistical results on the AASP.

AASP	**TA Group** M (SD)	**SEN Group** M(SD)	**Norms** M(SD)	**ANOVA** *p*	**Effect size** η^2
Sensory quadrants					
Registration	31.61 (10.26)	36.88 (9.16)	33.57 (7.6)	.005**	.069
Seeking	44.35 (8.33)	42.54 (7.48)	49.42 (8.9)	.231	.013
Avoiding	31.11 (9.11)	34.16 (10.01)	33.02 (7.0)	.101	.024
Sensitivity	33.46 (10.38)	37.46 (8.76)	33.98 (7.3)	.029*	.042
Sensory systems					
Auditory	26.17 (6.76)	29.58 (7.26)		.013*	.054
Visual	21.33 (6.10)	23.34 (6.10)		.011*	.057
Touch	29.39 (9.53)	30.70 (8.26)		.439	.005
Movement	19.74 (5.24)	20.30 (5.08)		.572	.003
Taste/Smell	18.65 (4.74)	18.30 (4.64)		.692	.001
Activity level	25.24 (6.02)	27.82 (5.33)		.018*	.049

Norms extracted from the Adolescent/Adult Sensory Profile, the manual does not provide individual norms for the sensory systems (Brown & Dunn, 2002, page 20). Significant differences between groups at **<.01, *<.05. Effect size= partial n^2.

5.4.3 Association between learning difficulties and the sensory profile.

Correlation analyses were run to investigate whether or not there was an association between the sensory processing profile, measured by AASP scores, and academic achievement, measured by the CLDQ. Due to the non-normal distribution of the CLDQ measures, Spearman's rank-order correlations were computed, all of these correlations were adjusted for multiple comparisons with Bonferroni (see table 5.5). The test showed positive correlations between both the reading and maths scales and the sensory quadrants of Registration and Sensitivity, and the sensory systems of auditory, and activity level. There were no other significant correlations after the Bonferroni correction.

Table 5.5 Correlations between CLDQ and AASP

	CLDQ total sum	CLDQ-R	CLDQ-M
Sensory quadrants			
Registration	.420**	.421**	.384**
Seeking	-.035	-.034	.082
Avoiding	.207*	.208*	.237*
Sensitivity	.320**	.321**	.315**
Sensory systems			
Auditory	.381**	.382**	.376**
Visual	.289*	.290*	.283*
Touch	186*	.186*	.170
Movement	.195*	.195*	.202*
Taste/Smell	-.002	-.002	.199*
Activity level	.313**	.313**	.377**

Correlation significant at *p<.05; Bonferroni corrected at **p <.001

Having observed significant relationships between the variables of interest, additional analyses were conducted using multiple linear regression on the learning difficulty measure (results in Table 4.6). The multiple linear regression was conducted to evaluate whether the four sensory quadrants (Registration, Seeking, Avoiding, and Sensitivity) were necessary to predict the measure of learning difficulties of participants (the CLDQ general scale was used as dependent variable). All four quadrants were entered to the model using the stepwise method.

The slope coefficient (unstandardized B) from the regression analysis showed that the scores of the CLDQ will increase by .282 points as the scores on Registration increases. The R^2 value was .177, which indicates that 17.7% of the variation in the CLDQ can be explained by the model containing only Registration. The scatterplot (figure 5.2) of standardised predicted values versus standardised residuals, showed that the data met the assumptions of homogeneity of variance and linearity and the residuals were approximately normally distributed (Figure 5.3).

Table 5.6 Regression outcome

Model		**B**	**Coefficient std. error**	**Standardized coeff. Beta**	**t**	**Sig.**
1	Registration	.282	.058	.420	4.880	<.001
Excluded variables						
	Seeking	-.048			-.549	.584
	Avoiding	-.111			-1.032	.304
	Sensitivity	-.021			-.175	.862

Stepwise method, dependent variable CLDQ general scale.
Model 1 summary: R=.420; R^2=.177; Adjusted R^2=.169

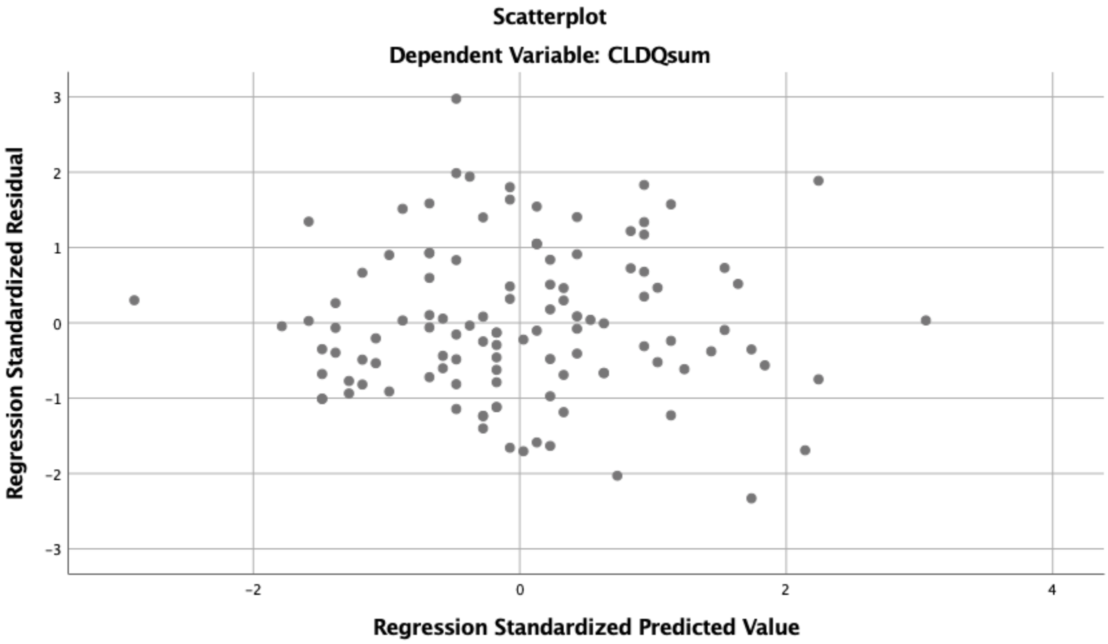

Figure 5.2 Scatterplot shows homoscedasticity of data.

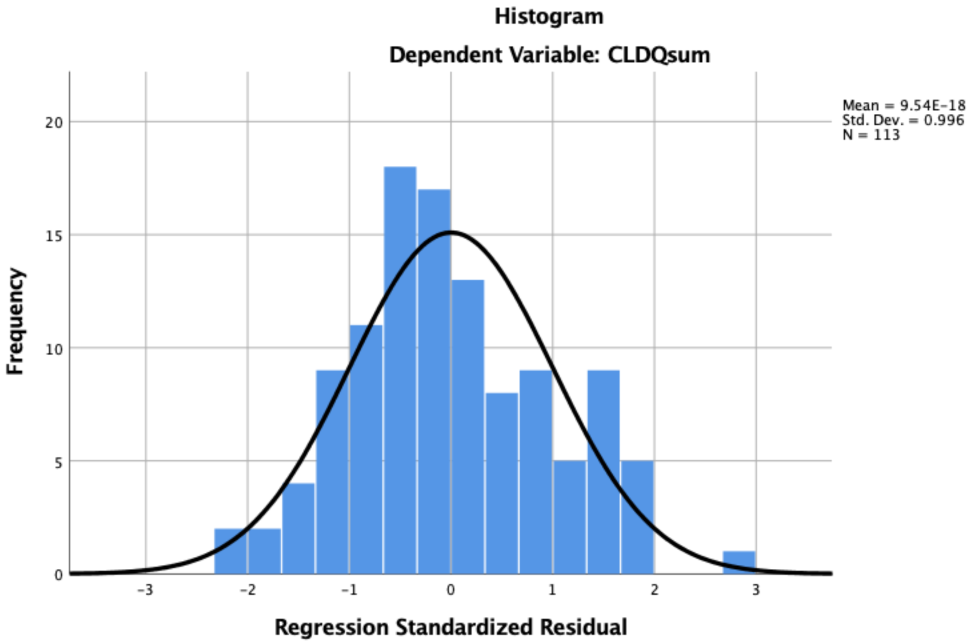

Figure 5.3 Histogram shows normality distribution of residuals

5.5 Discussion

First, there were significant differences between the LD group and the typical group on some scales in the Adults/Adolescents sensory profile questionnaire (AASP). The direction of these differences showed greater scores for the LD group; however, these differences did not meet Dunn's criterion for clinical significance (Brown & Dunn, 2002).

Second, significant correlations were found between the CLDQ and the AASP scores, which demonstrated a mutual influence between academic skills and sensory-related behaviours in adolescents. These findings will be discussed below.

5.5.1 Sensory processing profile of adolescents with LD.

The comparison between the profile of sensory processing of adolescents with and without LD showed a similar pattern in the sensory quadrants of Seeking and Avoiding (both in the active self-regulation continuum), but significantly higher scores in the Registration and Sensitivity quadrant (both in the passive self-regulation continuum) for the LD group. Despite the differences observed in the sensory profile between the groups, the LD group obtained an overall profile within the mean range according to the normative data. This sensory profile revealed that the adolescents as a group were able to manage the sensory input in a similar way like others of the same age (Brown & Dunn, 2002; Dunn, 1997). These results partially support the first hypothesis, since there were no scores above the mean for the LD group, but we did find significant differences between the LD group and typically learning group. However, it is important to take into account that despite the adolescents within the LD group were referred and/or self-report themselves as having learning problems, they did not meet the criterion of 1SD above the mean on the CLDQ test (Patrick et al., 2013). Thus, the LD group might be representative of adolescents that present attainment difficulties in the academic context, but such difficulties does not fulfil clinical significance.

On the other hand, when comparing the profiles between the two groups who participated in Study 2, a particular trend is possible to observe for the LD group. A high frequency of behaviours on both the Registration and Sensitivity quadrants, and similar behaviours in Seeking, and Avoiding quadrants when compared to adolescents without LD, characterised the LD adolescents as having a trend of presenting a general passive self-regulation strategy. In the educational context, it is possible to hypothesize that adolescents with LD may lose information in some circumstances by not acting, which may affect their academic performance due to their inability to adjust their actions to achieve the desired results (Brown & Dunn, 2002; Dunn, 1997). On the other hand, as discussed in Study 1 (section 4.5.1), the presence of high frequency of behaviours in both high and low neurological threshold challenges Dunn's framework and may suggest subgroups of sensory profile.

As was reported in the results section (see section 5.4), the quadrant of Seeking did not show significant differences between the groups, and the categorical classification showed that the LD group obtained a low frequency of behaviours in this quadrant. In typical development, it is expected that adolescents will show a high frequency of behaviours associated with seeking, that is, they will actively try to engage with stimulating experiences (Larsen & Luna, 2018). Engel-Yeger et al. (2016) have suggested that low seeking behaviour may be linked with affective disorders in the line of depression and anxiety, and previous studies have demonstrated that adolescence is an emotionally vulnerable stage, which increases for those with LD (Daniel et al., 2007; Eissa, 2016; Martinez & Semrud-Clikeman, 2004; Palfiova et al., 2016; Svetaz et al., 2000; Willcutt & Pennington, 2000b). These results are coherent with a trend to present passive regulation strategies, yet more research is needed to explore the implications of the sensory profile for emotional development.

The sensory systems data showed significant differences in auditory and visual because the LD group obtained higher scores in both sensory systems compared to the typical group.

There is extensive evidence that auditory sensory processing deficit is linked with reading disorders, from the early studies of Tallal (1980) to recent research (Francisco et al., 2017). Also, difficulties in the integration of audio-visual stimuli (Blau et al., 2010; Heinz Wimmer et al., 2000; Windfuhr & Snowling, 2001) have been observed in people with learning difficulties. These findings may suggest that adolescents with LD are less accurate in processing auditory and visual information.

Overall, the suggestion that adolescence is a critical period for neural maturation (Fuhrmann et al., 2015; Larsen & Luna, 2018; Spear, 2000) may explain the sensory processing profile of adolescents with LD observed in Study 2. The frequency of behaviours on response to sensory stimuli were on the mean for the corresponding age group in the LD group, which might be associated with better academic skills. Nevertheless, we did find significant differences in the sensory profile between the groups that would be an indicator of divergence associated with learning skills, but these results are not conclusive.

5.5.2 Association between sensory processing profile and learning difficulties.

Study 2 showed a significant association between the reading and math scales of the CLDQ, and scores for the sensory profile. Accordingly, high scores on the CLDQ measures, which indicate the likelihood of learning difficulties, were positively associated with a high frequency of behaviours on the sensory processing profile. Consequently, the data provided evidence that sensory-related behaviours are significantly associated with academic achievement, as previously suggested by Dove and Dunn, (2008), and also discussed in Study 1. The correlation between the sensory profile and the CLDQ was found with both, reading and math scales that evidence an involvement of sensory processing for the acquisition of academic skills, as suggested previously (Sigmundsson et al., 2010).

The association between learning difficulties and sensory profile was furthered through a regression analysis, where the effect of the Registration sensory quadrant was found to be a significant predictor of learning difficulties, but not the other three quadrants. Thus, for adolescents, a profile of high neurological threshold and passive self-regulation would predict the likelihood of learning difficulties. Comparison of the findings with those of other studies (Richardson et al., 2004; Sigmundsson et al., 2010; Sperling et al., 2005; Talcott, et al., 2000) confirmed that people with learning difficulties have a trend to present high neurological threshold. Accordingly, this suggests that some adolescents with high frequency of behaviours that evidence a high neurological threshold may be at risk of developing learning difficulties.

Regarding the scores on the CLDQ, the results exposed significant differences between the groups. The LD group were more likely to have learning problems in reading and maths. However, compared with the normative cut scores, the scores of the LD group were below the +1SD criterion. Larsen and Luna, (2018) described a significant improvement in cognitive skills during adolescence and proposed that at this stage students are able to cope with their learning problems (American Psychiatric Association, 2013). A small proportion of students with LD from the Study 2 referred they were currently receiving specific educational support (28.4%), and there was no information about whether or not they received educational support in their previous school years. Still, it is possible to presume that their gaining experience as students together with some academic support along with their academic life, may have helped them to cope with their academic difficulties (Cole et al., 2004; Jitendra et al., 2018; Wanzek et al., 2010). Such cognitive improvement may explain the CLDQ scores, though specific difficulties are likely to remain in adolescents (Snowling et al., 2007).

Within the limitations of Study 2, it is necessary to keep in mind that the information about sensory processing and academic achievement were obtained via self-report questionnaires, thus the interpretation is restricted to the reliability of this data. This methodology is not free of bias considering that requires a high level of self-awareness and reading comprehension to complete the instruments (Leavett et al., 2014; Reid, 2009; Schoen et al., 2014). It would be an improvement to have a record of the actual academic performance of students and/or their attainment in reading and maths, to contrast with their self-report.

CHAPTER 6

STUDY 3: SENSORY PROCESSING IN ADULTS

6.1 Introduction

This chapter presents empirical data regarding learning difficulties and sensory processing in adults. The study had three aims: first, to provide an initial description of the sensory processing profile of adults with learning difficulties; second, to provide evidence consistent with the idea that adults with learning difficulties will present differences in their sensory-related behaviours by comparing their profile with typically learning adults; and third, to assess whether there is a correlation between sensory characteristics and reading skills. In order to reach those aims, Chapter 6 includes two studies with an adult population. Study 3A was designed as a general examination of the sensory processing characteristics of adults, while Study 3B included additional measures to test the association between sensory processing and reading.

In the previous Chapter 2, there was explained that the sensory abilities are age-dependent (Johnson-Ecker & Parham, 2000). The first years of life rely on the maturation of the neural system together with gaining experiences, to acquire progressive improvements in the perception of sensory stimuli, and the interpretation for further response (Nardini et al., 2016; Stein et al., 2014; Wallace & Stein, 2001). The exploration of the sensory processing characteristics in adults with learning difficulties is scarce. A study that compared the sensory quadrants described by Brown and Dunn, (2002) on adults with autism diagnosis has observed a profile characterised by a high engagement in sensory-related behaviours, though a trend to get close to the typical population in older participants (Kern et al., 2007).

Therefore, the following two studies aimed to characterise the sensory processing profile of adults and to explore their relationship with learning problems. In the first study

(Study 3A) adults answered an online self-questionnaire concerning their behavioural responses to everyday sensory experience. The second study (Study 3B) was designed in the lights of the findings from Study 3A, thus, only one scale was included in Study 3B, and a standardized reading questionnaire was incorporated to obtain specific information about reading issues.

Learning disorders may continue throughout an individual's lifespan, and it has been demonstrated that dyslexia is a persistent condition and not just a developmental lag that is present in early years (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1996; Scarborough, 1984). Previous chapters (see Chapter 2 and 3) showed that there may be a close relationship between sensory processing deficits and neurodevelopmental disorders (e.g. Dionne-Dostie et al., 2015). Also, studies like Francisco et al. (2017) and Harrar et al. (2014) were presented on the association between sensory processing and learning. Thus, given that everyday demands are likely to be different for children and adults, it is relevant to characterise the particular sensory processing profile of adults with a background of LD.

6.1.1 Characteristics of adults with learning difficulties

Most of what is known about learning difficulties are based on empirical studies that have investigated dyslexia in children, but such studies have been less well explored in adults (Swanson et al., 2013). Since reading problems are the most frequent deficits within the LD group, the characterisation of learning difficulties in adulthood is mainly based on reading, and spelling skills (Brosnan et al., 2002; Kahta & Schiff, 2016; Kemp, Parrila, & Kirby, 2009; Laasonen et al., 2002; Laycock et al., 2008; Lefly & Pennington, 1991; Menghini, Hagberg, Caltagirone, Petrosini, & Vicari, 2006; Nergård-Nilssen & Hulme, 2014; Smith-Spark, Henry, Messer, Edvardsdottir, & Ziecik, 2016).

The prevalence of specific learning difficulties in adults is not clear. The Higher Education Statistics Agency (HESA, 2017) found that 12% of students reported a disability (it may be referred to as a specific learning difficulty; a sensory or physical impairment; or a medical condition). Although precise figures for specific learning difficulties cannot be inferred from the HESA report, LD seems to be prevalent in high education. Similarly, the lack of adult measures in the sensory processing field is unfortunate, given evidence that the sensory concerns in children are also experienced by adults (Pohl et al., 2003).

While it is true that the childhood problems of specific learning difficulties and developmental dyslexia extend into adulthood, the manifestations and severity of these problems across the life span may vary regarding affective, cognitive, language, and achievement abilities (Gregg, 2014). Lefly and Pennington (1991) introduced the concept of compensated dyslexics, to refer to adults with a history of reading and spelling problems who have overcome the difficulties and can obtain average scores in literacy tests. Lefly and Pennington estimated that about a quarter of individuals with reading difficulties in childhood are able to compensate for their problems. Hämäläinen, Leppänen, Torppa, Müller, and Lyytinen (2005) used the same concept – compensated dyslexics – for those adults who reported early literacy problems and had relatives with a record of literacy problems. Brosnan et al. (2002) referred to adults at university who still demonstrated some underlying problems in verbal fluency and some executive functions. Parrila, Georgiou, and Corkett (2007) identified underperformance in decoding and spelling in university students, but who had good reading comprehension. Adults with these characteristics have also been called high-functioning dyslexics (Kemp et al., 2009). While these students may have developed coping strategies, it is likely that they will still experience academic challenges. Richardson and Wydell (2003) described general difficulties in the progression, and accomplishment of the careers of students with a history of reading difficulties. Likewise, Olofsson, Taube, and Ahl

(2015) noticed that even when university students were able to compensate for their difficulties, they may have needed more hours of study than their peers to achieve their academic goals.

Most of the remaining literacy difficulties in adults are manifested by problems in the phonological domain. Felton, Naylor, and Wood (1990) identified rapid naming, phonological awareness, and pseudo-word reading as significant discriminating measures in adults with dyslexia. Kemp et al. (2009) examined a group of adults with a history of dyslexia and showed that the adults had poor spelling in both words and pseudo-words and had particular difficulties in spelling unfamiliar words compared with typical readers, which may indicate a characteristic feature in the manifestation of dyslexia in adults. Hämäläinen, Leppänen, Torppa, Müller, and Lyytinen (2005) explored the performance of adults with different reading levels in rise time detection tasks, a basic skill associated with phonological and reading skills. Some of the adults with dyslexia showed a deficit in the detection of rise time. In addition, Nergård-Nilssen and Hulme (2014) assessed the performance of self-reported dyslexic adults compared with typical readers. Nergård-Nilssen and Hulme found poor performance in reading efficiency and accuracy, as well as spelling deficiency for the dyslexic group. Mortimore and Crozier, (2006) identified failures in specific skills such as note-taking, the organization of writing work, and the expression of ideas in writing. These studies (Felton et al., 1990; Hämäläinen et al., 2005; Kemp et al., 2009; Mortimore & Crozier, 2006; Nergård-Nilssen & Hulme, 2014) revealed the need for further investigation of learning difficulties in adulthood, including those who participate in higher levels of education.

Characteristics outside the phonological domain have been studied in adults with reading difficulties. Ramus et al. (2003) undertook a variety of tasks to assess psychometric, phonological, and cerebellar performance and measures of auditory and visual perception in university students who had a diagnosis of dyslexia. All of the university students in Ramus et al showed phonological problems, which confirmed their condition as impaired readers. Some students also showed motor problems, and a high number of students presented auditory problems (Ramus, 2003). These results are similar to those reported by Stoodley and Stein (2006), who found motor impairments in some participants in their dyslexic group, and a general processing speed deficit that affected both motor and literacy tasks. Jordan, McGladdery, and Dyer, (2014) reported high levels of anxiety and other emotional signs associated with mathematics in university students with dyslexia.

Some executive functions problems have also been described as part of the features of adults with dyslexia. Previous studies have demonstrated difficulties in adults with reading problems in the phonological and no/phonological executive functions such as short-term memory problems, letter updating tasks (a working memory measure) (Smith-Spark, Fisk, Fawcett, & Nicolson, 2003), difficulties with managing current and future task demands, keeping track of successes and failures in problem-solving, and switching between cognitive operations (Smith-Spark et al., 2016). An examination of inhibitory control by Brosnan et al. (2002) showed that both adults and children with a diagnosis of dyslexia had a deficiency in inhibitory processing, a skill associated with working memory. In turn, this deficit may be explained by a malfunctioning of the left prefrontal cortical hemisphere (Brosnan et al., 2002).

Neuroimaging studies have contributed to the comprehension of the dyslexic brain in adults. Studies using a PET scan identified abnormal functional activation during a word repetition task in a group of adults diagnosed as dyslexics (McCrory et al., 2000) and atypical processing of written stimuli as reflected in abnormal functioning of the left hemisphere (Brunswick et al., 1999).

6.1.2 Sensory processing in adults with learning difficulties

The approach used in the study of children and adolescents with learning difficulties and reading problems is similar to the approach used for adults. The phonological theory leads the explanations for reading problems (Ramus et al., 2003; Vellutino et al., 2004). So far, however, there has been little discussion in the research about the role of the individual's responses to sensory stimulation concerning their academic achievements. Interactions among the senses deeply influence relevant human functions, such as cognition, emotion, and behaviour (Stein & Meredith, 1993). As argued in the introduction to this thesis, studying the sensory characteristics of people with learning difficulties can contribute to the understanding of the multifactorial problem of learning disorders (see Chapter 1). Likewise, the multisensory nature of everyday life experiences (Ayres, 2005) demands an ecological approach that includes the exploration of learning issues, starting from the very basic variables, like the senses and their interconnection.

To date, the study of sensory integration has provided insights into the brain mechanisms involved in the processing of sensory input (Macaluso & Driver, 2005). Behavioural and neuroimaging studies have used both unimodal – the presentation of one sensory modality at a time (Laasonen et al., 2001) and cross-modal – the presentation of two or more sensory modalities at a time – (Hairston et al., 2005) methods in their experiments. Visual and auditory stimuli have received more attention due to their relevance to learning. For instance, Laasonen et al., (2001) tested the temporal acuity of Finish adults with a diagnosis of dyslexia in the visual, auditory and tactile modalities. The adults had to identify which of two modality stimuli was presented first. Laasonen et al. (2001) found poorer performance among adults with reading problems typically learning adults about the audition and tactile senses, but not with the visual stimulus.

Within the cross-modal studies, Hairston et al. (2005) studied the effect of adding a task-irrelevant auditory stimuli on the performance on the visual temporal order judgement task. The results of Hairston et al. suggested there was an extended period of integration (temporal window of integration, TWI) in adult dyslexics and visual temporal processing abnormalities. Francisco et al. (2017) tested whether or not dyslexic adults present audio-visual deficits. Francisco et al. found significant differences between dyslexic adults and typical readers in the perception of audio-visual stimuli, because dyslexic adults made more mistakes in a temporal sensitivity task, but had similar results to typical readers for TWI and audio-visual speech perception. Conlon et al. (2011) reported poorer counting accuracy in adults who were poor readers compared with typical readers, which may reflect a sensory processing deficit regarding the length of the inter-stimulus interval. These results contribute to the hypothesis that adults with reading difficulties have a general audio-visual temporal deficit (Laasonen et al., 2001), that cannot be explained by the main phonological framework.

Emotional issues, like depression and anxiety, have been linked with a sensory profile predominantly of a low neurological threshold (Engel-Yeger & Dunn, 2011; Engel-Yeger et al., 2016), that is, people who recognised stimuli more often due to an easy activation of the neurological system, would present high frequency of emotional problems.

Chapter 2 pointed out that sensory abilities are directly related to the maturation of the nervous systems and the gaining of daily life experiences (section 2.4). Thus it is expected that adults will present an enhanced response to sensory stimuli (Hartcher-O'Brien et al., 2014; Hillock et al., 2011; Lewkowicz, 2012), and more efficient use of multisensory cues for integration than younger people (Peiffer et al., 2007). However, the natural degenerative process of the brain due to ageing negatively influences sensory processing abilities, for example in tactile inputs (Wickremaratchi & Llewelyn, 2006). Engel-Yeger, Hus, and Rosenblum, (2012) studied the sensory profile (with the AASP questionnaire) and handwriting skills of a group of healthy adults, aged 31 to 76 years. Engel-Yeger et al. observed that age predicted the sensory processing abilities of the participants, and the oldest adults showed lower abilities. An earlier study (Pohl et al., 2003) said 65 years was the age when it was more likely to observe adults struggling with noticing sensory stimulation.

6.2 Design of Studies 3A and 3B

6.2.2 Hypotheses

For study 3A, the main hypothesis was that adults with LD would obtain scores above the mean on the sensory profile questionnaire, and will show significant differences with a group of adults without LD. For the study 3B, the main hypothesis was that a significant positive correlation would be found between the reading measure (ARQ) and the sensory processing profile (AASP).

These hypotheses were based on previous evidence suggesting that some adults with reading difficulties also presented motor and auditory problems (Ramus, 2003); processing speed deficit that affected both motor and literacy tasks (Stoodley & Stein, 2006), and experimental studies that showed poor audio-visual performance in adults with reading disorders (Conlon et al., 2011; Hairston et al., 2005; Harrar et al., 2014; Rose et al., 1999). The theory of Stein (Stein, 2001a, 2001b) who proposed a basic sensory involvement on phonological issues. Additionally, Laasonen and colleagues (2001, 2002) extended such findings by showing that dyslexic adults had impairments in tasks that included audio, visual, and tactile stimuli, and had a positive correlation between temporal acuity and phonological awareness.

6.3 Study 3A.

6.3.1 Methodology

6.3.1.1 Participants

One hundred and thirty-four adults participated in the study. Participation was voluntary and the study was described as an investigation into the way that people are able to use all of their senses (vision, hearing, touch) in everyday life, and those senses connection with learning. Participants were recruited via the university student volunteer list and social media via Facebook sponsored posts with a target audience of UK, English-speakers. Participants' responses to nine questionnaires were incomplete, and nine participants referred to having either hearing problems, visual non-treated problems or orthopaedic problems, so these participants were excluded from the final sample.

The final sample consisted of N = 116 adults; the mean age was 26.59 years (Range = 18-64, SD = 8.39) and 79 participants were female (see Table 6.1 with details). Of the participants, 62.9% had undertaken postgraduate studies (Masters, PhD or equivalent), and 35.3% had undertaken undergraduate studies. Two participants did not answer this question.

Two groups were created based on the participants' answers regarding whether or not they had experienced either early (13 participants) or early and current (13 participants) academic problems; one participant did not answer this question. Those who referred to academic problems were included in the learning difficulties (LD) group; 27 participants were in this group. Those who had no history of reading, writing or maths difficulties were taken as the typically learning group (89 participants).

Within the LD group, 70.4% referred to problems associated with literacy, and the rest of the participants referred to other problems, such as maths and problems related to executive functions (i.e. 'making connections').

Table 6.1. Participants characterisation

Group	Gender & Age	Study level	Learning characteristics
Typical group (typically learning)	27 Male 61 Female Total: 89 participants. Mean age: 25.9	Undergraduate: 28 Postgraduate: 60 Missing: 1	Adults who referred not having a history of reading, writing, and maths difficulties.
LD group (learning difficulties)	8 Male 18 Female Total: 27 participants. Mean age: 29	Undergraduate: 13 Postgraduate: 13 Missing: 1	Literacy problems: 19 Maths and other problems: 8
Surveys excluded:	Sensory conditions:	Untreated visual problems: 3 Untreated hearing problems: 2 Orthopaedic problems: 4	
	Incompletes: 9		

6.3.1.2 Measures and Procedures

Adults were invited to take part in the study by following a Qualtrics link. An information sheet was presented with an explanation of the details of the study, and then a consent form was presented, which asked for their permission to take part in the study. Adults who agreed to take part were asked to complete eight closed questions requesting demographic information including age, gender, academic qualifications and the presence of any learning problems, and when applicable, what kind of learning problems (reading, writing, and maths). The eight questions are shown in Table 6.2.

Table 6.2. Online questionnaire Study 3A

Questions	Alternatives
1. Which of the following describes how you think of yourself?	❍ Male ❍ Female ❍ In another way not listed here ❍ Prefer not to say
2. How old are you?	
3. Are you a native-speaker of English?	❍ Yes ❍ No
4. What is your current level of study?	❍ Postgraduate student (Master or equivalent). ❍ Postgraduate student (PhD or equivalent). ❍ Undergraduate student
5. Have you had any problems, such as difficulties with reading, maths, writing, during your primary and, secondary school education or university studies?– Except those related to the acquisition of a second language-	❍ Yes ❍ No
If answer yes (question 4) is selected. 6. When have you experienced learning problems? (Select all that apply)	❍ Primary school ❍ Secondary school ❍ Undergraduate ❍ Postgraduate
If answer yes (question 4) is selected. 7. Which of the following skills have you experienced learning problems? (Select all that apply)	❍ Reading ❍ Writing ❍ Maths ❍ Motor skills ❍ Other
8. Do you have any of the following conditions?	❍ Orthopaedic abnormality ❍ Untreated visual problems ❍ Untreated hearing problems.

After completing the demographic questionnaire, participants were presented with the Adults/adolescent sensory profile questionnaire (Brown & Dunn, 2002).

General self-report and specific self-report questionnaires of learning difficulties have been used previously and have been shown to be a useful measure to characterise difficulties and to identify group membership (Mortimore & Crozier, 2006; Nicolson & Fawcett, 1997; Parrila et al., 2007; Snowling, Dawes, Nash, & Hulme, 2012; Welcome & Meza, 2018). A study with adults (Nergård-Nilssen & Hulme, 2014), reported good correlations between objective literacy tests and self-report of literacy skills. Nergård-Nilssen & Hulme (2014) also found that the self-report scale differentiated significantly between individuals with and without literacy difficulties. The participants who stated that they had either current or earlier literacy difficulties showed more difficulties in spelling, word identification and phonological awareness and poor performance on cognitive skills associated with reading, compared with a typical reading group (Nergård-Nilssen & Hulme, 2014).

Adolescent / Adult Sensory Profile.

The Adolescent/Adult Sensory Profile (AASP; Brown & Dunn, 2002) was used in this study as a measure of the sensory profile of adults. The AASP was explained in detail in Chapter 3.

In Studies 3A and 3B, the questionnaire was conducted using Qualtrics online software. The paper questionnaire instructed participants to mark any statement that they were unable to answer because they had not experienced the situation. Thus, in the online version a 'does not apply' option was included. The statements were organized regarding six sensory systems: taste/smell, movement, visual, touch and auditory, and a scale of activity level.

6.3.2 Results

6.3.2.1 Data check and descriptive statistics

The data were screened for normality and outliers. Kolmogorov-Smirnov test and the visual inspection of histograms showed a normal distribution of the AASP scores, so parametric tests were used. First, the data were analysed with age as a covariate, because sensory functioning is known to be age-dependent. Overall, the results showed that age did not have a significant effect on the dependent variables of interest ($p>.05$).

6.3.2.2 Sensory processing profile of adults with learning difficulties.

Cronbach's alphas for the AASP sum of scales consisted of 60 statements was $\alpha =.824$, which indicates a good level of internal consistency for the scale with this specific sample.

6.3.2.3 Distribution of categorical scores along with the normative data.

Normative cut scores were used to classify participants into the five categories of the AASP that reflect groups of scores along a bell curve (more information of categories in Chapter 3, section 3.2).

The distribution of the scores of the typical and learning difficulties groups in each of the four quadrants data showed similarities between the groups. Both groups had an even distribution along the sensory profile categories, and only the Registration quadrant showed a greater percentage of scores in the 'More than others' category (55.6%) for the LD group. In terms of the normative data, the LD group showed 1SD above the mean in the Registration (1.36 SD) and Sensitivity (1.15 SD) quadrants. The scores of the typical groups mainly fell into the 'Just like the majority' category, with an average of 53.65%, and the other scores were spread between the 'Less than others' and 'More like others' categories (see figure 6.1). Chi-square test of independence showed that there was significant association between group and the sensory profile classification for Registration X^2 (3) = 14.24, p = .003, and Avoiding X^2 (3) = 8.72, p = .033. LD adults were more likely to show 'More than others' scores on those quadrants than the typical group.

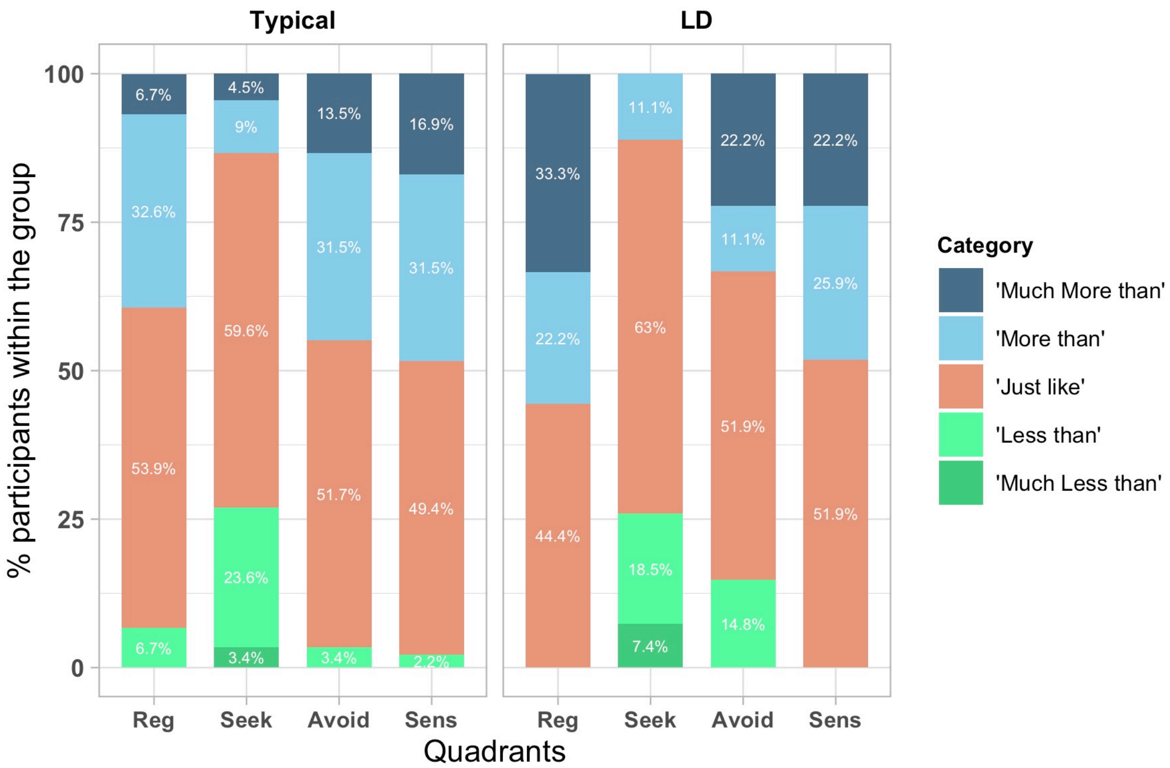

Figure 6.1 Representation of the groups on each of the four quadrants of Dunn's model along the categorical ranges. Quadrants: Reg= Registration, Seek= Seeking, Avoid= Avoiding, Sens= Sensitivity.

6.3.2.4 Mean comparison between groups.

A mean comparison test was run to provide evidence consistent with the idea that adults with learning difficulties will present maladjusted sensory behaviours, by comparing their profile with typically learning adults. The Levene's F test revealed that the homogeneity of variance assumption was not met (p <.05) for two of the sensory quadrants; as such, the Welch's F test was used to test the hypothesis.

The Welch robust test of equality of means revealed a significant difference between the groups on the sensory quadrant of Registration F(1, 35.1) = 4.656, p = .038, but no significant differences were found on the quadrants of Seeking F(1, 39.7) = .142 , p = .708, Avoiding F(1, 32.1) = .001, p = .981, and Sensitivity F(1, 35.3) = .744, p = .394. The direction of the difference found on the Registration quadrant indicated higher scores for the LD group compared to the typical group.

The comparison among the sensory systems showed no significant differences between the groups, with all of the p values being >.05.

Mean and standard deviation for both the typical and LD group was obtained. Table 6.3 shows descriptive scores for the two groups on the sensory profile questionnaire.

Table 6.3 Mean and SD on the AASP scales by group.

CSP-2	**TA Group** M (SD)	**LD Group** M(SD)	**Norms** M(SD)	**Welch** *p*	**Effect size** *d*
Sensory quadrants					
Registration	34.66 (6.94)	38.85 (9.33)	30.29 (6.2)	.038*	.509
Seeking	48.46 (8.02)	47.74 (8.88)	49.91 (6.8)	.708	.085
Avoiding	40.01 (7.76)	40.07 (12.6)	34.57 (7.3)	.394	.005
Sensitivity	40.62 (8.10)	42.56 (10.7)	33.71 (7.6)	.981	.204
Sensory systems					
Auditory	31.73 (6.35)	33.19 (8.59)		.421	.193
Visual	27.64 (5.38)	27.79 (5.38)		.786	.020
Touch	32.57 (4.64)	34.15 (7.36)		.317	.256
Movement	21.20 (4.37)	22.70 (5.69)		.215	.295
Taste/Smell	21.91 (3.41)	21.41 (3.43)		.508	.146
Activity level	28.70 (4.57)	29.81 (4.86)		.295	.235

Norms extracted from the Adolescent/Adult Sensory Profile, the manual does not provide individual norms for the sensory systems (Brown & Dunn, 2002, page 20). Significant differences between groups at *<.05. Effect size= Cohen's *d*.

In summary, the comparison of the sensory profile between adults with and without learning difficulties showed that those with LD presented more engagement in behaviours on the high neurological threshold and passive self-regulation strategies. Also, scores above the mean on Sensitivity quadrant that represent low neurological threshold and passive self-regulation. The other quadrants that included low and high neurological threshold with active self-regulation strategies presented a similar profile to the typical group.

6.4 Study 3B

6.4.1 Methodology

6.4.1.1 Participants

One hundred and twenty-one adults participated in the study. Participation was voluntary. The study was an investigation into the way that people are able to use all of their senses (vision, hearing, touch) in everyday life, and their connection with learning and reading. Participants were recruited via a university student volunteer list from two institutions in the UK. In total, forty questionnaires were excluded due to being either incomplete and/or surveys from participants who referred to having sensory conditions (hearing problems, visual non-treated problems or orthopaedic problems). The final sample consisted of n = 81 adults; the mean age was 26.7 years (Range = 18-56, SD = 8.66) and 65 participants were female (see Table 6.4 for details). In the sample, 56.8% of the participants had studied at postgraduate level (Masters, PhD or equivalent), and 43.2% had undertaken undergraduate studies, and 66.7% of the participants were native English speakers.

Table 6.4. Participants characterisation

Gender	Age	Study level	Language
16 Male 65 Female Total: 81 participants.	Range 18 - 56 Mean age: 26.7	Undergraduate: 35 Postgraduate Master: 21 PhD: 25	English native speaker: 54 Other language: 27
Surveys excluded:	Sensory conditions:	Untreated visual problems: 3 Untreated hearing problems: 2 Orthopaedic problems: 1	
	Incompletes: 34		

6.4.1.2 Measures and Procedures

Adults were invited to take part in the study by following a Qualtrics link. An information sheet was presented with an explanation of the details of the study, and then a consent form was presented that asked for their permission to take part in the study. Adults who agreed to take part were asked to complete five closed questions requesting personal information including age, gender, and academic qualifications (see Table 6.5).

Table 6.5 Online questionnaire for Study 3B

Questions	Alternatives
1. Which of the following describes how you think of yourself?	○ Male ○ Female ○ Prefer not to say
2. What is your date of birth? (dd/mm/yyyy)	
3. Are you a native-speaker of English?	○ Yes ○ No
4. What is your current level of study?	○ Undergraduate student ○ Postgraduate student (Master or equivalent). ○ Postgraduate student (PhD or equivalent).
5. Do you have any of the following conditions?	○ Orthopaedic abnormality ○ Untreated visual problems ○ Untreated hearing problems.

After completing the five questions, participants were presented with a subscale of the AASP, a reading questionnaire (ARQ), and a reading task.

Adolescent / Adult Sensory Profile.

The Adolescent/Adult Sensory Profile (AASP; Brown & Dunn, 2002) was used to characterize the sensory characteristics of participants. Study 3A showed significant differences between groups of adults with and without learning difficulties in the Registration quadrant of the AASP (p=.038) (see section 6.4.2.2) so this quadrant was selected for Study 3B.

The AASP contains a total of four subscales that enable the calculation of scores for each of the four quadrants independently (such as the Registration quadrant), which makes it possible to administer only one of them (Brown & Dunn, 2002; Brown et al., 2000). However, because the Registration scale is made up of only 15 items, the individual scores for each sensory system was not calculated. The items administered asked about specific behaviours associated to the Registration quadrant, such as "I seem slower than other when trying to follow an activity", "I don't notice when my name is called", and "I get scrapes or bruises but don't remember how I got them". The 15 statements of the Registration quadrant subscale were administered to participants, using Qualtrics online software.

The survey consisted of 15 Likert-style five-point statements, ranging from "almost never" (0) to "almost always" (5). The paper questionnaire instructed participants to mark any statement if they were unable to answer it because they had not experienced the situation. Thus, in the online version a "does not apply" option was included. Scoring of the questionnaire was made following the procedures of study 3A (see section 6.3.1.2).

Adult Reading Questionnaire (ARQ)

The ARQ was designed by Snowling, Dawes, Nash, and Hulme, (2012) based on the Adult Dyslexia Checklist (Smythe & Everatt, 2001) and is useful for identifying adults with reading difficulties (Leavett et al., 2014; Snowling et al., 2012). The ARQ is a self-report of reading and related skill, it includes nine statements that underlie three factors regarding aspects of reading (items 1, 2, 3, 5 & 6), word finding (items 7, 8, 9, and attention (item 10), two items required the respondent to rate how frequently they read and write (items 4 and 11), plus four questions about dyslexia diagnosis. The statements included questions regarding reading and self-spelling proficiency, frequency of reading and writing and self-report of dyslexia. Items from the questionnaires were scored numerically, with higher scores associated with more severe difficulty or greater likelihood of impairment. Item scores ranged from 0–1or 0–4, depending on the question (see Table 6.6 for ARQ items and scoring details).

The validation of the questionnaire was made with a sample of 417 adults from a major study with families with and without a history of dyslexia (Wellcome Language and Reading Study, Nash, Hulme, Gooch, & Snowling, 2013). The mean age of the participants was 36.17 years (SD= 6.33). Participants were asked to complete the ARQ questionnaire, the adult ADHD scale, and four psychometric tests, which included a nonverbal ability task, a vocabulary task, a spelling task and a reading task. The authors (Snowling et al., 2012) reported good reliability of the questionnaire (alpha over .58) and provided normative cut off scores for each scale based on the parent-reports. The reading factor showed a strong correlation with literacy skills, which provides a good validity measure.

Table 5.6 shows the normative data for the first 11 statement of the questionnaire. Scores close to zero reflected better reading skills and less likelihood of having reading disorders.

Table 6.6 Adult Reading Questionnaire normative data

Statement	Mean	SD	Min.	Max.
1. Do you think you are a good reader?	0.17	0.36	0	1
2. Can you read quickly and easily?	0.21	0.40	0	1
3. How good is your spelling?	0.84	0.81	0	3
4. In your job, how often do you read?	0.91	0.95	0	4
5. Do you find it difficult to read words you haven't seen before?	1.48	1.00	0	4
6. Do you find it difficult to read aloud?	1.19	1.15	0	4
7. Do you find it difficult to find the right word to say?	1.59	0.81	0	4
8. Do you ever confuse the names of things?	1.29	0.88	0	4
9. Do you confuse left and right	0.96	1.18	0	4
10. Do you have problems with organization or time management?	1.30	1.04	0	4
11. How often do you write in everyday life?	1.03	0.95	0	4
12. Based on this, do you think you are dyslexic? (yes/no/maybe)				
13. How would you rate your difficulties? (no difficulties/ mild / moderate/ severe)				
14. Has anyone ever raised concerns about your reading? (yes/no)				
15 Have you ever had a diagnosis of dyslexia? (yes/no) If YES, by whom?				

Min. and Max. correspond to the minimum and maximum response values of the scale respectively.

Reading task

Study 3B included a reading task to assess the performance of participants when reading single words. The task was based on the application “Assess for Success” (Nicolson, Fawcett & Jones, 2018), and was modified to be used in Qualtrics. The objective was to measure the speed and accuracy of participants while reading. The task consisted of reading a list of single words and selecting a category for each one from animals, numbers, clothes, household and fruits in a maximum of 120 seconds. The maximum score for the task was 54 points.

From the reading task two types of scores were obtained, the number of correct responses, which was a measure of accuracy, and the reaction time, which was the time taken to complete the task. There were no normative cut-offs available for this task, so the results will be used for descriptive purposes and correlation analyses.

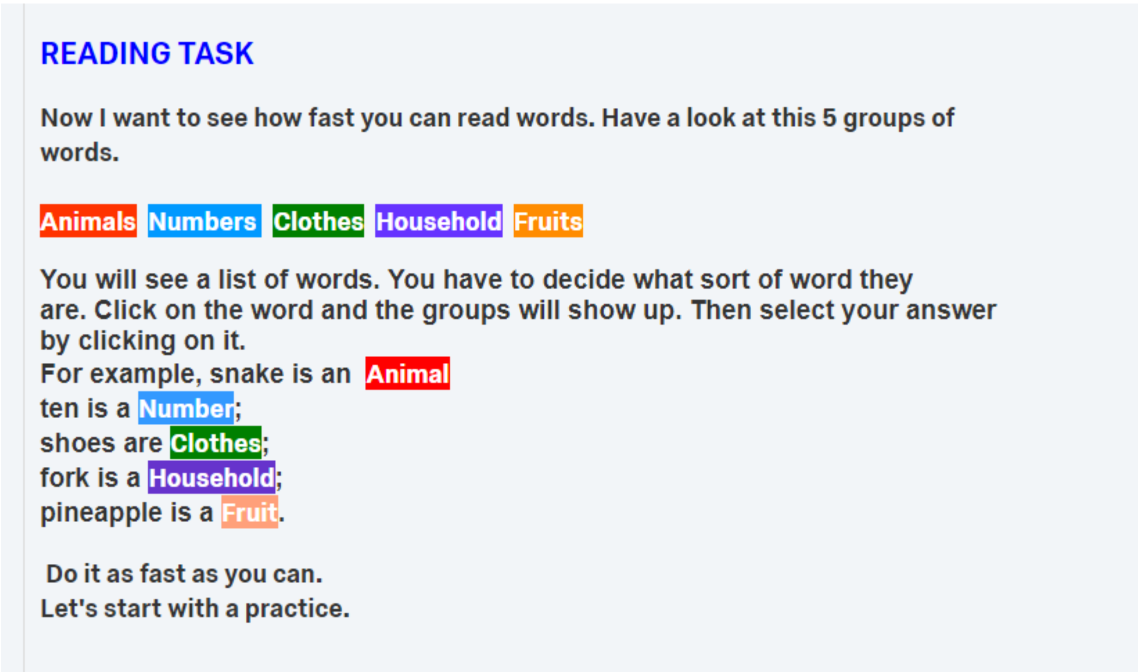

Figure 6.2 Example of the instructions of the reading task.

6.4.2 Results

6.4.2.1 Data check and descriptive statistics

The data were screened for normality and outliers, and non-parametric tests were used for the analysis due to the non-normal distribution of most of the variables.

For the ARQ, following the validation procedures (Snowling et al., 2012), the sum of the items 1, 2, 3, 5, 6, 7, 8, 9 & 10 was used to obtain a general ARQ score for reading, which will be called the ARQ-G for now on. Items 4 and 11 contained statements regarding the frequency of reading and writing, and items 12 to 15 were qualitative self-report statements, so none of them were included in the quantitative analysis.

Descriptive statistics of the overall scores for ARQ-G, the reading task and the sensory profile Registration quadrant, are shown in Table 6.7.

Table 6.7 Descriptive statistics for ARQ-G, reading tasks, and AASP.

Task	Mean	SD	Min.	Max.
Adult reading questionnaire				
ARQ-G	9.13	4.26	1	20
Reading measures				
Correct responses	52.19	3.54	36	54
Reaction time	101.62	14.17	68.86	120.07
AASP				
Registration quadrant	29.76	9.11	13	58

Min. and Max. correspond to the minimum and maximum raw scores obtained by the sample.

6.4.2.2 Reading abilities

Both the ARQ and the reading task were included in Study 3B to test the literacy skills of the participants. The last four questions of the ARQ addressed the self-report of participants about having a dyslexia diagnosis. Only 7% of participants responded positively to these questions; thus, the majority of participants referred not having reading disorders. Concerning the frequency of reading and writing participants self-reported that 85.2% of them always or frequently read, and that 82.7% of them always or frequently wrote.

Similar to the results of the self-report, the results of the reading task showed that 60.5% of the subjects accurately completed the full task; 12.3% failed in one item. The participants who failed in between 2 to 18 items were 27.1% of the sample. The correlation between the correct responses and reaction time showed a significant negative association ($r_s = -586$, $p<.01$), which mean that participants who were more accurate in their answers were also faster in completing the task.

Cronbach's alpha for the ARQ-G (items 1, 2, 3, 5, 6, 7, 8, 9 & 10) was $\alpha = .735$, which indicates an acceptable level of internal consistency for the scale with this specific sample. A Spearman's correlation test was run to assess the relationship between the scores of the ARQ-G and the reading task correct response scores and the reading task reaction times. There was no correlation between the general ARQ-G score and the two scores of the reading task ($p > .05$), and only marginal correlations at $p<.05$ between some items of the ARQ and the reading task.

In summary, most of the participants obtained top scores on the reading task, which means that the task had a ceiling effect because it was not difficult or challenging enough for the participants. The reading task did not show a significant association with the ARQ-G, which confirmed its lack of sensitivity in terms of measuring literacy skills.

6.4.2.3 Sensory profile characteristics and association with reading.

Cronbach's alphas for the Registration subscale of the AASP was $\alpha = .863$, which indicates a good level of internal consistency for the subscale with this specific sample. The overall score of Registration is located at the mean regarding the normative cut-off. The analysis of the categorical scores showed that the majority of the participants (48.1%) in Study 3B obtained scores in the 'Just like the majority' category (mean), 30.9% fell into the "Less than others" category (below the mean), and 21% obtained scores in the "More than others" category (above the mean). The Registration scale did not meet the criterion of normality (Kolmogorov-Smirnov = .013), but the distribution of the scores among the three categories had a normal-like trend, with most of the participants showing adequate behaviours in response to sensory stimuli.

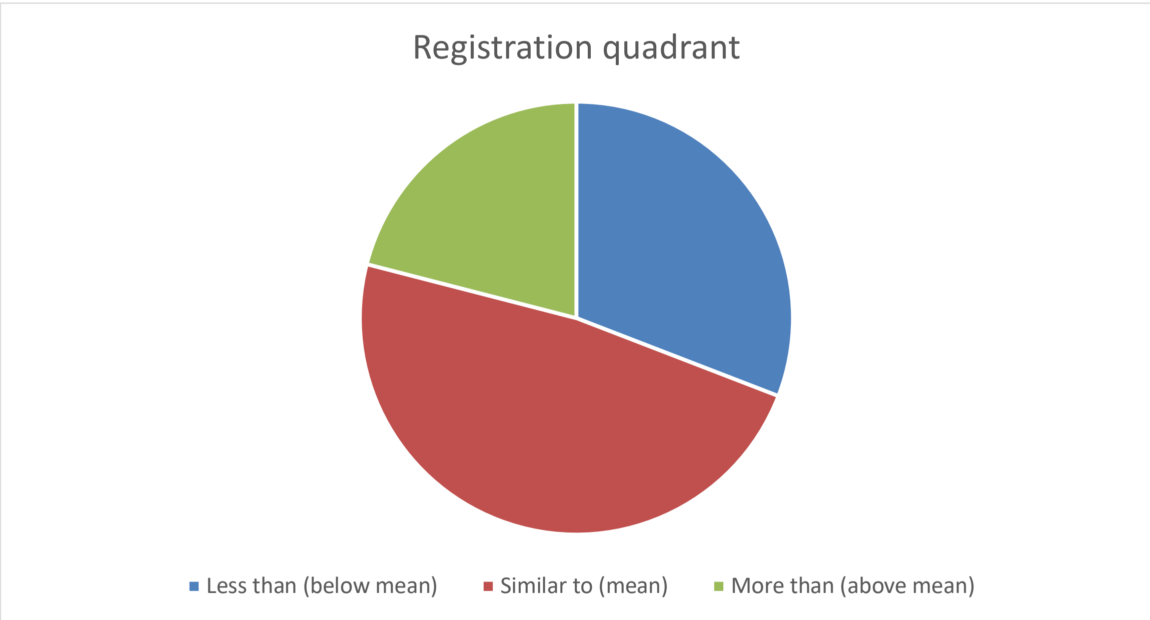

Figure 6.3 Registration quadrant, distribution of categorical scores

A Spearman's correlation test was run to assess the relationship between the scores for the Registration scale and the reading task scores and the ARQ scores (see table 6.8). Bonferroni correction was used with a significant alpha level at $p<.004$.

There was no significant correlation between the Registration quadrant and the two scores for the reading task. The correlations between the Registration quadrant and the ARQ-G showed a significant positive association, as well as with specific statements from the word finding factor (items 7, 8, 9).

Table 6.8 Correlations between measures of the AASP, ARQ, and reading task

	Registration quadrant
Adult Reading Questionnaire (ARQ)	
ARQ-G	.539**
ARQ 1	.148
ARQ 2	.153
ARQ 3	.108
ARQ 5	.271*
ARQ 6	.377**
ARQ 7	.498**
ARQ 8	.495**
ARQ 9	.345**
ARQ 10	.297*
Reading task	
Corr. resp	.114
React.time	-.167

Correlation significant at *p<.05; Bonferroni corrected at **p <.004

Linear regression was conducted to evaluate whether the Registration quadrant was necessary to predict the measure of reading skills of participants (ARQ-G). The outputs of the test showed relationship between the Registration quadrant and ARQ-G (p <.001). The slope coefficient (unstandardized B) showed that the scores of the ARQ-G will increase by .304 points as the scores on Registration increases. The R^2 value was .421, which indicates that 42.1% of the variation in the ARQ-G can be explained by the Registration scores. The scatterplot (figure 6.4) of standardised predicted values versus standardised residuals, showed that the data met the assumptions of homogeneity of variance and linearity and the residuals were approximately normally distributed (Figure 6.5).

Table 6.8. Regression outcome

Model		**B**	**Coefficient std. error**	**Standardized coeff. Beta**	**t**	**Sig.**
1	Registration	.304	.040	.649	7.585	.000

Stepwise method, dependent variable ARQ-G
Model 1 summary: R=.649; R^2=.421; Adjusted R2=.414

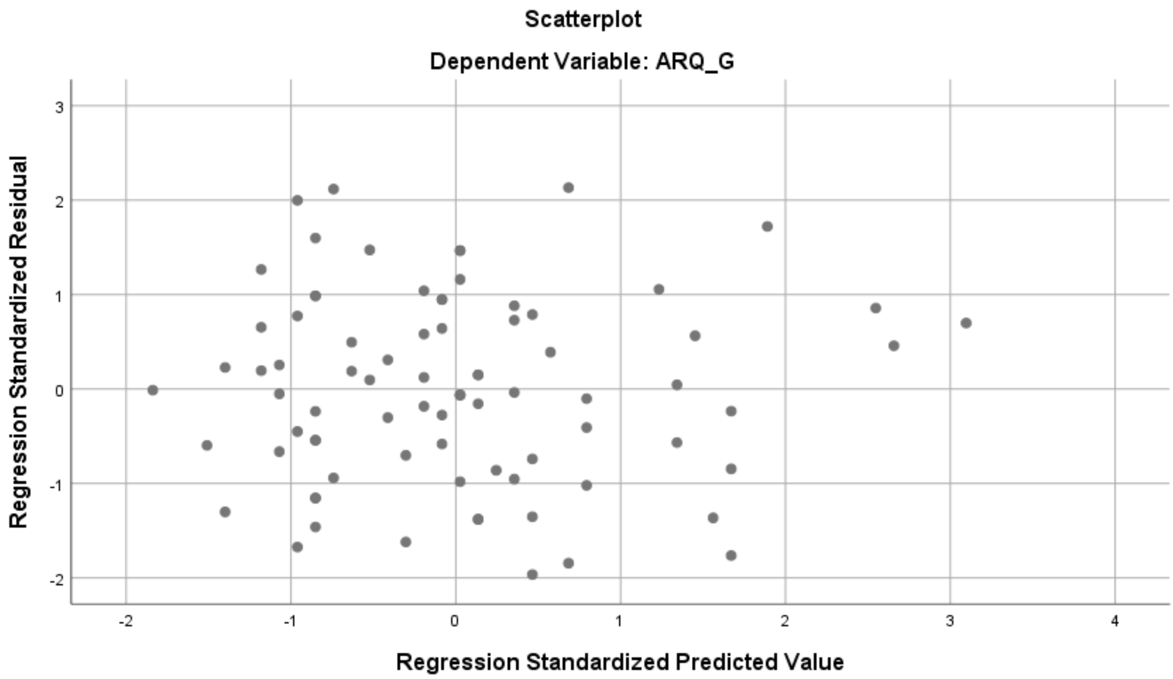

Figure 6.4 Scatterplot shows homoscedasticity of data.

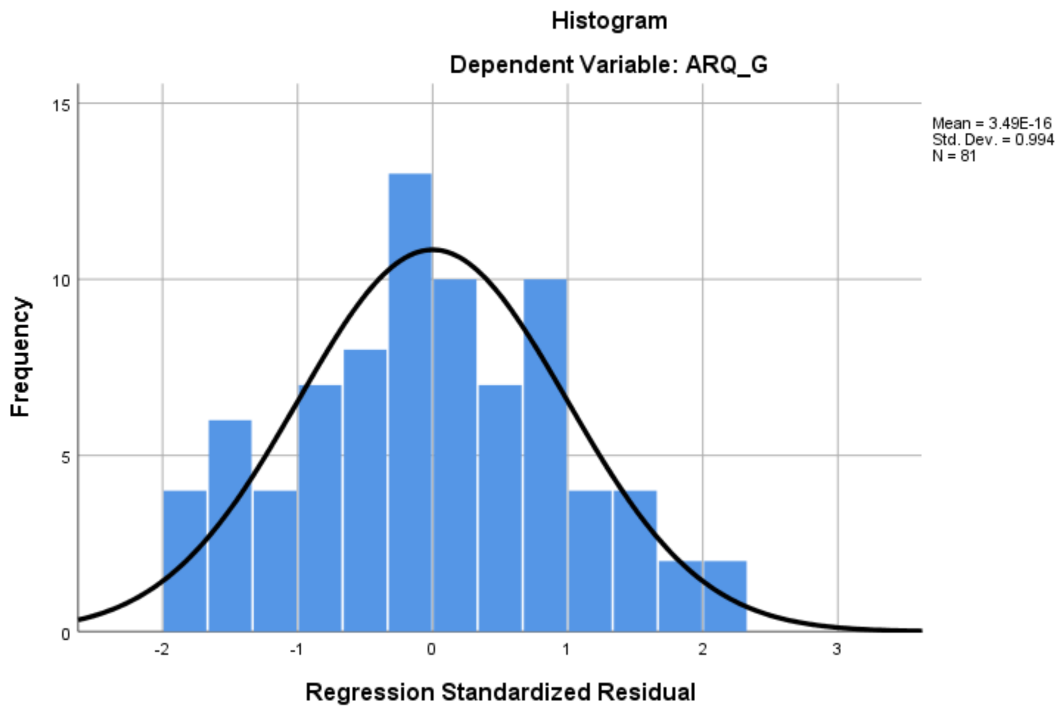

Figure 6.5 Histogram shows normality distribution of residuals

6.5 Discussion

Studies 3A and 3B characterised the sensory processing profile of adults and explored their association with learning problems. Consistent with the literature, this research found that participants who reported having learning difficulties presented some differences with adults without learning difficulties on their sensory processing profile. The scores for the Registration quadrant were higher for the LD group, and the percentage of subjects in the 'More than others' category was greater than the typical group. Besides, the quadrant of Sensitivity showed scores above the normative mean, but no differences between the groups. Thus, it can be inferred that the sensory profile of adults would be characterized by a trend to behave in a passive way and high frequency of behaviours in the high neurological threshold, and a lesser frequency of low neurological threshold (Dunn, 1997; Little et al., 2016).

In Study 3B there was a significant correlation between the Registration quadrant and the reading questionnaire (ARQ), but not with the reading task. These results demonstrated an association between sensory-related behaviours and self-report of reading proficiency, but not between performance measures of reading. The results will be discussed below.

6.5.1 Sensory profile of adults with learning difficulties

The results of Study 3A showed differences on the Registration quadrant in groups with and without LD, and scores above the mean on Sensitivity, but no other differences, either in the quadrants or in the sensory systems. According to Dunn's definition (Brown & Dunn, 2002; Dunn, 1997b) the adults with LD would display passive self-regulation behaviours to respond to environmental demands, with a sensory profile mainly in the high neurological threshold. Overall, this sensory profile appears relatively close to the expected behaviour for typical adults, since the statistically significant differences were in one sensory quadrant only (Registration).

These results may be explained by neurological maturation and by the influence of academic and personal experiences (Olofsson, Taube, & Ahl, 2015b; Peiffer et al., 2007; Wallace et al., 2006; Wallace & Stein, 2001). Previous researchers using the same framework of sensory processing (Brown & Dunn, 2002; Dunn, 1997) have demonstrated that sensory abilities peak during adulthood (Engel-Yeger et al., 2012; Pohl et al., 2003). Similarly, Kern et al. (2007) reported a smaller gap on the sensory profile of older adults with ASD and those from the typical population, which is interpreted as an improvement in the sensory abilities of those adults with ASD, although they still presented behaviours that might cause a maladaptation to the environment. The broad age group of the participants of the Study 3A (18 – 64 years old) may have impacted in these results since at early adult age an enhancement of the sensory functioning is to be expected (Hartcher-O'Brien et al., 2014; Hillock et al., 2011; Lewkowicz, 2012), but later, a degenerative process is expected (Engel-Yeger et al., 2012; Wickremaratchi & Llewelyn, 2006).

As mentioned in the introduction to Chapter 5 some researchers (Brosnan et al., 2002; Gregg, 2014; Hämäläinen et al., 2005; Kemp et al., 2009; Lefly & Pennington, 1991; Parrila et al., 2007) have suggested that learning difficulties change throughout development and that adults might be able to overcome their difficulties as they learn from experiences. Adults with university education were the majority of the sample in both studies 3A and 3B; therefore, these group of subjects with LD may have learnt to compensate for their difficulties, so they may have both a better academic performance and functional sensory processing strategies than those who have not attained higher education. The interaction between experience-driven changes and neural maturation may have an impact on sensory-related behaviours (Koziol et al., 2011). Further studies are needed to investigate this issue.

Some studies (Felton et al., 1990; Hämäläinen et al., 2005; Kemp et al., 2009; Mortimore & Crozier, 2006; Nergård-Nilssen & Hulme, 2014; Smith-Spark et al., 2003) have reported that there are remaining problems in reading, spelling, executive function, and others even for adults who have met the requirements of university entrance. These mild but remaining difficulties may have a negative impact on the attainment of the academic goals of adults with a background of learning difficulties (Olofsson et al., 2015; Richardson & Wydell, 2003). Leavett, Nash, & Snowling (2014) compared adults who self-reported as dyslexic with those who did not, concerning actual performance tests. Leavett et al. (2014) concluded that adults with more severe literacy difficulties were more likely to self-report as dyslexics, but those adults who had overcome their learning difficulties would not have reported themselves as having LD. Taking this together with the findings of Leavett et al. (2014), the ability to overcome learning difficulties may have influenced the participants' answers, and so miss-classified those who should have been allocated to the LD group.

6.5.2 Association between sensory profile and learning difficulties measures

Study 3B showed a correlation between the AASP scores and the ARQ, but not with the performance in the reading task. Additionally, the regression analysis showed a significant effect of the Registration sensory quadrant as a predictor of reading difficulties. Similar results were found in Study 2 between the AASP and the CLDQ, and Registration as a significant predictor of learning difficulties (see Chapter 5, section 5.4.3). These findings suggest that the sensory-related behaviours measured by the sensory profile questionnaires - both the adult and children versions – do correlate with learning difficulties. Furthermore, the Registration quadrant is a significant predictor of learning difficulties. These finding may be interpreted as a positive association between a high likelihood of learning difficulties, and a great frequency of behaviours associated with sensory stimuli within the quadrant of a high neurological threshold and passive self-regulation strategies. Further analyses showed that the most relevant associations were with the items 6, 7, 8 & 9 of the ARQ. One of these items represented the reading factor and the rest represented the word-finding factor of the ARQ. The word-finding factor has been associated with expressive language, as a dyslexia-associated trait (Snowling et al., 2012).

The results of no association between the ARQ with the performance on the reading task in study 3B may be due to a flaw of the measure to assess different levels of reading ability, also known as ceiling effect (see Taylor, 2012 for more information about ceiling effect) since most participants obtained the maximum score.

Hence, how are high scores on the Registration quadrant associated with adults learning? In Study 3A, the Registration quadrant showed significant differences between adults with and without LD, and over half the adults in the LD group obtained scores in the 'More than others' category (see figure 6.1). Therefore, while learning problems are commonly studied during the early years, there are cognitive skills that may remain low even when reaching adulthood (Francis et al., 1996; Scarborough, 1984). In the same way, Dunn's (1977) model of sensory processing depicted the sensory preferences as stable traits; therefore, it is likely that sensory processing lags would be found in adults. The statements that belong to the Registration quadrant were written to expose the amount that a person notices or misses sensory information based on responses across various sensory domains, for example, 'I don't notice when my name is called' (auditory), or 'I am unsure of footing when walking on stairs' (movement) (Brown & Dunn, 2002). The Registration quadrant represents disengagement behaviours from on-going circumstances, a loss of experiences from daily life routines, and passive response strategies. The individuals may need more time to respond to stimuli than others who already notice and present quick habituation to stimuli. The Sensitivity quadrant did not present significant differences between the groups, but there was clinical significance for the LD group according to Dunn's criterion (Brown & Dunn, 2002). High frequency of behaviours in this quadrant may represent an over-sensitivity to subtle stimuli (Brown & Dunn, 2002). Although Registration and Sensitivity are opposite quadrants in the continuum of high and low threshold, it is important to remark that the sensory preferences may change in regard to the environmental needs and contradictory behaviours can coexist in the same individual (Dunn, 1997b).

This sensory profile may contribute to the underachievement in the academic context and the need of more hours of study for adults with history of LD compared with typically learning peers (Mortimore & Crozier, 2006; Olofsson et al., 2015; Richardson & Wydell, 2003). However, high Registration may be beneficial for some individuals who need to focus on specific tasks by avoiding the surrounded stimuli (Dunn, 1997). Nevertheless, although Dunn's framework justifies the presence of contradictory sensory profiles in the same individuals as related to circumstantial environmental demands. The presence of sensory-related behaviours in opposite neurological thresholds challenges the sensory processing profile framework and raise the question of subgroups, as suggested in previous studies (Gonthier et al., 2016; Little et al., 2016). Thus, the possibility of subgroups of the sensory profile means that the identification and generalization of a particular sensory profile for adults with LD may not be not feasible.

There were limitations to Study 3A. First, the small number of participants in the LD group might have been an under-representation of the group. Second, the sensory processing measures were restricted to self-report data, so it is important to bear in mind the possible bias in these responses and possible miss-classification of the sample (Leavett et al., 2014; Reid, 2009; Schoen et al., 2014). For Study 3B, it would have been an advantage to have information of the participants' performance in a battery of cognitive tests, to obtain more information of their abilities. Additionally, although the variable of age did not have a significant effect on the dependent variables of interest, a limitation is that the sample was not matched by age. The participants were from late adolescents to old age adults which may have affected the results because of age-specific sensory differences.

CHAPTER 7

STUDY 4: SENSORY PROCESSING PROFILE OF CHILDREN WITH AND WITHOUT NEURODEVELOPMENTAL CONDITIONS.

7.1 Introduction

In Study 1, the results showed significant differences in the sensory processing profile on three sensory quadrants, and the body position sensory system when compared children with and without LD associated with reading problems. While the results provide evidence of a particular sensory profile for children with LD, it is relevant to take into account key variables, such as comorbidity. As explained in Chapter 2 (section 2.1), the individual differences and variety of symptoms within the learning difficulties may be associated with other conditions that co-occur (Reid, 2009; Vellutino et al., 2004). Study 4 extended the finding of Study 1 by examining a larger sample of children and including a comorbidity component that may account for the sensory processing outcomes of children. Since neurodevelopmental disorders are known to overlap with other conditions (Stein, 2012), it may be expected to find a sensory profile linked with the developmental trajectory of the participants. Thus, Study 4 explored whether or not there were differences in the sensory profile between typical children and those with neurodevelopmental disorders. Study 4 also explored whether or not the sensory profile of neurodevelopmental disorders such as ASD, ADHD and SLI combined with learning difficulties differed to the sensory profile of children with LD only.

The link between LD and sensory processing issues has previously been stated, although still controversial (see Laasonen et al., 2002; Rose et al., 1999; Tallal et al., 1993) more research is needed (see Chapter 2, section 2.4). This section presents a review of some neurodevelopmental disorders that have high comorbidity with LD and their sensory processing implications.

7.1.1 Neurodevelopmental disorders and comorbidity.

The group of neurodevelopmental disorders was defined in Chapter 2 as a group of conditions manifested in the early development period that may affect a person in different areas such as personal, social, academic or occupational (American Psychiatric Association, 2013; Reed & Warner-Rogers, 2008; Vargo, 2015). The range of deficits and their severity varies from defined difficulties in some functions to pervasive impairments that affect overall development and may delay some milestones (American Psychiatric Association, 2013). The conditions that belong to the neurodevelopmental disorders group often co-occur in the same individuals, which is also mentioned as overlapping or comorbidity between conditions (Kaplan et al., 2001). The concept of comorbidity comes from the health sciences to describe the co-occurrence of two or more conditions in the same individual (Feinstein, 1970). Comorbidity refers to the probability that a child with a primary diagnosis of neurodevelopmental disorders will be diagnosable with a second (Reed & Warner-Rogers, 2008). Specific learning difficulties present high comorbidity with other developmental disorders, and problems in other areas such as motor skills and executive function (Gooch, Hulme, Nash, & Snowling, 2014).

Due to the recurrently high overlap among the neurodevelopmental disorders group, some authors have pointed out the difficulty of considering these disorders as individual entities. Kaplan et al. (2001) studied school-age children and found that more than half the children had at least one other associated condition. Based on their findings and the revision of previous studies, Kaplan and colleagues proposed that the concept of comorbidity is inaccurate and that, rather “atypical brain development” would characterise those developmental problems that often overlap. Gilger and Kaplan, (2001) posited that the occurrence of comorbidity among the neurodevelopmental disorders is a rule rather than an exception, and this can be also found within the LD, where mathematics, spelling or writing skills rarely are affected in isolation. Hence, reading and mathematical failures would share neuropsychological flaws associated with some executive functions (working memory), processing speed and verbal comprehension (Willcutt et al., 2013). This comorbidity 'rule' questions the aetiology and independence on the manifestation of the neurodevelopmental disorders (Gilger & Kaplan, 2001; Karmiloff-Smith, 2009; Kruger et al., 2001). On the other hand, a recent study (Pullen, Ashworth, & Ryoo, 2019) supported the proposed of Hallahan and colleagues providing further evidence on the legitimacy of the construct of LD, by showing a minimal variability within the learning disabilities. The heterogeneity on the manifestation of learning difficulties, particularly reading disorders or dyslexia, is well recognized (Cumming et al., 2015; Harrar et al., 2014; Nicolson et al., 2010; Swanson et al., 2013) and may explain the presence of symptoms no related to phonological deficits. However, Bental and Tirosh, (2007) found that children with comorbidity of ADHD and RD experienced unique problems in rapid naming and severe problems in working memory that those with the pure conditions, thus the comorbid group may differ in their range and severity of problems than pure RD or ADHD children.

ADHD, SLI, and LD present high comorbidity, which has been reported in several studies (e.g. Alloway, Tewolde, Skipper, & Hijar, 2017; Brookman, McDonald, McDonald, & Bishop, 2013; Kaplan et al., 2001; Martin, Levy, Pieka, & Hay, 2006). In terms of ASD, its manifestation is extremely varied and its symptoms included deficiencies in different areas of the development (Matson & Cervantes, 2014). The presence of learning difficulties in both literacy and numeracy are common within the manifestation of ASD (American Psychiatric Association, 2013). Further explanation of each of these conditions is given in the next sections.

7.1.1.2 Autism Spectrum Disorders (ASD)

Autism spectrum disorder is a complex neurodevelopmental disorder that encompasses a wide spectrum of symptoms that vary in severity (Frith, 2008; Stein, 2012; Vargo, 2015). There is general agreement about the three core deficits that are common in all manifestations of ASD: difficulties in social interactions, difficulties in communication and language skills, and restricted areas of interests with some stereotypical behaviours (such as repetitive body movements or repetitive movement of objects) (American Psychiatric Association, 2013; Frith, 2008). Children within the autism spectrum may present a broad repertory of behaviour, with or without IQ decline.

Genetic and neurological studies of ASD has provided relevant insight to understand this condition (Marti-nez-Sanchis, 2014). The heritability of ASD is estimated to be above 45% (Hallmayer et al., 2011). A meta-analysis revision of fMRI studies on ASD (Philip et al., 2012) reported consistent differences in the activation of the social brain in ASD participants, and a failure in the integration and modulation of functional brain regions that may have an impact on different cognitive tasks, such as visual processing, executive functions, and social processing.

LD may accompany the main condition of ASD as part of its broad range of symptoms (Frith, 2008). The performance of subjects with ASD in academic abilities like reading, writing and mathematical calculations, is associated with the IQ range - better performance when close to the mean -, and age - the academic skills enhance through age - (Mayes & Calhoun, 2003). Subjects with ASD may present some weaknesses in academic functioning, for example, poor reading comprehension is often observed in ASD subjects (O'Connor & Klein, 2004). But also, there have been reported some strengths in the academic profile of subjects with high functioning autism (subjects with IQ close to the mean), such as adequate performance on word identification, decoding and automaticity (Vargo, 2015).

7.1.1.2 Attention-Deficit / Hyperactivity Disorder (ADHD)

Attention deficit hyperactivity disorder is a common life-long disorder with onset on the childhood (American Psychiatric Association, 2013). An ADHD diagnosis is given when inattention, hyperactivity, and impulsivity are manifested at more severe levels and with more frequency than is developmentally expected (Vargo, 2015). Inattention entails difficulties with maintaining focus on a specific task; hyperactivity refers to excessive motor activity unrelated to the environmental demands; and impulsivity is the need for immediate rewards or the inability to delay gratification (Dionne-Dostie et al., 2015).

Kaplan et al. (2001) posited that children with a diagnosis of ADHD have an 80.4% of chances of having a second disorder, so the occurrence of this condition alone is unlikely. The comorbidity between LD and ADHD is large, ranging from 10% to 50%, this comorbidity is presented most commonly with reading difficulties (Bental & Tirosh, 2007; Dykman & Ackerman, 1991). The occurrence of reading disorders and ADHD has been observed especially with the inattentive subtype (Martin et al., 2006), and processing speed has been identified as a shared predictor of reading disorders and ADHD (Mcgrath et al., 2011). Gender differences have been informed on the comorbidity between reading disorders and ADHD, boys would present more hyperactivity-impulsivity signs than girls (Willcutt & Pennington, 2000a). Twin analysis indicated genetic factors that influence the comorbidity between reading disorders and ADHD (Willcutt et al., 2010; Willcutt, Pennington, Olson, & Defries, 2007).

7.1.1.3 Specific Language Impairment (SLI)

SLI is a neurodevelopmental disorder characterised as developmental delays and deficits across different areas of the language domain (Vargo, 2015). SLI and specific learning difficulties like dyslexia are both related to poor development of language in the absence of intellectual discrepancy, and the exclusion of socio-emotional, and sensory-based deficits, though the aetiology and manifestations are different (Catts, Adlof, Hogan, & Weismer, 2005). While dyslexia is a specific learning difficulty manifested by problems in learning the written language (see Chapter 1, section 1.2), SLI is a developmental communication disorder, related to oral language (American Psychiatric Association, 2013).

The diagnosis of SLI is given when children show difficulties in the oral component of language, manifested by semantic, syntax, and discourse failures (Catts et al., 2005). The oral component comprises two skills: expressive, which refers to the production of vocal, gestural, or verbal signals; and receptive, which refers to the process of receiving and comprehending those language signals (American Psychiatric Association, 2013). Besides, Briscoe, Bishop, and Norbury, (2001) have reported phonological issues in children with SLI, including phonological awareness impairment. Poor word reading and word recognition have been observed in children with SLI at a high rate - of about 35 -50% - which may be related to phonological lags (Catts, Fey, Tomblin, & Zhang, 2002; McArthur et al., 2000; Nathan, Stackhouse, Goulandris, & Snowling, 2004; Snowling, Bishop, & Stothard, 2000).

The overlap between SLI and reading disorders can be manifested by similarities in the cognitive impairments of both conditions, associated to a phonological deficit, and similarities in their aetiology due to genetic influences (McArthur et al., 2000; Pennington & Bishop, 2009).

7.1.2 Sensory processing and neurodevelopmental disorders.

Several studies that provided evidence of sensory processing impairments linked to neurodevelopmental disorders were presented in Chapter 2 (section 2.4) (e.g. Cheung & Siu, 2009; Kruger et al., 2001). It has been proposed that children with learning, behaviour and motor difficulties often show associated impairments in sensory processing (Beaudry-

Bellefeuille, 2006). Therefore, sensory abilities are an important feature in development, and sensory issues can be significant underlying difficulties associated with different conditions that may affect the development (Ayres, 2005).

As pointed out previously in section 7.1.1, given the high comorbidity among the neurodevelopmental disorders, it would be expected to find some similarities in the sensory profile of the different conditions. However, at the same time as the sensory features may show similarities, insights on the sensory abilities may provide useful information to differentiate between them, as has been suggested by some researchers (Brown, Leo, & Austin, 2008; Cheung & Siu, 2009). O'Brien et al. (2009) examined whether patterns of sensory stimuli were able to discriminate between children with ASD and with LD. O'Brien and colleagues reported high presence of sensory-related behaviours in both conditions compared with a third control group of participants with typical development. The ASD participants showed the highest frequency of behaviours in visual stimulus-seeking, and auditory hypersensitivity (O'Brien et al., 2009). Another study (Sanz-Cervera et al., 2015) looked into the differences between children with ASD and those with ADHD in the sensory processing characteristics. The results of Sanz-Cervera et al. (2015) showed a consistent association between high scores in the sensory measures and the severity of ASD, but different profiles for the ADHD group with a significant correlation ($p<.03$) between inattention and auditory processing. Likewise, Little and colleagues (Little et al., 2018) examined the sensory profile of children with ASD, ADHD, and typical development. The findings of Little (Little et al., 2018) indicated that ASD and ADHD might present sensory characteristics that overlap, and that atypical behaviours associated to sensory stimuli are more frequent than for typical development groups.

The existence of sensory problems in children and adults with ASD is well established and has been reported that over 95% of people with ASD present associated sensory issues (Baker et al., 2008; Gonthier et al., 2016; Kern et al., 2007; Kientz & Dunn, 1997; Tomchek &

Dunn, 2007; Tomchek et al., 2014). The incorporation of sensory symptoms as diagnosis criteria on the 5th Edition of the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013) has highlighted its relevance as a main characteristic in ASD. The sensory patterns observed in ASD are manifested by difficulties to display adaptive responses to sensory stimulation, which interfere in peoples' daily life activities and their social inclusion (Baker et al., 2008; Dunn, Saiter, & Rinner, 2002; Gonthier et al., 2016; Kern et al., 2007; Tomchek et al., 2014). Studies have shown that ASD is manifested together with sensory issues. Ausderau et al., (2014) suggested that maladaptive sensory patterns in ASD contribute to the severity of the disorder, likewise, Hilton, Graver, and LaVesser, (2007) observed a relationship between atypical sensory profile and the severity of the social competence in high functioning adults with ASD. The revision of sensory profiles of children and adults of different ages (Lane, Molloy, & Bishop, 2014; Little, Dean, Tomchek, & Dunn, 2016; Watling, Deitz, & White, 2001) supported the hypothesis that people with a diagnosis of ASD may display subtypes of sensory processing abilities that can be characterised as hypo or hypersensitive in regard of the environmental demands. Additionally, at least 40% of children with ASD present abnormal auditory hypersensitivity (hyperacusis) (Rimland & Edelson, 1995). The hyperacusis may cause aversive behaviours in children with ASD, such as covering the ears, crying, or running away, that can disrupt academic and social functioning (Khalfa et al., 2004).

Regarding the sensory processing profile difficulties among ASD, ADHD, and SLI, a study by van der Linde, Franzsen, and Barnard-Ashton (2013) considered the sensory profile of children with SLI compared to typical children, and those with ADHD, and ASD diagnosis. The sensory profile of the SLI group was different than the profile of the typical group, and similar to the ADHD group, showing both groups' ADHD and SLI scores above the mean in some scales. However, the ASD group showed the highest scores on the sensory profile, which demonstrated more sensory difficulties in ASD than in the other conditions (van der Linde et al., 2013).

Taal et al., (2013) studied sensory processing characteristics in children with SLI, their results showed a high percentage of atypical behaviours when compared with matched typical developed groups. The differences had a large effect size (Cohen's d $\geq$0.80) and were most prevalent in the auditory, touch, vestibular, oral and visual sensory systems, where the SLI group responded in a deviant way compared to children with typical development (Taal et al., 2013). Regarding phonological skills, Cumming, Wilson, and Goswami, (2015) proposed basic auditory processing impairments in the perception of the rhythm of a speech. McArthur and Bishop, (2005) reported abnormal frequency discrimination in the processing of pure tones and vowels in SLI children and young adults.

Studies on ADHD (Dunn & Bennett, 2002; Parush, Sohmer, Steinberg, & Kaitz, 1997) have reported difficulties in modulating sensory responses, and failure to perceive and process sensory information, along with a sensory profile that is significantly different from the typical population. Evidence of an abnormal integration of stimuli from multiple senses in participants with ADHD-like traits was proposed by Panagiotidi et al., (2017b). Panagiotidi et al. observed a misjudgement of simultaneity in subjects with high ADHD-like traits that may account for the distractibility component of this condition. Jung, Woo, Kang, Choi, and Kim, (2014) assessed children with ADHD and sensory processing disorder associated, finding poor visual perception. Sensory modulation dysfunction has been reported in children with ADHD based on physiological and parent-report measures (Mangeot et al., 2001).

In summary, the current literature has provided clear evidence of sensory processing difficulties in ASD (Baker et al., 2008; Gonthier et al., 2016; Kern et al., 2007; Kientz & Dunn, 1997; Tomchek & Dunn, 2007; Tomchek et al., 2014), ADHD (Dunn & Bennett, 2002; Jung et al., 2014; Mangeot et al., 2001; Panagiotidi et al., 2017; Parush et al., 1997) and SLI

(Cumming et al., 2015; McArthur & Bishop, 2005; Taal et al., 2013). However, as has been explained throughout the chapters of this thesis (see for example Chapter 1, section 1.3), the presence and extent of sensory processing issues on subjects with learning difficulties is still controversial (Goswami, 2014).

7.2 Design of the study

7.2.1 Hypotheses

The main hypothesis of Study 4 was that children with neurodevelopmental disorders (LD, ASD, ADHD, and SLI) would obtain scores above the mean on the sensory profile questionnaire and would show significant differences to a group of children without neurodevelopmental disorders. A second hypothesis was that children with ASD, ADHD, and SLI would obtain the highest scores on the sensory profile compared to children with LD only and typically learning abilities. A third hypothesis was that learning difficulties measured by the Colorado Learning Difficulties Questionnaire (CLDQ) would show a significant positive correlation with the sensory profile scores (CSP-2).

The first and second hypotheses were based upon previous findings that found differences in the sensory processing abilities of children with learning difficulties (Dove & Dunn, 2008; Padankatti, 2005), the evidence of sensory processing problems as part of the main symptoms of ASD (e.g. Baker et al., 2008), and evidence of sensory processing differences between groups with ADHD (e.g. Dunn & Bennett, 2002) and SLI (e.g. Taal et al., 2013) when compared to typical groups. Also, due to the lack of consistent results about the sensory processing characteristic of children with LD (see Richardson, Thomson, Scott, & Goswami, 2004; Sperling, Lu, Manis, & Seidenberg, 2005) it was expected to find significant differences with the typical group, but milder than observed in children with either ASD, ADHD, or SLI. The third hypothesis was built based on research that has demonstrated dysfunction in the auditory and visual sensory systems of poor readers (Rose et al., 1999; Tallal, 1980; Tallal et al., 1993), and the theory of Stein (Stein, 2001a, 2001b) who proposed a basic sensory involvement on phonological issues.

7.3 Methodology

7.3.1 Participants

Eighty-nine parents took part in the study through online surveys about their children's characteristics. The parents were recruited via social media and were asked for informed consent to take part in the study. Incomplete surveys were excluded (28 surveys). Children with untreated physical and sensory problems were also excluded (5 participants). The final sample included 56 participants, 51 mothers and 5 fathers (details in Table 7.1). The parent-surveys report a group of children aged between 8-10 years old (Mean age = 8.94, SD = .818), with 21 females.

Three groups were created based on the reports of parents about whether or not their children presented learning difficulties, and other neurodevelopmental disorders. The typical group included children with typical development and learning skills (typically achieving, TA). The LD group included children with pure LD and no other associated conditions. Although Kaplan et al. (2001) stated that talking about 'pure' may be inexact, this group was made up of those children whose parents mentioned learning difficulties, but no other known difficulty. The third is the neurodevelopmental disorders group (ND), its included children with SLI, ASD and ADHD that also referred to having learning difficulties.

Table 7.1 Groups characterisation.

Group	Number participants	Characteristics
Typically achieving (TA)	19 participants 8 females, 11 males	Children with neither developmental disorder nor learning difficulties.
Learning difficulties only (LD)	24 participants 10 females, 14 males	Type of LD 8 (33.3%) literacy (reading and writing) 3 (12.5%) maths alone 10 (41.7%) literacy and maths 3 (12.5%) other alone (such as motor)
Neuro-develomeptal disorders (ND)	13 participants 3 females, 10 males	Diagnosis 2 (15.4%) ADHD 3 (23.1%) SLI 8 (61.5%) ASD Associated LD 3 (23.1%) literacy 10 (76.9%) literacy and maths
Surveys excluded: Sensory conditions (visual, hearing, orthopaedic problems) = 5 Incompletes = 28		

7.3.2 Measures and Procedures

Participants were recruited by social media via Facebook sponsored posts with a target audience of UK families, English-speakers, family social groups, and advertising sent to local schools. The data collection was based on the parent-report information and their appraisal of their children's characteristics. While this method may be subject to parents' bias, researchers have suggested that parent-reports are a reliable and accurate method to obtain information regarding behavioural, developmental, and academic problems (Daniels et al., 2012; Faraone, Biederman, & Milberger, 1995a; Little et al., 2016). Also, Glascoe and Dworkin (1995) proposed that parents are a reliable source of information when they are asked about appraisals, estimations, and predictions of their children, and are able to recall historical facts and report current skills.

The study was designed using the Qualtrics online software. An information sheet was presented to parents with the details about the purposes of the study, data management and contact details. Then parents were asked to read and complete a consent form if they agree to take part in the study. Those who agreed to take part, answered a questionnaire with seven closed questions, requesting information about their children. The seven questions were regarding demographic information of the children, gender, age, and specific questions: “Has your child ever been clinically diagnosed (for a qualified professional, as your GP) with a developmental disorder? If so, please select all that apply” (Learning disorder (reading, writing, or maths problems), Attention and hyperactivity disorder, Communication disorder (language, speech problems), Intellectual disability, Autism spectrum disorder, Developmental coordination disorder (dyspraxia), other); “Has your child presented any academic difficulty at school?” (among reading, writing, maths, motor skills, and other); “Does your child receive additional educational support at school, e.g. via an in-class teaching assistant, extra classes to support the learning, other Special Educational Needs support?”; and “Has your child any of the following conditions?” among orthopaedic abnormality, untreated visual problems, untreated hearing problems.

The questionnaires were used to characterise the sample regarding the presence of developmental disorders and the type of learning problems. All parents who reported a neurodevelopmental disorder in their children reported an LD as well.

After completing the seven questions, parents were asked to complete the Colorado Learning Difficulties Questionnaire and the Child Sensory Profile -2. The full survey finished with a message of thanks for their participation.

7.3.2.1 Colorado Learning Difficulties Questionnaire (CLDQ)

The CLDQ Willcutt et al. (2011) was designed to screen for learning difficulties, which they defined as behaviours that are likely to indicate the possibility of LD. As in Study 2, in the present Study 4 the short version of the CLDQ adapted by Patrick et al. (2013) was used with the parents of children. Details of the CLDQ questionnaire in Chapter 5, section 5.3.2.1.

7.3.2.2 Child Sensory Profile -2 (CSP-2).

The CSP-2 provides a profile of sensory processing that characterised the behavioural sensory modulation abilities of children across different sensory modalities and four theoretical quadrants that outline their sensory features. The questionnaire was completed by parents in an online format. Details of the questionnaire in Chapter 3.

7.4 Results

The sample of Study 4 was composed of a varied group of children with particular developmental characteristics (details in Table 7.1). The section of results will show a graphical distribution of scores regarding the children's sensory profile.

For the statistical analyses, the mean scores of the CSP-2 were compared across the three groups. The first analysis was made regarding the four sensory quadrants, and then the six sensory systems. Finally, correlation analyses were run between the CSP-2 scores and the reading and maths scales of the CDLQ.

7.4.1 Data check and descriptive statistics

Before the analyses, all variables were screened for outliers and normality. Concerning normality, the sensory profile scores were screened with Kolmogorov-Smirnov test and visual inspection of histograms showing an adequate distribution. Thus, parametric tests were used for the analysis. The CLDQ measures scores showed a non-normal distribution, and therefore non-parametric tests were run for those cases.

The CLDQ scores were checked to identify the reading and maths characteristics of the groups. Cronbach's alphas for the CLDQ sum of scales consisted of 11 statements was $\alpha = .929$, which indicates a high level of internal consistency for the scale with this specific sample.

The typical group obtained a mean of 1.64 (SD = .55) in CLDQ-R, and 1.87 (SD= 1.13) on the CLDQ-M scale, which placed the group in the normative mean range previously reported. The children with LD showed overall scores above +1SD on both the reading and maths scales. The mean comparison among the groups showed statistically significant differences in both the reading and maths scales between the typical group and the LD group and between the typical group and the ND group (Kruskal-Wallis H test $\chi^2(2) = p < .001$), but not between the LD group and ND group.

Table 7.2 Mean and standard deviation of the CLDQ scales per group.

CLDQ	**Groups**			Kruskal-Wallis test			
	TA M (SD)	**LD** M (SD)	**ND** M (SD)	χ^2 p	Pairwise comparisons TA/LD	TA/ND	ND/LD
Reading	1.64 (.55)	3.43 (1.0)	3.15 (1.1)	26.13 <.001	<.001	.001	1.00
Maths	1.87 (1.1)	3.18 (1.1)	3.26 (.95)	14.94 .001	.002	.004	1.00
Sum of scales	19.2 (6.8)	36.5 (10.0)	35.2 (9.3)	24.89 <.001	<.001	.001	1.00

Significance values have been adjusted by Bonferroni correction for multiple tests. For comparison purposes, the normative cut scores for CLDQ-R=2.67, CLDQ-M=2.60 (Patrick et al., 2013)

7.4.2 Sensory processing profile of children.

7.4.2.1 Distribution of categorical scores along with the normative data.

CSP-2 data for each participant for each 'quadrant' were converted into an age-normed classification (less than others, just like the majority, more than others) using Dunn's CSP-2 norms (2014) as shown in Figure 1. Before further analyses, the internal consistency of the whole questionnaire (86 items) was tested. Cronbach's alpha was α =.982, which indicated a high level of internal consistency for the scale with this specific sample.

The typically developed group revealed a normal-like distribution, that is, more frequency of scores into the mean, and less frequency in the extreme ranges ('Less than others', and 'More than others'). For the LD and ND groups, they showed a low frequency of scores in the Less than others category, which is smaller for the ND group. Conversely, these groups showed a high frequency of scores above the mean; the ND group were more likely to fall into this category, especially in the Sensitivity quadrant (92.3%), followed by the Registration quadrant (84.6%). The LD group obtained scores that mostly fell into the mean and above the mean, except for the Avoiding quadrant where 54.2% showed scores into the 'More than others' category.

In terms of the scores compared to the normative data, the LD group showed scores above the mean in the quadrants of Avoiding (1.59 SD), and Sensitivity (1.11), while the ND group showed scores above 2SD in all the quadrants.

Chi-square test of independence showed that there was significant association between group and the sensory profile classification for Seeking X^2 (8) = 17.54, p = .025, Avoiding X^2 (8) = 18.49, p = .018 and Sensitivity X^2 (8) = 28.82, p < .001. Children with comorbidity were more likely to show 'More than others' scores on those quadrants than both LD and the typical groups.

Figure 7.1 Representation of the groups on each of the four quadrants of Dunn's model along the categorical ranges. Quadrants: Reg= Registration, Seek= Seeking, Avoid= Avoiding, Sens= Sensitivity.

The nature of the distribution is depicted regarding the diagnosis of participants. As can be seen in figure 7.2, the typical group is represented by the green flat-like line with scores close to the mean of the normative data. The red line represents the LD group with a peak point in Avoiding. Then, the differential diagnosis within ND group showed a clear trend of scores; children with a diagnosis of ASD obtained the highest scores, followed by children with ADHD, and finally children with SLI. Both, LD and SLI showed similar shape line across the quadrants (peak in Avoiding, lower in Seeking), as well as those with ASD and ADHD (peak in Sensitivity, lower in Seeking).

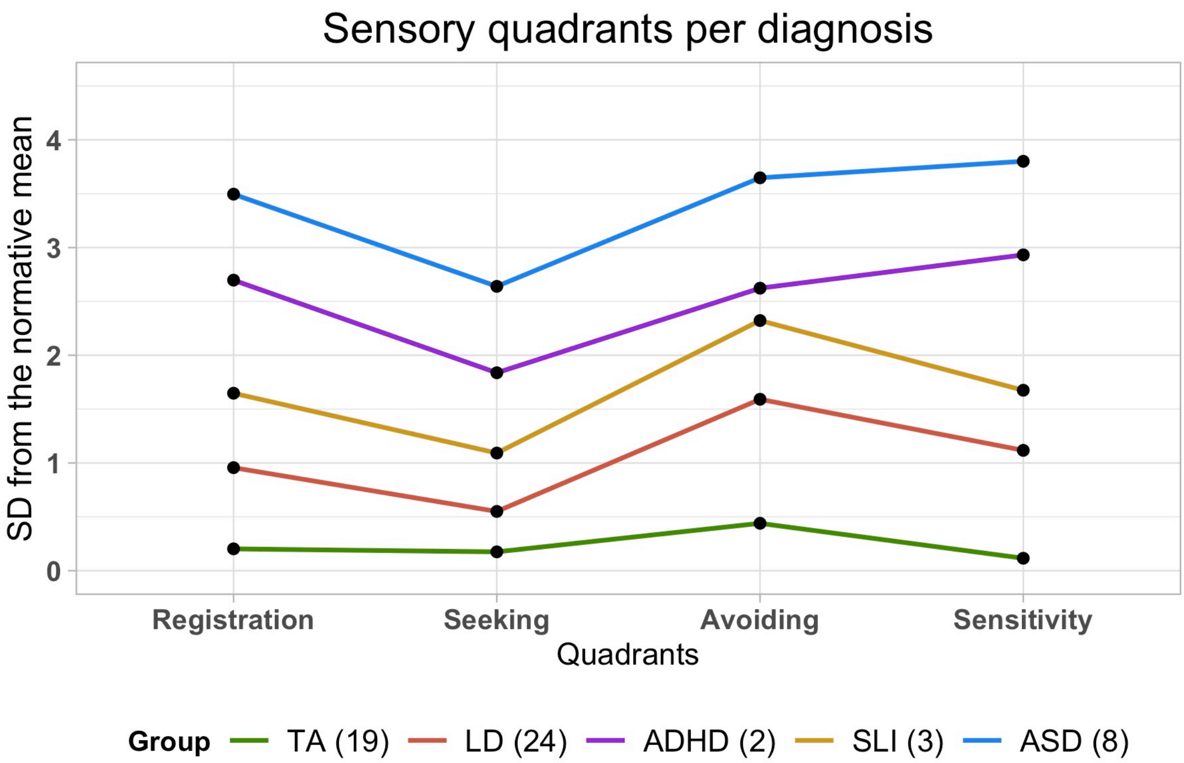

Figure 7.2 Distribution of sensory quadrants per specific diagnosis. Note for the y-axis, raw scores were transformed into Z-scores to facilitate the visual inspection and then SD were derived regarding the normative data. Numbers in brackets refer to the number of participants in each group.

7.4.2.2 Mean comparison between groups.

Table 7.3 with descriptive data per group and statistical test results from the general linear model test.

Table 7.3. Group differences and follow-up comparisons on sensory processing patterns and sensory systems.

Sensory profile	**Groups** Typical	LD	NeuroDev	**Norms**	**Univariate ANOVA**			**Tukey Posthoc** Typical - LD	Typical - NeuroDev	NeuroDev - LD
	M (SD)	M (SD)	M (SD)	M (SD)	*F*	*p*	n^2	*p*	*p*	*p*
Sensory quadrants										
Registration	32.89 (16.99)	42.16 (19.23)	65.61 (19.18)	31.4 (11.7)	12.40	<.001***	.319	.241	<.001***	.002**
Seeking	32.05 (15.94)	36.66 (18.50)	56.46 (17.42)	35.9 (13.7)	8.20	.001**	.236	.666	.001**	.005**
Avoiding	37.36 (18.27)	51.41 (19.44)	70.84 (18.25)	33.9 (12.5)	12.25	<.001***	.316	.047*	<.001***	.011*
Sensitivity	30.26 (14.32)	42.08 (14.84)	66.38 (17.35)	30.3 (11.0)	21.82	<.001***	.452	.039*	<.001***	<.001***
Sensory systems										
Auditory	16.31 (6.94)	21.20 (6.56)	29.30 (6.07)	17.7 (6.9)	15.02	<.001***	.362	.049*	<.001***	.002**
Visual	10.15 (4.43)	13.54 (5.14)	18.69 (5.89)	13.6 (4.0)	10.80	<.001***	.290	.088	<.001***	.014*
Touch	16.10 (10.79)	16.87 (8.50)	31.46 (9.14)	15.2 (6.9)	12.41	<.001***	.319	.962	<.001***	<.001***
Movement	11.68 (6.92)	14.37 (9.32)	23.76 (5.83)	13.7 (5.6)	9.67	<.001***	.267	.509	<.001***	.003**
Body position	10.73 (7.14)	13.58 (9.77)	20.00 (9.46)	10.0 (4.5)	4.26	.019*	.139	.554	.015*	.100
Oral	15.57 (8.77)	17.37 (12.17)	32.07 (13.24)	16.2 (7.4)	9.38	<.001***	.261	.865	.001**	.001**

GLM Sensory quadrants: $F(8, 100) = 5.289$, $p < .001$; Wilk's $\Lambda = .494$, partial $\eta^2 = .29$. Significant differences between groups at ***< .001, **<.01, *<.05. Effect size: partial eta squared n^2. Norms correspond to the mean raw score extracted from the CSP-2 user's manual (Dunn, 2014, page 219).

7.4.2.2.1 Sensory quadrants.

The hypothesis that children with neurodevelopmental disorders would have significant differences in the sensory profiles compared with typically developing children were tested with a multivariate analysis of variance (see Table 7.3 for details). A pre-analysis of the association showed a significant correlation among the quadrants, and no significant effect was found for age and gender (covariance analyses). Thus, a MANOVA analysis was run with group as the independent variable (typical, LD, and ND), and the sensory quadrants of Registration, Seeking, Avoiding, and Sensitivity as the dependent variables. With equality of variance assumed (Box test and Levene's test $p=.243$) there was a statistically significant multivariate effect for the sensory quadrants based on the group of children, $F(8, 100) = 5.289$, $p < .001$; Wilk's $\Lambda = .494$, partial $\eta^2 = .29$. Univariate ANOVAs showed that differences among the groups were found for all of the four sensory quadrants; all $p <.001$. A Tukey HSD post hoc analysis showed that for the quadrants of Registration, Seeking, Avoiding, and Sensitivity the NeuroDev group had significantly higher scores than both the typical and LD groups ($p<.05$). The LD group obtained significantly higher scores than the typical group on Sensitivity ($p= .039$) and Avoiding ($p= 0.47$) quadrants.

These results suggest that the sensory profile, relative to the four main sensory quadrants, varied significantly regarding the developmental and learning trajectories of the children. Thus, whilst the sensory profile seemed to present increased scores for children with neurodevelopmental conditions like ASD, ADHD and SLI, the LD presented milder differences with the typical group, as reflected by differences in only two sensory quadrants.

7.4.2.2.2 Sensory Systems.

Further analyses comparing the effect of the group on the sensory systems are presented. Six one-way ANOVAs were run to test each sensory system as the dependent variable, and the three groups of children as the independent variable. Levene test indicated that the assumption of homogeneity of variance was met for the six sensory systems ($p>.05$).

The outcomes showed a significant effect of group on all of the sensory systems at $p<.05$ (see Table 7.3 for details). Post hoc comparisons using Tukey HSD test indicated that the mean scores for the ND group were significantly higher than the typical and LD groups on most of the sensory systems, except Body position where the difference between ND and LD groups was not significant. The differences between the LD and typical groups were statistically significant only for the Auditory sensory system ($p = .049$). In all of these comparisons, the ND group had higher scores than both LD and typical groups. Overall, consistent with the results of the sensory quadrants and the hypothesis, those children that presented neurodevelopmental disorders explained the differences in the sensory profile from typical children, whereas LD children obtained a profile with milder differences compared to typical learning children.

7.4.3 Association between learning difficulties and the sensory profile.

To investigate the association between the sensory processing characteristics of children - measured by the scores on the sensory profile - and their academic skills - measured by the CLDQ - correlation analyses were run. Due to the non-normal distribution of the CLDQ measures, Spearman's rank-order correlations were computed with Bonferroni correction for alpha level at $p<.001$.

The analyses showed positive significant correlations between the CLDQ general scores and the sensory quadrant of Sensitivity. The inspection of the correlation between the two scales of the CLDQ (reading and math) and the CSP-2 scores showed that the association was mostly between the CLDQ-M and the CSP-2 scores in Avoiding, Sensitivity, and Registration quadrants, and auditory and body position sensory systems. Table 7.4 shows the details of the correlations. There were no other significant correlations after the Bonferroni correction.

In summary, the high scores on the CLDQ, which indicate a high frequency of perceived academic difficulties in reading and maths, were positively associated with high scores on some scores of the CSP-2. Likewise, high scores on the CSP-2 indicated a high frequency of behaviours in response to sensory stimuli, which may affect adaptation to the environment. Contrary to what was expected, the highest correlations were found between the maths scale and not the reading scale.

Table 7.4 Correlations between measures of the CLDQ and CSP-2 questionnaires.

	CLDQ total	**CLDQ-R**	**CLDQ-M**
Sensory quadrants			
Registration	.379*	.245	.488**
Seeking	.230	.098	.376*
Avoiding	.403*	.261	.485**
Sensitivity	.425**	.290*	.492**
Sensory systems			
Auditory	.320*	.178	.440**
Visual	.368*	.261	.414*
Touch	.281*	.154	.378*
Movement	.279*	.175	.378*
Body position	.325*	.158	.476**
Oral	.151	.091	.202

Correlation significant at *p<.05; Bonferroni corrected at **p <.001

Further analyses were performed through linear regression on the learning difficulty measure. Due to the large difference among the ND group with the scores of children in the LD group, the regression analysis was conducted with children from the typical and LD groups only.

Multiple linear regression was conducted to evaluate whether the four sensory quadrants (Registration, Seeking, Avoiding, and Sensitivity) were necessary to predict the measure of learning difficulties of participants (the CLDQ general scale was used as a measure of learning difficulties). All four quadrants were entered to the model using the stepwise method.

Significant relations were found between the CLDQ and Registration (p =.007) and Seeking quadrants (p= .001). The model that includes both quadrants showed a larger percentage of variance explained (R^2=28.3%) than Registration quadrant individually (R^2 = 16.3%). This model presents a positive slope coefficient for Registration (B=.609), which indicates that high Registration scores will increase the CLDQ scores; conversely, the Seeking quadrant showed a negative coefficient (B= -.443) that indicates an opposite relation. The scatterplot (Figure 7.3) of standardised predicted values versus standardised residuals, showed that the data met the assumptions of homogeneity of variance and linearity and the residuals were approximately normally distributed (Figure 7.4).

Table 7.5 Regression outcome

Model		**B**	**Coefficient std. error**	**Standardized coeff. Beta**	***t***	**Sig.**
2	Registration	.609	.159	.927	2.825	<.001
	Seeking	-.443	.171	-.627	-2.587	.013
Excluded variables						
	Avoiding	.307			1.591	.120
	Sensitivity	.377			1.746	.089

Stepwise method, dependent variable CLDQ general scale. Model 2 summary: R=.532; R^2=.283; Adjusted R^2=.247

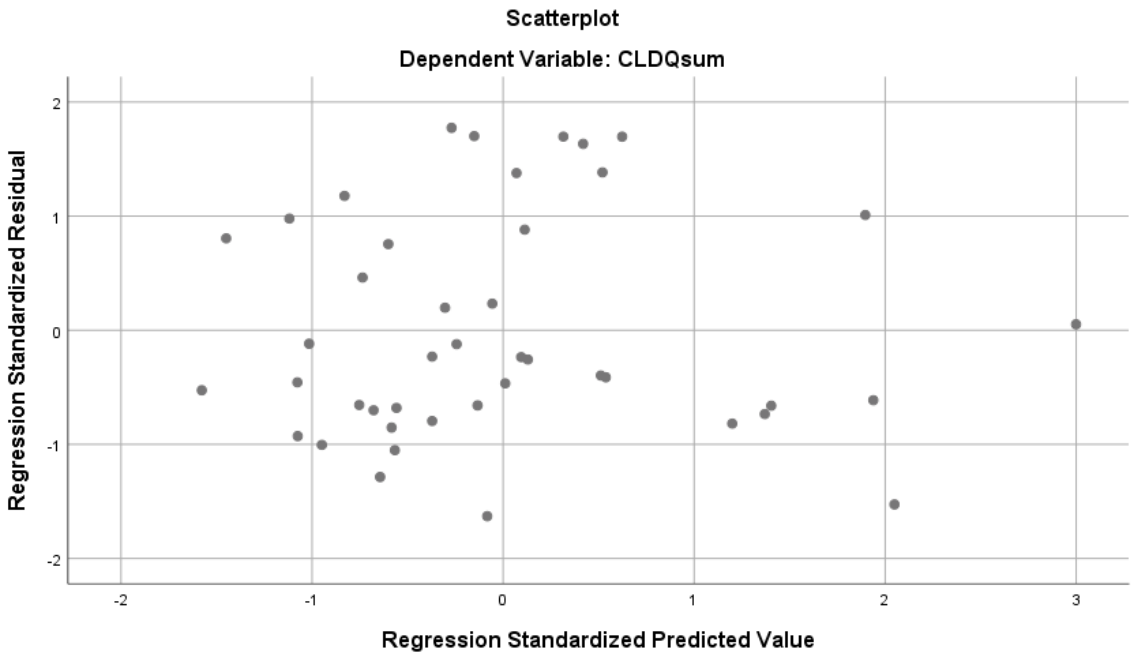

Figure 7.3 Scatterplot shows homoscedasticity of data.

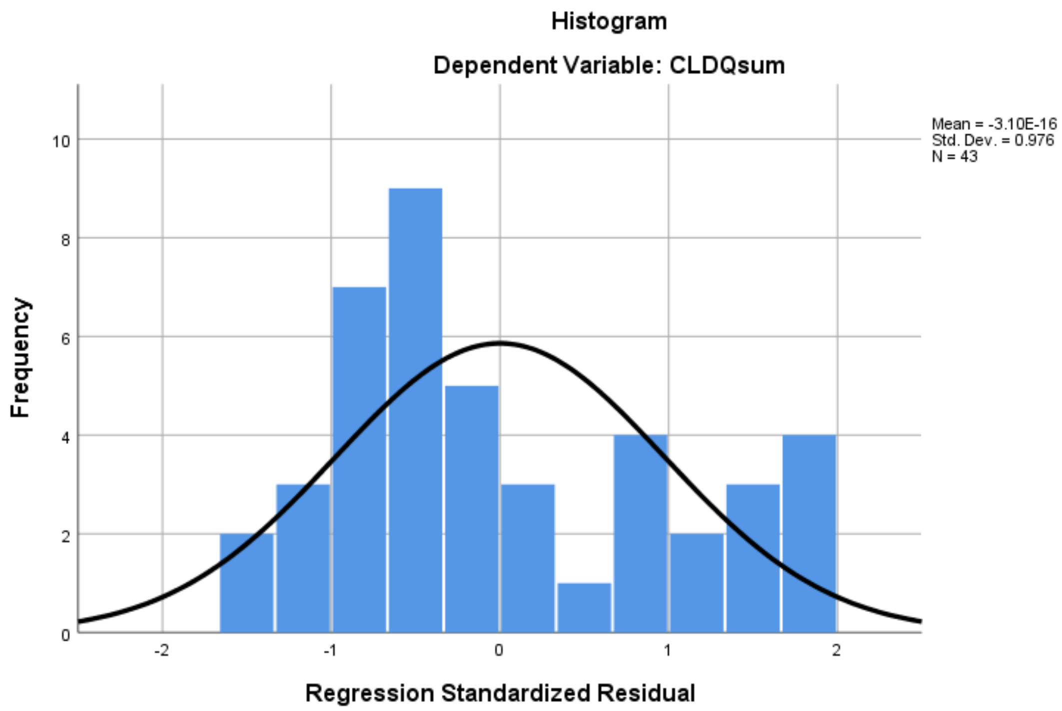

Figure 7.4 Histogram shows normality-like distribution of residuals

7.4.4 Additional analyses

Mean comparisons analyses (section 7.4.2.2) showed differences in the sensory processing profiles regarding the group of participants and its diagnoses. In addition, there was a significant association between the sensory profile quadrants and learning difficulties (section 7.4.3). As these previous analyses were made on the base of group comparisons, the exploration of individual profiles may provide further information concerning the influence of the sensory processing abilities on learning.

Subgroups of the sensory processing profile were derived based on the individual raw scores of participants in the CSP-2, upon which the CLDQ scores can be compared. The subgrouping was made through two different approaches: following an a priori classification proposed by Little et al. (Little et al., 2016) and through hierarchical cluster analysis.

7.4.4.1 A priori classification

Little et al. (2016) created subgroups of children in a community sample with and without developmental conditions, based on sensory processing profiles. Little et al. derived five subgroups that differed on the scores of the four sensory quadrants of the CSP-2 questionnaire. In Study 4, there were found three of these five subgroups: 'Balanced' that represents scores within the mean range in all the four quadrants, 23 participants fell into this subgroup; 'Intense' that represents scores above the mean in all the four quadrants, 18 participants fell into this subgroup, and 'Vigilant' characterised by scores in the mean range on Registration and Seeking, but scores above the mean on Avoidance and Sensitivity quadrants, 4 participants fell into this subgroup. A further subgroup was observed that will be called 'Other', which included 11 participants. The 'Other' subgroup did not match with the Little et al. classification and was characterised by uneven scores across the quadrants.

A cross-tabulation was performed to test relations between the three groups of participants (TA, LD, ND) and the derived CSP-2 subgroups (Balanced, Intense, Vigilant, Other). Table 7.6 shows that most of the participants from the TA group were located in the 'Balanced' subgroup (73.7% of the subjects). The participants of the LD group were spread across the subgroups, with most of the participants in the 'Balanced' subgroup followed by the 'Other' subgroup. For the ND group, most of the participants were in the 'Intense' subgroup (61.5% of the subjects).

Table 7.6 Crosstab between groups and CLDQ-2 subgroups

	CLDQ-2 subgroups			
Group	**Balanced**	**Intense**	**Vigilant**	**Other**
TA	14 (73.7%)	4 (21.1%)	0	1 (5.3%)
LD	8 (33.3%)	6 (25%)	3 (12.5%)	7 (29.2%)
ND	1 (7.7%)	8 (61.5%)	1 (7.7%)	3 (23.1%)

The numbers represent the frequency of participants per group into each subgroup and the percentage within such a group.

Univariate analysis of variance was run with the subgroups as an independent variable, and the CLDQ sum of scales as a dependent variable to examine the effect of the subgroups on the learning difficulties of participants. With homogeneity of variance assumed (Levene´s test $p>.05$), there was a statistically significant difference between the groups determined by the ANOVA ($F(3, 52) = 4.44$, $p=.007$; partial $\eta^2 = .204$). A Bonferroni post hoc test revealed that the learning difficulties were statistically significantly lower for the 'Balanced' (mean= 24.13) subgroup compared to the 'Intense' (mean= 35.77) subgroup ($p= .008$). There were no differences after a Bonferroni post hoc test between the other subgroups ($p>.05$).

7.4.4.1 Hierarchical cluster classification

The second approach for deriving subgroups from the CSP-2 questionnaire scores was by running a hierarchical cluster classification test with the Ward method (Murtagh & Legendre, 2014), to explore the presence of clusters in the Study 4. The results of the test showed two clusters after visual inspection of the percentage change in the agglomeration criterion as can be seen in Figure 7.5. The percentage change was highest when joining two clusters, therefore, the agglomeration could better be stopped at that stage.

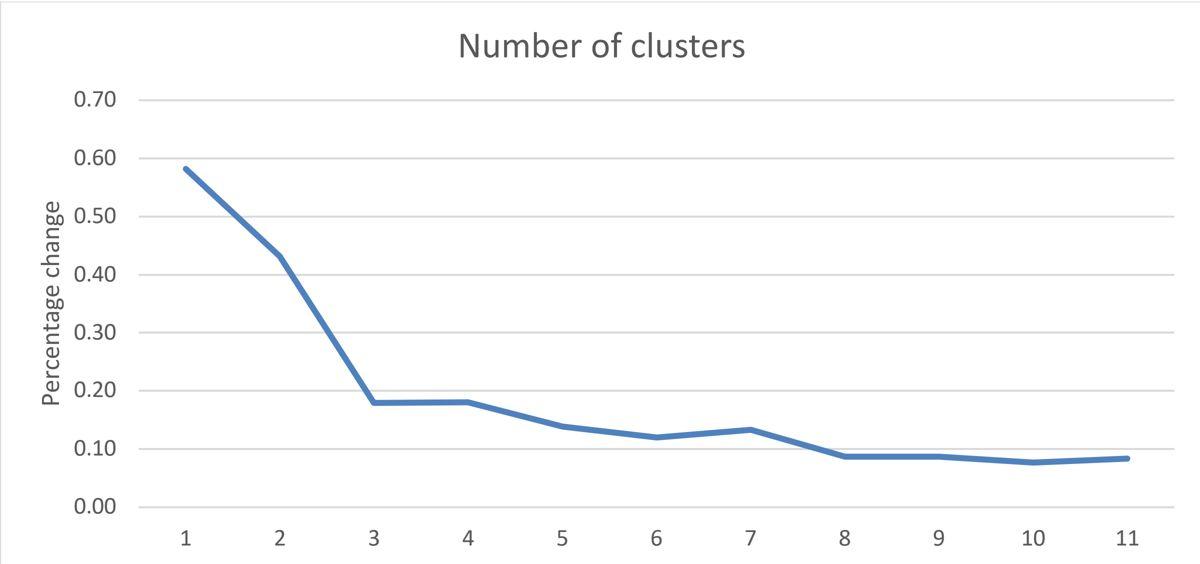

Figure 7.5 Percentage change in agglomeration criterion (hierarchical cluster analysis).

Cluster 1 was composed of 23 participants; Cluster 2 was composed of 33 participants. The characteristics of the two clusters regarding the scores in the CSP-2, the distribution of the groups of participants (TA, LD, ND), and the scores of the CLDQ sum of scales over the hierarchical cluster is presented in Table 7.7. The table shows most of the TA group into Cluster 1, with 73.7% of the cases, while the ND group were completely in Cluster 2 (100% of the cases). The LD group mostly fell into Cluster 2 (62.5%), with a smaller percentage of participants in Cluster 1 (37.5%).

Table 7.7 Characteristics of the clusters

	Cluster 1	Cluster 2
Group of participants		
TA	14 (73.7%)	5 (26.3%)
LD	9 (37.5%)	15 (62.5%)
ND	0	13 (100%)
CSP-2	M (SD)	M (SD)
Registration	23.95 (8.42)	58.75 (16.42)
Seeking	22.56 (10.81)	51.63 (14.84)
Avoiding	31.13 (10.39)	65.12 (17.07)
Sensitivity	25.17 (8.32)	56.63 (15.41)
CLDQ		
Sum of scales	24.96 (12.13)	34.12 (10.27)

For group of participants, the numbers represent the frequency of participants per group in each cluster and the percentage in each group.

A univariate analysis of variance was run with the clusters as independent variable, and the CLDQ sum of scales as the dependent variable to examine the effect of the clusters on the learning difficulties of participants. With homogeneity of variance assumed (Levene´s test p>.05), there was a statistically significant difference between groups determined by the ANOVA (F (1, 54) = 9.28, p=.004; partial η^2 = .147). Participants in Cluster 2 had higher learning difficulties (mean= 34.12) compared to participants in Cluster 1 (mean= 24.95).

7.5 Discussion

Study 4 had important findings that provide evidence to elucidate the root of the differences in sensory processing abilities between typically developed children and children with conditions. First, children with neurodevelopmental disorder as ASD, ADHD, and SLI presented the highest frequency of behaviours associated with sensory processing compared with children with only specific learning difficulties, and typical children. Second, a significant association was seen between learning measures and the sensory profile. Below a discussion of these findings will be presented.

7.5.1 The impact of comorbidity in the sensory processing abilities of children with specific learning difficulties.

The results of the present study demonstrated that children with neurodevelopmental disorders like ADHD, SLI, and ASD with learning difficulties associated, and to a lesser extent, children with pure LD, had a high frequency of sensory-related behaviours that may be an indicator of problems in processing sensory inputs. In Study 4 the comorbidity variable was explored given the large body of evidence that suggests that neurodevelopmental disorders often coexist (Bental & Tirosh, 2007; Kirby et al., 2008; McArthur et al., 2000; Semrud-Cllikeman et al., 1992; Willcutt & Pennington, 2000a). Consequently, Study 4 extended the results reported in Study 1 by incorporating information about other conditions that may account for the differences in the sensory profile.

The findings of Study 4 provided further evidence of sensory processing issues for children with neurodevelopmental disorders with learning difficulties associated, in line with previous studies on ASD (Baker et al., 2008; Gonthier et al., 2016), ADHD (Panagiotidi et al., 2017b; Parush et al., 1997) and SLI (McArthur & Bishop, 2005; Taal et al., 2013). The sensory profile of children with learning difficulties and comorbidity as a whole is depicted as having an overall high frequency of sensory-related behaviours. That is, the distribution of the quadrants was skewed to the upper end (‘More than others’), which is confirmed by the significantly higher scores compared with both the LD and the typical group of children. In practical terms, the high frequency of sensory-related behaviours may cause a maladaptation to the environment due to the coexistence of behaviours at both extreme ends of the neurological thresholds and the passive/active self-regulation strategies used to face external and internal demands (Dunn, 1997b; Little et al., 2016) Thus, the sensory profile would characterise the behaviour of children within a spectrum of opposite responses such as the missing of sensory cues, and high engagement in sensory experiences; as well as a fast and intense reaction, but also a tendency to retreat from unfamiliar situations. In addition, children with neurodevelopmental disorders and comorbidity within ASD, ADHD, SLI, and LD may present an aversion to sensory experiences and difficulties registering sensory inputs. This lack of ability to modulate sensory information may affect the developmental path of children along with the achievement of academic skills (Jorquera-Cabrera et al., 2017; Miller et al., 2009; Taal et al., 2013).

Given the results of Study 1 and the findings reported by Dove and Dunn (2008), it was expected to find differences in the profile of children with 'pure' specific learning difficulties and typically learning children in the sensory quadrants of Registration, Avoiding, and Sensitivity. The analyses showed that participants in Study 4 indeed obtained higher scores on two of these sensory quadrants since the Registration quadrant did not show significant differences between the LD and typical groups. The Sensitivity quadrant referred to statements of low neurological threshold (the receptors are easily activated by the sensory event), and a passive self-regulation strategy (the child does not have an active role around the environment), whereas the Avoiding referred to statements of low neurological threshold and active self-regulation strategies (the child have an active role around the environment) (Dunn, 2007, 2014). The scores obtained for the LD group are located at the upper limit of the mean range in Sensitivity and Avoiding quadrants, which might be interpreted as a failure to habituate to sensory inputs. A profile of higher scores in Sensitivity and Avoiding sensory quadrants is called 'Vigilant' (Little et al., 2016), which is described as children likely to avoid sensory experiences and may show aversion to sensory stimuli. This over-responsiveness may interfere with the participation of children in their daily life activities, such as playing, learning, socializing, and the achievement of academic goals, thus constraining children from a significant engagement with sensory information (Schaaf & Miller, 2005; Smith-Roley, Mailloux, Miller-Kuhaneck, & Glennon, 2007).

On the other hand, although researcher as Kaplan et al., (2001) have posited that the concept of comorbidity within the neurodevelopmental disorders is inaccurate, the examination of the sensory profile may provide a tool to elucidate differences among them. In accordance with previous studies (Baker et al., 2008; Dove & Dunn, 2008; O'Brien et al., 2009; Padankatti, 2005; van der Linde et al., 2013), the results of the present study demonstrates the existence of a particular profile of sensory processing in children with LD. That is, the results of Study 4 showed particular sensory profile for a group of children with either ASD, ADHD, or SLI, children with LD, and children with typical development. Hence, while children with neurodevelopmental disorders, in general, presented the highest scores on the sensory profile questionnaire, children with pure LD would present a mixed profile with adequate abilities in some areas and misbalance in those associated with low neurological threshold. The details for each diagnosis as exposed in figure 7.2, showed that children with LD and SLI presented a similar distribution of scores on the sensory profile, but the SLI children would have higher scores.

Previous studies have reported similarities in the manifestation of children with SLI and LD, in particular with reading disorders (Catts et al., 2005, 2002; McArthur et al., 2000); coexistence of symptoms, such as auditory discrimination (Goswami et al., 2016); and have posited the risk of literacy difficulties for children with early SLI (Briscoe et al., 2001; Nathan et al., 2004; Snowling et al., 2000). Thus, children with LD and SLI may present similar patterns of the sensory profile, however, the frequency of sensory behaviours is higher for the last condition. Likewise, children with a diagnosis of ASD and ADHD presented a similar distribution of scores on the sensory profile. It is well established that children with ASD have associated sensory processing impairments (Kientz & Dunn, 1997; Kwakye et al., 2011; Tomchek et al., 2014), as well as reports of sensory issues in children with ADHD (Dunn & Bennett, 2002; Jung et al., 2014; Mangeot et al., 2001). Previous studies have explored similarities in the sensory abilities between ADHD and ASD (Sanz-Cervera et al., 2015), and co-occurrence of ASD and ADHD traits in adults (Panagiotidi, Overton, & Stafford, 2017a). Thus, the results of the present study confirmed previous findings that reported similarities in sensory processing patterns for children with ASD and ADHD (Little et al., 2018).

Study 4 showed that the group of children with NeuroDev, and to a lesser extent the LD group of children, had problems in their ability to behaviourally modulate or regulate sensory input and the subsequent response. This problem is echoed in both over habituation and over-sensitisation to stimuli and as a consequence, the attainment of milestones and skills may be harder than for typical children, as was previously reported in other studies (Jorquera-Cabrera et al., 2017; Koziol et al., 2011). The sensory profile patterns observed in Study 4 corroborated the presence of extreme scores on both high and low neurological threshold in children with neurodevelopmental disorders (NeuroDev group). In addition, the results of Study 4 supported the hypothesis that children with neurodevelopmental disorders present significant impairments in the sensory processing abilities (Richardson et al., 2004; Rose et al., 1999; Sperling et al., 2005). An unbalanced or intense sensory profile (Little et al., 2016) as the one observed for the NeuroDev group is indicative of behavioural modulation deficit (Jorquera-Cabrera et al., 2017; Kern, 2002; Miller et al., 2009) that restricts children with neurodevelopmental disorders from calibrating the input-response system in order to obtain meaningful experiences.

Problems in the modulation of incoming sensory input have been widely reported and there is currently agreement of its relevance within the autism characteristics (American Psychiatric Association, 2013; Kientz & Dunn, 1997; Tomchek & Dunn, 2007). The differences between subject with ASD compared to typical groups is larger than the one observed among ADHD, SLI with typical groups (van der Linde et al., 2013). Therefore, the remarkable high scores of the Neurodevelopmental group may have been biased by the presence of an important number of children with ASD (61.5% of the children). A comparison of a larger sample of children with different neurodevelopmental disorders on the sensory processing abilities would be relevant to examine in detail the differences in the profile.

7.5.2 Significant association between learning and the sensory profile.

On the question of whether or not there are correlations between learning difficulties in children, measured by the scores on the CLDQ, and their sensory processing profile, this study found a positive association between the degree of learning difficulties and a high frequency of behaviours rated in the CSP-2.

Study 1 mentioned (see Chapter 4, section 4.5) the lack of evidence about the association of the sensory processing profile and both the performance measures of learning and the learning questionnaires, but significant correlation between the CSP-2 and accuracy of audio-visual condition of the Object classification task. Hence, the findings of Study 1 suggested that the sensory processing profile of children are linked to cognitive skills, such as rapid naming. The results of Study 4 extended these findings, showing a mutual influence between some scores of the sensory profile and a general measure of learning difficulties. The association between the CLDQ, especially the math scale was consistent with the hypothesis that sensory processing is relevant for cognitive development (Koziol et al., 2011; Kruger et al., 2001). These results reflect those of Sigmundsson et al., (2010) who reported an association between sensory deficits and poor mathematics skills.

Dionne-Dostie et al. (2015) have proposed an association between the integration of multiple sensory cues and the development of cognitive processes, in particular in dyslexia and ADHD. The lack of association between the CSP-2 scores and the reading scale was somewhat surprising, particularly the fact that there was no significant correlation neither with Auditory nor Visual sensory systems. Reading is known to be an audio-visual process that is highly dependent on the ability to process sensory information, so an association among these measures was expected (Francisco et al., 2017; Harrar et al., 2014; Rose et al., 1999). It may be the case that the reading scale has been shown better scores on the participants in Study 4, even for those with LD, due to the extensive remediation or support that children received at school, at the expense of specific support in maths. However, more information and complementary measures are needed.

Additionally, the regression analysis showed that both, Registration and Seeking quadrants are significant predictors of learning difficulties. Thus, when analysing children with and without LD, high scores on the Registration quadrant will predict high scores on the CLDQ, and so, the likelihood of learning difficulties. On the contrary, high scores on the Seeking quadrant will predict less scores on the CLDQ, that is, low chances of having learning difficulties. These results corroborate the findings of Studies 2 and 3 that showed the Registration quadrant as a predictor of learning difficulties in adolescents and adults. Also, in accordance with the results of Ermer and Dunn, (1997), moderate levels of seeking behaviours would be a sign of typical development.

The results of the subgrouping analyses supported previous findings (Gonthier et al., 2016; Little et al., 2016) by showing two main clusters of sensory profile, one with scores on the mean and the other with scores above the mean. These clusters differentiated between children with typical development and those with conditions, that in turn are associated with the presence of learning difficulties. Indeed, both subgrouping approaches of the CSP-2 scores, the a priori classification of Little et al. (2016), and the hierarchical cluster analysis, showed similar results. Two main subgroups were derived from the scores of the CSP-2: the first subgroup with scores close to the mean and with a low frequency of behaviours in response to sensory stimuli, and a second subgroup with scores above the mean and thus, a high frequency of behaviours in response to sensory stimulation. These two contrasting subgroups were broadly associated with the presence/absence of conditions, where typically achieving children were included in a subgroup characterised by a sensory profile close to the mean and low likelihood of learning difficulties. Conversely, children in the neurodevelopmental disorders group were placed in the subgroup characterised by a sensory profile with scores above the mean and high likelihood of learning difficulties. The group of children with learning difficulties and no comorbidity were spread between the subgroups, showing an uneven sensory profile, which was similar to the results of Mangeot et al. (2001) who reported large variability in a sample of children with ADHD. This finding indicates differences within the LD group where not all the individuals would present sensory difficulties associated, thus a further exploration of LD subgroups will be relevant.

Finally, concerning the limitations of Study 4, the data collected was obtained from the reports of parents of the children. While parents' reports have successfully demonstrated good reliability in regard to gathering information regarding children with different conditions (Daniels et al., 2012; Faraone et al., 1995b; Glascoe & Dworkin, 1995a; Little et al., 2016), it may not be free of bias. For instance, parents of typical children may have tried to show their child as more adjusted. On the contrary, parents of children with some neurodevelopmental disorder may be more aware of, or more sensitive to any difficulty their children may have, and this may be reflected in their answers by increasing the report of sensory-related behaviours. In that case, the outcomes of this study should be taken with caution, since the data reflects the sensory preferences of children according to their parents' perception.

The interpretations about the sensory profile of children with ASD, ADHD and SLI should be made with cautions giving the small number of children in each condition. Another limitation is the lack of behavioural or performance measures for children. Parents reported on their children's learning abilities, as well as the sensory profile of their children. Future research may benefit from including an assessment of abilities that includes the children's performance.

Despite the limitations mentioned above, Study 4 provided empirical evidence that supports the hypothesis of the influence of sensory processing abilities on the development of children. A complete profile of the strengths and weaknesses of these children is relevant for the comprehension of the characteristics of children with learning difficulties across the board.

CHAPTER 8

General discussion

This final chapter outlines the main findings that emerged from the empirical studies in this thesis in terms of theoretical explanations and the extent of the conclusions. This section also provides a discussion of the importance of the findings in terms of the contribution to the field of learning difficulties. The limitations of the current study are presented, followed by recommendations for future research.

Learning the academic skills associated with reading and mathematics is a relevant developmental milestone that sets the foundations for the pursuit of further skills. To obtain more insight into the process of typical and atypical learning abilities, it is necessary to investigate all aspects of learning. In this thesis, the focus was on a basic aspect, namely the behaviours in response to sensory stimuli, which was investigated in children, adolescents, and adults with and without learning difficulties. The sensory profile in each age group was measured using a questionnaire based on Dunn's (1997) sensory processing framework.

8.1 Thesis aims and summary of findings

The thesis aimed to explore the sensory processing characteristics across three developmental stages: childhood, adolescence, and adulthood, and their association with learning difficulties. Four studies were designed to address the research question. The first study (Chapter 4) involved children between 7 and 12 years old with and without learning difficulties, with a focus on literacy problems. The second study (Chapter 5) was about adolescents between 13 and 16 years old with and without learning difficulties. The third study (Chapter 6) was composed of two sub-studies: Study 3A compared the sensory profile of adults with and without a background of learning difficulties, and Study 3B was focused on a particular sensory quadrant, Registration, to assess whether there was a correlation with learning difficulties. The final study (Chapter 7) comprised a sample of children aged 8 to 10 years old and included a variable of comorbidity to investigate its influence on the sensory profile.

Study 1 comprised a complete assessment of children's characteristics: the DST-J, (Fawcett & Nicolson, 2004) which provided information about the literacy skills of the children; the CSP-2 (Dunn, 2014), which depicted the children's sensory profile according to their parents' report; and the Object Classification task, which showed the performance of the children in a rapid naming test on a visual, and audio-visual conditions. Children in the LD group showed significantly poorer performance compared to their typically learning peers and a higher likelihood of risk scores on the reading of single words and spelling, as well as low scores in recognising rhymes, but had a similar performance on the rapid naming, bead threading, and phonemic segmentation tasks. As described in the test manual (Fawcett & Nicolson, 2004), Reading and Spelling tasks account for general literacy skills, and Rhymes is a measure of phonological awareness. Thus, the children who were located within the LD group were characterised by inaccurate and hesitant reading, weak phonological awareness skills, and intact fine motor skills and naming speed. The general balance task measured with the WBB did not show significant differences between the groups, and the data were highly noisy. This lack of significance may be interpreted as equal balance abilities for both groups. However, another possibility is that the task has failed in sensitivity for children, by not measuring their abilities. The Wii board has been extensively tested with adult participants (Bower et al., 2014; Clark et al., 2010; Handžić & Reed, 2015; Huurnink et al., 2013; Jeter et al., 2015; Sgrò et al., 2014), but there are fewer reports on children (Larsen et al., 2014). Hence, it is speculated that the attitude of the children (playful and overexcited) may have affected the collection of this data.

Studies 2 and 3 assessed the participants' sensory processing profile with the Adolescent/Adult Sensory Profile questionnaire (AASP; Brown & Dunn, 2002). For the adolescent study (Study 2) the short version of the CLDQ (Patrick et al., 2013) was used to obtain information regarding learning difficulties in reading and maths. For both Study 2 and Study 3, the Registration quadrant presented significantly higher scores for the groups with LD compared to the typical group. Additionally, the Sensitivity quadrant rates were high compared with the typical group, but there was no clinical significance, following Dunn's criteria (Brown & Dunn, 2002), for either the Sensitivity or Registration quadrant in the adolescents' study. The group of LD adolescents in Study 2 may present a more balanced and so, an efficient sensory profile. However, this sensory profile showed significant differences with typically learning peers, which suggested a potential to have problems in the processing of salient or subtle stimuli. Although there is no previous report on the sensory profile of adolescents with LD, those with ASD reported that a profile of high sensitivity affected their learning mainly due to a reduction in concentration (Howe & Stagg, 2016).

There are no previous studies on the sensory profile of adults with learning difficulties, nevertheless, it is possible to hypothesise that the sensory characteristics may contribute to some of the difficulties observed in university students and the need for more time to achieve academic goals in adults with a history of LD compared to their typically learning peers (Mortimore & Crozier, 2006; Olofsson et al., 2015; Richardson & Wydell, 2003). According to Dunn (Brown & Dunn, 2002; Dunn, 1997) high scores in Registration suggest that individuals need more salient stimuli to efficiently perceive and process the incoming information.

The sensory profile observed in Studies 1, 2, and 3 is an indicator of how the participants behaviourally react to sensory information regarding their threshold for detecting the signals, and their strategy for managing such information (Dunn, 1997). In particular, the findings showed that children and adults with LD might present an unbalance in their ability to perceive, organise and respond to the environment. The under- and over-responsiveness to sensory inputs observed in participants with LD may be interpreted as problems in the modulation of the incoming information, that is, failure to monitor and regulate the information and consequently produce an inappropriate response in a behavioural level (Dionne-Dostie, Paquette, Lassonde, & Gallagher, 2015; Kern, 2002). In the case of children with LD, their sensory profile is highly diverse, characterised by constant distraction due to extra sensitivity to stimuli, but at the same time, they may lose information due to excess of habituation to such stimuli. This profile may interfere with participation and the achievement of goals, so the children would not be able to establish a significant interaction with the environment (Schaaf & Miller, 2005; Smith-Roley et al., 2007). Similarly, the passiveness trend observed in adolescents and adults with LD reflects an inability to cope with the environmental demands, so they may lose information by not acting and may have difficulties guiding their interests and choices in all types of contexts, including the academic (Brown & Dunn, 2002; Dunn, 1997; 2014).

The final study with children included the comorbidity component, which contributed to elucidating the influence of more than one condition on the sensory profile of children. As expected, given the literature available about the sensory profile of children with ASD, ADHD, and SLI (Cheung & Siu, 2009) the findings revealed that children with these conditions obtained the highest scores on the sensory profile questionnaire, followed by children with 'pure' LD. These results suggest that the sensory profile of children with comorbidity (the ND group), relative to the four main sensory quadrants, varied significantly regarding their developmental and learning trajectories, and are represented by behaviours that are outside the proposed ranges for functional performance (Brown & Dunn, 2002; Dunn, 1997; 2014). Also, the sensory profile of children with LD is influenced by the presence of comorbidity that may lead to a wrong estimation of their sensory abilities. Figure 8.1 shows a summary of the sensory profile mean scores between the groups across the four studies of this thesis.

These results will be discussed concerning the hypotheses of this thesis.

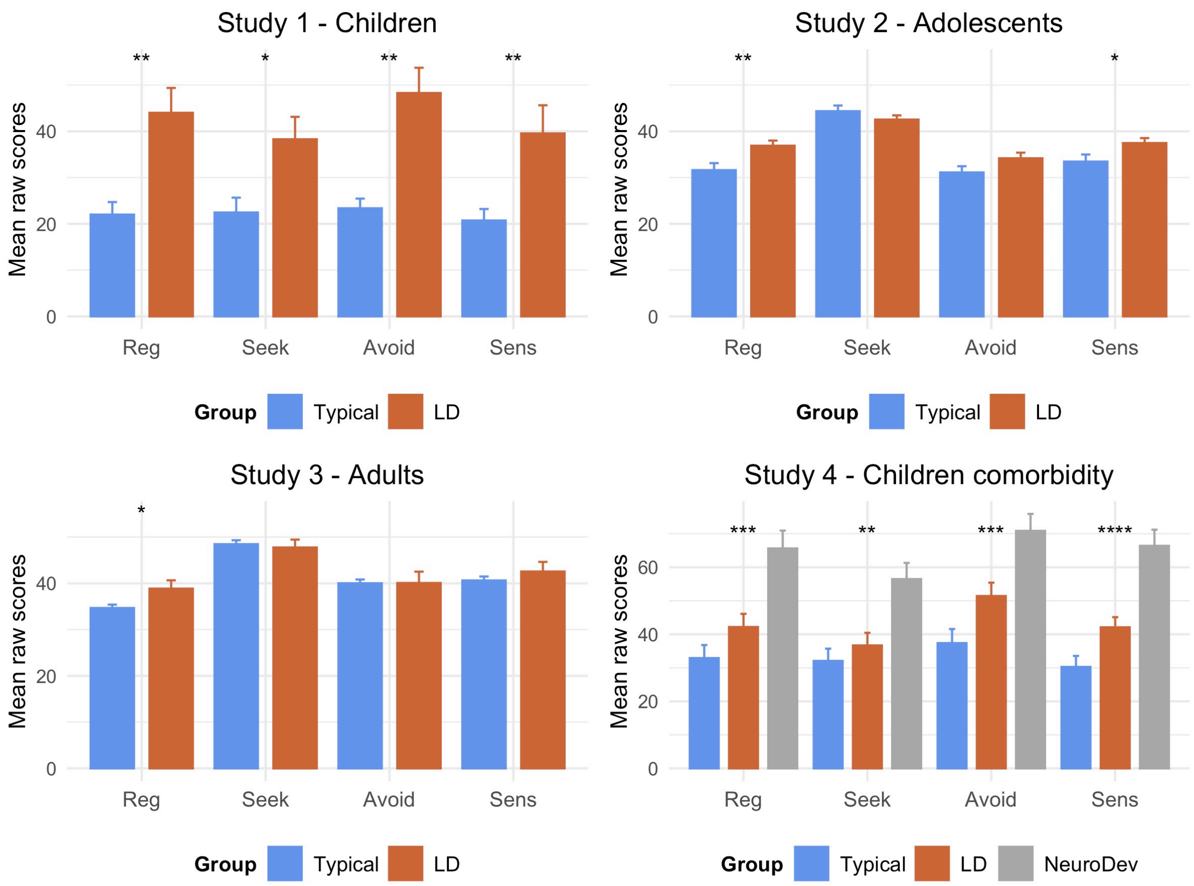

Figure 8.1 Summary of the sensory profile across the four studies and compared between groups.
Reg= Registration, Seek= Seeking, Avoid= Avoiding, Sens= Sensitivity quadrants.
Significant differences between groups at ***< .001, **<.01, *<.05. Error bars represent standard error.

8.1.1 Hypothesis 1

The sensory processing profile will reveal differences in the scores between groups with and without learning difficulties. That is, children, adolescents, and adults with learning difficulties will obtain scores above the mean on the sensory profile questionnaires and will show significant differences with typically learning peers.

As mentioned in the literature review, there is extensive evidence of sensory processing issues within the neurodevelopmental disorders (Cheung & Siu, 2009; Koziol et al., 2011; Kruger et al., 2001; Magallón et al., 2015). For children and adults with ASD, sensory processing issues have consistently shown pervasive problems that affect their general interaction with the environment (Baker, Lane, Angley, & Young, 2008; Gonthier, Longuépée, & Bouvard, 2016; Kern et al., 2007; Tomchek, Huebner, & Dunn, 2014). Similarly, studies of children and adults with ADHD have shown extended difficulties in sensory processing (Dunn & Bennett, 2002; Panagiotidi et al., 2017b; Parush et al., 1997), children with learning difficulties with and without ADHD (Dove & Dunn, 2008), and children with SLI (Cumming et al., 2015; McArthur & Bishop, 2005; Taal et al., 2013; van der Linde et al., 2013). By contrast, the sensory processing characteristics of children and adults with LD is not clear; the present results show marked differences for these group when compared with their typically learning counterparts.

Studies 1 and 4 demonstrated that children with learning difficulties had significantly higher scores on the sensory profile compared to their typically learning peers, and Study 2 and 3 showed high scores in one of the measures of the sensory profile in adolescents and adults with LD. Regarding the normative data, the children and adults with LD (but not the adolescents with LD) presented scores sufficiently above the mean, to indicate ‘clinically relevant’ difficulties.

The results of the empirical studies in this thesis showed significant differences in the sensory profile compared with typically learning groups, and those differences were characterized by high scores in the sensory quadrants, which demonstrated a trend of high frequency of sensory-related behaviours for the LD group. Thus, our results support the first hypothesis by showing that a profile of high frequency of sensory-related behaviours would discriminate LD groups from typically learning groups. Nevertheless, there are some issues to take into account. There is a proportion of the general population that may respond to sensory stimuli in a different way than expected, as the sensory profile scores are arranged according to the normal distribution (Dunn et al., 2016, Dunn, 2014). Likewise, and similar to previous findings from studies with people with and without conditions (Engel-Yeger, 2008; Lane et al., 2014; Mangeot et al., 2001) the data showed a large degree of variability in the sensory profile across the sample with LD. These data suggest that some people with LD present typical behavioural response to sensory stimuli, whereas another group may be characterised by hyper-reactivity to sensory stimuli.

A subgroup analysis was made in Study 4 that confirmed that some children with LD presented atypical sensory profiles, while others were within the typical ranges, as suggested in previous studies (Gonthier et al., 2016; Little et al., 2016). Scores within the normative mean range represent responses that fall into the 'Just like the majority' classification, that is to say, the person reacts to sensory stimulation in a typical way (Dunn, 1997). These clusters are based on the frequency of the manifestation of the sensory-related behaviours listed in the sensory profile questionnaires (Brown & Dunn, 2002; Dunn, 2014). These 'frequency' clusters are consistent with previous studies (Ermer & Dunn, 1997; Little et al., 2018) that have reported that the sensory profile can discriminate between children with and without conditions regarding how often a sensory-related behaviour is observed. However, the classification seems unable to display a more detailed profile to categorize individual scores of children and adults.

Furthermore, the sensory characteristics are not an unquestionable indicator of conditions (Van Hulle et al., 2012) so, sensory differences by themselves are not enough to predict the presence of learning difficulties.

As discussed in Study 3 (section 5.7.2), these results defy Dunn's framework by showing that the frequency of sensory-related behaviour seems to be more relevant for discriminating populations of children with and without conditions rather than for the identification of a particular sensory profile. In the same way, as reported previously in section 2.4.1, children with a diagnosis of sensory processing disorders would present differences in brain structure (Owen et al., 2013). This raises the question of whether the existence of a sensory processing disorder might be the primary cause of further problems associated with neurodevelopmental disorders, or if it can be considered as a comorbid condition. Hence, a differential diagnosis would be relevant to sort this issue out.

In summary, the empirical studies showed a trend to high frequency of behaviours for children and adults with learning difficulties, which did not present Dunn's clinical significance for adolescents. Registration was the most salient quadrant that showed consistently high scores in the LD groups. Conversely, the quadrant of Seeking remained within the mean scores, and even showed great percentage of scores below the mean. Ermer and Dunn, (1997) reported that children with typical development showed a high incidence of behaviours in the Seeking quadrant, but without patterns of inattention that may cause problems. From Ermer and Dunn it is possible to infer that some levels of seeking behaviours may provide adaptive behaviours to interact with the environment; by contrast, in subjects with LD, the Seeking quadrant seems below the expected.

8.1.2 Hypothesis 2

The sensory processing profile will be particular regarding each age group, that is, children, adolescents, and adults will present distinctive profiles on Dunn's questionnaires.

Before presenting the conclusions of our results, it is important to consider that the questionnaires used to assess the sensory profile across the four studies were designed under the same theoretical framework (Dunn, 1997b), however, there were differences between the children and adolescent/adult versions of the questionnaires in terms of the number of items, scoring, and subscales. Also, the groups tested in each study were independent of each other, thus it is not possible to discuss the data in terms of longitudinal changes. For the above reasons, the differences across the profiles were not statistically tested and these data should be interpreted with caution.

The comparison of the sensory profile between the typically learning groups and LD groups exhibited significant differences, were the LD group showed higher scores in some sensory profile scales. In the studies with children, Study 1 revealed higher scores on the quadrants of Registration, Avoiding, and Sensitivity, and Study 4 had higher scores on Avoiding and Sensitivity for the LD group. Study 2 with adolescents showed higher scores in two quadrants: Registration and Sensitivity, but with no clinical significance. Finally, Study 3A with adults revealed higher scores in the Registration quadrant when compared with the typical group, and also in Sensitivity when checked against the normative data.

In the thesis we expected to observe higher differences from the typical groups for the children participants, then milder differences for adolescents, and lower differences for adults. The results partly corroborated this hypothesis by showing differences in both the number of quadrants with significant differences and the quadrants with significant differences across the studies. However, the LD adolescent group (Study 2) showed no clinically significant results, which was unexpected given that both studies with children (Studies 1 and 4) showed clinical significance, together with the adults in Study 3A. The results of this thesis demonstrate that the sensory profile has characteristics regarding the developmental stage of the subjects, which corroborates Padankatti (2005) who found different sensory profiles among typical younger and older children in all the categories assessed with the sensory profile questionnaire. The younger children were more likely to exhibit sensory-related behaviours than the older ones (Padankatti, 2005).

As discussed in Chapter 2, section 2.4.3, during typical development, the nervous system and the sensory processes undergo relevant changes that enable the acquisition of complex skills and adaptive behaviours (Ernst, 2008; Hillock et al., 2011; Robinson & Sloutsky, 2010). Increasing multisensory ability provides a well-organised integration of the incoming sensory information and the enhancement of the response (Stein et al., 2014; Wallace et al., 2006; Wallace & Stein, 2001). The enhancement of sensory processing throughout development has been observed in performance tasks, in which adults showed a faster reaction time, and more efficient integration of sensory cues than younger groups (Davies et al., 2009; Ernst, 2008; Hartcher-O'Brien et al., 2014; Peiffer et al., 2007). It may be the case that neurological maturation improves the ability to register and organise sensory inputs, as in the case of the group of adults in Study 3A, and therefore they were able to display adaptive behaviours, similar to their typically learning counterparts, and more so than young people with learning difficulties. In addition, studies (Kern et al., 2007; Pohl et al., 2003 Ernst, 2008; Hartcher-O'Brien, Di Luca, & Ernst, 2014) have reported a significant enhancement in sensory processing abilities in adults, for example, adults show faster reaction time than youngers counterparts (Peiffer, et al. 2007).

Contrary to expectations, the finding of clear sensory difficulties for children and adults, but not for adolescents with LD is surprising, as it is known that multisensory abilities peak in adulthood (Nardini, Dekker, & Petrini, 2014; Stein, Stanford, & Rowland, 2014; Wallace & Stevenson, 2014). A possible explanation of this discrepancy could be attributed to the measure of sensory processing employed in our studies. First, the sensory profile questionnaires included statements about single sensory experiences, which may not reflect the actual abilities of the participants in multi-sensory conditions. Second, the questionnaire was completed by parents in the case of the children, but as self-report by adults and adolescents. It may be that adolescents were less aware of their behaviours in regard to sensory experiences; they may have shown themselves as more adapted, or even have had problems understanding the statements. Likewise, the LD group of adolescents did not meet the criterion of +1SD above the mean in the learning difficulties questionnaire (CLDQ), despite the clear reports of presenting academics difficulties. In addition, gaining experiences as students along with academic support from the school may have helped them to feel more confidents regarding their academic skills (Cole et al., 2004; Jitendra et al., 2018; Wanzek et al., 2010). Another possible explanation is that in fact, the adolescents in the LD group did not present differences in their sensory profile characteristics, which would corroborate the existence of subgroups within the LD (Gonthier et al., 2016; Little et al., 2016). All of these issues may explain the lack of clinical significance for the group of adolescents with LD.

Thus, the results of the four studies partially confirm Hypothesis 2 by showing particular sensory profile for children, adolescents and adults with LD. These results corroborate the proposed by Engel-Yeger and colleagues (Engel-Yeger et al., 2012) that age is a significant predictor of sensory processing abilities.

8.1.3 Hypothesis 3

It was predicted a significant association between the level of learning difficulties and the sensory profile.

The data showed that the sensory profile questionnaire scores did correlate with reports of learning difficulties. However, the performance tasks for reading included in Studies 1 and 3 (Chapters 4 and 6 respectively) did not show significant correlations with the sensory profile. The results of Study 2 with adolescents and Study 4 with children showed significant correlations between the Registration, Sensitivity and Avoiding sensory quadrants and the scores of the CLDQ. High scores on these measures represent more sensory challenges and learning difficulties respectively; thus the results are indicative of association between learning difficulties and high frequency of sensory-related behaviours (Harrar et al., 2014; Kruger et al., 2001). The correlation between the AASP and the ARQ-G (Snowling et al., 2012) in Study 3B showed a significant positive association between the scales, which contributes to the idea of an association between sensory characteristics and the level of reading difficulty in adults. Consequently, the data provided evidence that sensory processing issues may be part of the characteristic of some learning difficulties, as previously suggested by Dove and Dunn, (2008) and is in line with the hypothesis that sensory processing is a relevant dimension for cognitive development, in particular for reading (Koziol et al., 2011; Kruger et al., 2001) and mathematical skills (Sigmundsson et al., 2010). Reading and mathematical problems have consistently shown high co-occurrence (Lewis et al., 1994; Sigmundsson et al., 2010), suggesting that they may share some foundational causes.

The correlation results were furthered with the regression analysis in Studies 2, 3, and 4 showing that the sensory processing profile may help to predict the presence of learning difficulties. Registration quadrant was found to be a significant predictor on all these studies, and also was found to be consistently different when compared children, adolescents, and adults with and without conditions (see Figure 8.1). The Seeking quadrant was found to be significant predictor in Study 4 with a negative correlation (high scores on Seeking predict less probability of LD). Therefore, low scores in the quadrant of Seeking – characterised by lack of active and engagement behaviours – were associated with learning difficulties in children. The data from this thesis suggests that a high neurological threshold, combined with passive self-regulation strategies would impact significantly on the likelihood of learning difficulties. Previous studies have found a sensory profile of high threshold on LD population under some conditions (Richardson et al., 2004; Sigmundsson et al., 2010; Sperling et al., 2005; Talcott, et al., 2000), for instance in performance tasks with high noise. Hence, a sensory profile characterised by high Registration represents disengagement behaviours from on-going circumstances, which may lead to a loss of experiences from daily life routines, and passive response strategies (Dunn, 1997). The individuals may need more time to respond to stimuli than others, which may contribute to underachievement and the need of more time to complete academic goals, with a consequent adverse effect on academic attainment (Mortimore & Crozier, 2006; Olofsson et al., 2015; Richardson & Wydell, 2003).

The negative association with Seeking quadrant observed in the regression analysis of Study 4, may reflect that a stable amount of sensation seeking is desirable in academic contexts. Ermer and Dunn, (1997) observed moderate frequency of behaviours belonging to this quadrant in typical children, which may serve as a protective factor of learning difficulties. However, there should be noted that excess of behaviours on the sensation seeking dimension may yield to maladaptive responses and a profile similar to ADHD, with a consequent impairment of learning processes (Vargo, 2015). Overall, both Registration and Seeking quadrants are located on the high neurological threshold, however the first is characterised by passive self-regulation while the latter is characterised by active self-regulation strategies. It may be the case that the children's capacity to respond to situations by adjusting their actions in order to achieve the desired results (Dunn, 2007) might have a positive impact on their learning abilities. Therefore, the interaction between internal cognitive processes and external regulation strategies results relevant for learning.

The Object Classification task in Study 1 showed that the incorporation of multiple sensory cues (visual and auditory) influenced the performance of the children in general. In particular, children with LD were able to achieve similar accuracy to (but longer reaction time than) the children without LD. A deficit in audio-visual integration has been reported in poor readers that suggests a failure in multisensory responses, so they seems to benefit less from integrating the two senses (Dionne-Dostie et al., 2015; Fischer et al., 2000; Harrar et al., 2014; Widmann et al., 2012). These findings were extended by Laasonen, Service, and Virsu (2001, 2002) who found an impairment in temporal input processing in dyslexics when visual, auditory and tactile stimuli were presented rapidly, and a positive correlation between temporal acuity and phonological awareness in dyslexic participants. The sensory processing profile comparison between the groups in Study 1 revealed that those with LD had significantly higher scores on the Registration, Avoiding, and Sensitivity sensory quadrants. The significant differences together with the lower performance on the multi-sensory task for children with LD suggest an underlying deficit in the sensory processing abilities of children with learning problems, as suggested by Stein (2001a, 2001b).

It is important to note that all the correlations had the significance p-value adjusted with the Bonferroni method. While this is a common approach in research, this method can lead to underestimation of the results, such as Type II errors (Cabin & Mitchell, 1999; Perneger, 1998).

8.2 Contribution to the learning difficulties research

The data from this study suggest that sensory processing abilities may account for some of the differences associated with academic skills in children, adolescents, and adults with learning problems. These results corroborate the approach of some authors, like Stein (2001b), who suggested that learning difficulties (in particular reading problems) have a sensory origin. Based on the findings of this thesis, we suggest that LD are associated with a general behavioural modulation problem that impact on the sensory processing abilities across the sensory channels. Although the present thesis did not test underlying brain mechanisms, based on Dunn's framework (Dunn, 1997b, 2001) the high frequency of sensory-related behaviours may reflect some problems in the ability to modulate sensory inputs and the subsequent output (Jorquera-Cabrera et al., 2017; Miller et al., 2009; Taal et al., 2013). A modulation problem may have a consequence in the attainment of milestones and skills for children and adults with learning difficulties.

In section 2.3 of Chapter 2, a brief summary was given of the main characteristics reported in studies of reading difficulties, the most frequent manifestation of learning difficulties, whereby the scope of the problems includes the reading, motor, sensory, and executive functions (e.g. Reed & Warner-Rogers, 2008; Fawcett & Nicolson, 1999; Reid, 2009; Vellutino et al., 2004; Tallal 1980). From these characteristics it is possible to infer that the nature of the problem is wide and related to different dimensions, and that learning difficulties are not manifested in the same way and with the same intensity for all. Hulslander et al., (2004) suggested that the effect of the sensory processing abilities on LD may be part of a general cognitive deficit, which might be a plausible explanation for the inconsistent literature about auditory (e.g. Breier et al., 2003; Tallal, 1980), visual (e.g. Goswami, 2014; Stein, 2001a), and audio-visual (Harrar et al., 2014; Ramus et al., 2003) deficits.

The findings that emerged from the sensory profile of children and adults in this thesis showed particular characteristics according to each age stage. The sensory profile shows that for children and adults with learning difficulties as a group the high frequency of sensory-related behaviours may reflect some problems in their ability to modulate sensory inputs and the subsequent output (Jorquera-Cabrera et al., 2017; Miller et al., 2009; Taal et al., 2013). This problem is echoed in both over habituation and over-sensitisation to stimuli, and as a consequence, the attainment of milestones and skills for children and adults with learning difficulties may be harder than for typical learners.

Previous researchers (Dionne-Dostie et al., 2015; Koziol et al., 2011; Nicolson & Fawcett, 2011; Cisek & Kalaska, 2010; Kruger et al., 2001) have suggested that the neurological structures involved in the modulation mechanism rely on the cortex-basal ganglia-cerebellum system. Dionne-Dostie et al. (2015) proposed that the integrated communication among these structures allows receiving, focusing, monitoring and adjusting of inputs. Therefore, sensory processing failures might be associated with the functioning of this subcortical network. The implication of the cerebellum in the modulation of sensory incomes has been observed in autism and other neurodevelopmental disorders (Kern, 2002), and described in the cerebellar deficit hypothesis (Fawcett & Nicolson, 1996), which makes plausible an association with LD. Accordingly, this association between the cerebellum and learning difficulties may be observed in the impairment of motor skills, and the lack of automaticity of skills (Nicolson et al., 2001a). The studies in this thesis provide evidence regarding automaticity difficulties in the results of Study 1 on the Object Classification task. These results may be explained by an automatization deficit, as proposed initially by Nicolson and Fawcett, (1990), and in further studies (Barela et al., 2011; Bucci et al., 2013; Viana et al., 2013; Vieira et al., 2009). The automatization deficit hypothesis was developed based on studies with dyslexics, who showed abnormal difficulties in making skills automatic, despite extensive practice, and regardless of whether the skill was cognitive or motor (Nicolson & Fawcett, 1990, 2008). Thus, as observed in the OC task, children with LD had poorer performance than the typical group in conditions that included more than one stimulus, which may indicate that these children need to invest cognitive control to monitor skills that should be automatic (like balance), and therefore its performance is adversely affected by any secondary task (Nicolson & Fawcett, 1990). The ultimate explanation of the automaticity problem might be an underlying cerebellar deficit. Nicolson and colleagues (Fawcett & Nicolson, 1999; Fawcett, Nicolson, & Dean, 1996; Nicolson & Fawcett, 2008) proposed that disorders of cerebellar development may impact on the impairments in reading and writing. Attentional problems might also be a possible explanation; however, the OC task was not designed to distinguish an effect of this nature.

This thesis contributes to our understanding of learning difficulties from a sensory approach that potentially may cover the broad variety on the manifestation of this condition. While the sensory differences observed in the groups of LD might be linked with subcortical networks, it is not possible to exclude other plausible explanation, such as the phonological theory (Liberman, 1971; Liberman et al., 1974) in a cognitive level, and the magnocellular theory (Stein, 2001b, 2001a) in the biological level. In our view, these frameworks contribute to an overall understanding of learning difficulties, due to the evident phonological issues on reading deficits (Goswami et al., 2010; Kim & Davis, 2004; Share & Levin, 1999; Heinz Wimmer, 1996; Ziegler & Goswami, 2005), and the high frequency of visual perception issues reported in previous studies (Galaburda & Livingstone, 1993). Hence, an inclusive approach may contribute to a better comprehension of the phenomenon.

This research highlights the importance of all of the sensory channels (auditory, visual, tactile, olfactory, oral, vestibular, and proprioceptive) for cognitive development. Recognising the importance of these channels may extend traditional instructional methods by including strategies that will enable learners to take advantage of all of their sensory receptors. Our data suggest that the balance between internal and external inputs was altered in the participants with LD, thus the basic cognitive mechanisms that afford learning processes may have been affected as well, as proposed by Dunn's (2001) conceptual framework of sensory processing. The particularities of such mechanisms cannot be discussed due to the nature of the current investigation.

8.3 Limitations and future research

The main limitations of the empirical studies in this thesis are addressed in this section to aid future research. The primary limitation was the sample size across the studies for both TA and LD groups, compounded by the relatively wide age range involved. Although this issue was addressed through an online data collection modality, this limits the generality of the results obtained and highlights the need for further replications. The sample size of the studies impeded to explore and divide the participants into subgroups, a larger number of participants may confirm that two distinct clusters exist within the population with LD. It should be stressed that for the children studies, the samples taken were the full set of those children (and parents) who agreed to participate using the ethics participation request, and that these children were representative of the schools involved.

The secondary limitation was that there was no information provided by the schools about the LD participants, except that they were in their SEN support systems and verbal confirmation of a dyslexia diagnosis in the case of the adolescent study. Indeed, the schools themselves had no externally validated diagnostic information available owing to the lengthy nature of SEN diagnosis in UK schools. In principle, these children might be diagnosable with any (or several) of a range of specific learning difficulties from dyslexia to ADHD to Language Disorder to Autism Spectrum Disorder. The robust nature of the differences found, especially given the relatively low numbers involved, is therefore particularly noteworthy, and highlights the value of avoiding premature specificity in participant selection given the major overlap between the symptoms of many learning disorders (Gilger & Kaplan, 2001; Kadesjo & Gillberg, 2001; Landerl & Moll, 2010; Nicolson & Fawcett, 2007).

The third limitation for studies after Study 1 was that logistical issues (and difficulties in obtaining NHS ethical approval for a study of children with developmental coordination disorder) led to the need for wholly internet-based testing approaches. These prevented the follow-up to the interesting findings regarding Object Classification, and more generally prevented the use of additional tests, such as psychometric tests of sensory processing and magnocellular function, which would have been invaluable in evaluating the underlying causes of the sensory profile findings established.

In general, the inclusion of other variables would have contributed to the results. For example, emotional issues, like depression and anxiety, have been linked with a sensory profile predominantly of a low neurological threshold (Engel-Yeger & Dunn, 2011; Engel-Yeger et al., 2016). That is, people who recognised stimuli more often due to an easy activation of the neurological system, will present high frequency of emotional problems. Also, a gender analysis could be important in the context of LD and sensory responsivity profiles. Longitudinal studies are required to investigate the sensory profile across the ages and to observe possible changes link with the development.

It should be acknowledged that the key measure of sensory profile is based on a parent-report, for children, and self-report for adults, from a particular model of sensory processing (Dunn, 1997b), and is therefore limited in this respect to parent's precision in identifying sensory deficits of their children or themselves (Leavett et al., 2014; Reid, 2009). This particular model of sensory processing (Dunn, 1997b) and its questionnaires (Brown & Dunn, 2002; Dunn, 2014) provide a general view of the sensory profile of children, adolescents, and adults; however, the questionnaires did not directly measure sensory deficit, and did not provide an operationalisation of the concept of sensory processing, as pointed by Koziol et al. (2011). One of the objectives of Dunn's framework of sensory processing was to provide a characterisation of the strengths and weaknesses of the subjects linked with their own characteristics and interests, and thus the assessment of their difficulties should be done according to that objective. Furthermore, the sensory profile reflected the assumption that the behaviours rated were associated with sensory processing abilities and preferences. However, other variables not measured in this thesis may have influenced the results. A multi-informant perspective (e.g., adolescent and parent reports for the same participants) would be an opportunity to assess the reliability of the Dunn measures in future studies, as well as to assess new samples of children, adolescents and adults to test whether or not the sensory profiles remain constant in each age stage. Future researchers should take these points into consideration, including performance in cross-modal tasks, and the use of neuroimaging techniques to obtain more insights of brain functioning.

8.4 Conclusions

The purpose of this thesis was to provide a characterisation of the sensory processing profile of children, adolescents, and adults with learning difficulties. The empirical studies demonstrated that such sensory profile was particular to each age-stage, and it may account for some of the difficulties with academic achievement. Overall, the findings provide a new view of learning difficulties by integrating aspects that are sometimes under-researched because of a focus on cognitive processes to the detriment of other aspects of development.

The conclusion from this thesis is that learning difficulties are frequently accompanied by problems in processing sensory information, in particular for the audio-visual channels. While clear interpretation of these differences in terms of underlying theoretical mechanisms would require additional study, possible explanations could be a malfunctioning of the behavioural modulation mechanism, together with, theories such as the Magnocellular Deficit and Cerebellar Deficit accounts. What is clear is that Dunn's Sensory Processing Profile questionnaires yield data that substantially augment the information generally derived for children with Special Educational Needs, may be acquired simply by school professionals, and might contribute significantly to the understanding and support of each individual child.

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APPENDIX A

CHILD

CHILD SENSORY PROFILE 2™

Winnie Dunn, PhD, OTR, FAOTA

Caregiver Questionnaire
3:0 to 14:11 years

FOR OFFICE USE ONLY

Calculation of Child's Age	Year	Month	Day
Test Date			
Birth Date			
Age			

Child's First Name: ____________ Child's Middle Name: ____________

Child's Last Name: ____________ ID Number: ____________

Child's Preferred Name (if different from above): ____________

Gender: ☐Male ☐Female Birth Date: ____/____/____ Test Date: ____/____/____

Examiner/Service Provider's Name: ____________

Examiner/Service Provider's Profession: ____________

Completed by/Caregiver's Name: ____________

Caregiver's Relationship to Child: ____________

Name of School/Daycare Center: ____________

School Grade/Level: ____________

In what order was your child born in relation to siblings (for example, 1st child, 3rd child, etc.)?
☐Only Child ☐1st ☐2nd ☐3rd ☐4th ☐5th ☐ Other____________

Have there been more than three children between the ages of birth through 18 years living in your household during the past 12 months? ☐Yes ☐No

INSTRUCTIONS

The pages that follow contain statements that describe how children may act. Please read each phrase and select the option that best describes how often your child shows these behaviors. *Please mark one option for every statement.*

Use these guidelines to mark your responses:

When presented with the opportunity, my child...

Almost Always	responds in this manner **Almost Always** (90% or more of the time).
Frequently	responds in this manner **Frequently** (75% of the time).
Half the Time	responds in this manner **Half the Time** (50% of the time).
Occasionally	responds in this manner **Occasionally** (25% of the time).
Almost Never	responds in this manner **Almost Never** (10% or less of the time).
Does Not Apply	If you are unable to answer because you have not observed the behavior or believe that it does not apply to your child, please check **Does Not Apply.**

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1 2 3 4 5 6 7 8 9 10 11 12 A B C D E

Product Number 0158700058

Almost Always = 90% or more	Frequently = 75%	Half the Time = 50%	Occasionally = 25%	Almost Never = 10% or less

Quadrant	Item	AUDITORY Processing My child...	Almost Always 5	Frequently 4	Half the Time 3	Occasionally 2	Almost Never 1	Does Not Apply 0
AV	1	reacts strongly to unexpected or loud noises (for example, sirens, dog barking, hair dryer).						
AV	2	holds hands over ears to protect them from sound.						
SN	3	struggles to complete tasks when music or TV is on.						
SN	4	is distracted when there is a lot of noise around.						
AV	5	becomes unproductive with background noise (for example, fan, refrigerator).						
SN	6	tunes me out or seems to ignore me.						
SN	7	seems not to hear when I call his or her name (even though hearing is OK).						
RG	8	enjoys strange noises or makes noise(s) for fun.						
		AUDITORY Raw Score						

AUDITORY Processing Comments: ______________________________

____

____

Quadrant	Item	VISUAL Processing My child...	Almost Always 5	Frequently 4	Half the Time 3	Occasionally 2	Almost Never 1	Does Not Apply 0
SN	9	prefers to play or work in low lighting.						
	10	prefers bright colors or patterns for clothing.						
	11	enjoys looking at visual details in objects.						
RG	12	needs help to find objects that are obvious to others.						
SN	13	is more bothered by bright lights than other same-aged children.						
SK	14	watches people as they move around the room.						
		VISUAL Raw Score						
AV	15	is bothered by bright lights (for example, hides from sunlight through car window).*						

* This item is not part of the VISUAL Raw Score.

VISUAL Processing Comments: ______________________________

____

____

APPENDIX B

Scores are provided for quadrants

WORKING COPY

ADOLESCENT/ADULT
SENSORY PROFILE™

Catana Brown, Ph.D., OTR, FAOTA
Winnie Dunn, Ph.D., OTR, FAOTA

Self Questionnaire

Name: ____________________ Age: ________ Date: ________

Birthdate: ____________________ Gender: ☐ Male ☐ Female

Are there aspects of daily life that are not satisfying to you? If yes, please explain. ____________________

____

____

____

INSTRUCTIONS

Please check the box that **best** describes the frequency with which you perform the following behaviors. If you are unable to comment because you have not experienced a particular situation, please draw an X through that item's number. Write any comments at the end of each section.

Please answer all of the statements. Use the following key to mark your responses:

ALMOST NEVER	When presented with the opportunity, you **almost never** respond in this manner (about 5% or less of the time).
SELDOM	When presented with the opportunity, you **seldom** respond in this manner (about 25% of the time).
OCCASIONALLY	When presented with the opportunity, you **occasionally** respond in this manner (about 50% of the time).
FREQUENTLY	When presented with the opportunity, you **frequently** respond in this manner (about 75% of the time).
ALMOST ALWAYS	When presented with the opportunity, you **almost always** respond in this manner (about 95% or more of the time).

PEARSON

28 29 30 31 32 33 34 35 A B C D E

PsychCorp

Item	A. Taste/Smell Processing	ALMOST NEVER	SELDOM	OCCASIONALLY	FREQUENTLY	ALMOST ALWAYS
1	I leave or move to another section when I smell a strong odor in a store (for example, bath products, candles, perfumes).					
2	I add spice to my food.					
3	I don't smell things that other people say they smell.					
4	I enjoy being close to people who wear perfume or cologne.					
5	I only eat familiar foods.					
6	Many foods taste bland to me (in other words, food tastes plain or does not have a lot of flavor).					
7	I don't like strong tasting mints or candies (for example, hot/cinnamon or sour candy).					
8	I go over to smell fresh flowers when I see them.					

Comments

Item	B. Movement Processing	ALMOST NEVER	SELDOM	OCCASIONALLY	FREQUENTLY	ALMOST ALWAYS
9	I'm afraid of heights.					
10	I enjoy how it feels to move about (for example, dancing, running).					
11	I avoid elevators and/or escalators because I dislike the movement.					
12	I trip or bump into things.					
13	I dislike the movement of riding in a car.					
14	I choose to engage in physical activities.					
15	I am unsure of footing when walking on stairs (for example, I trip, lose balance, and/or need to hold the rail).					
16	I become dizzy easily (for example, after bending over, getting up too fast).					

Comments

APPENDIX C

Ethic application and additional documentation Study 1

The University Of Sheffield.

Application 007264

Section A: Applicant details

Created:
Fri 18 December 2015 at 13:53

First name:
Stephanie Alejandra

Last name:
Armstrong Gallegos

Email:
sarmstrong2@sheffield.ac.uk

Programme name:
Psychology (PhD/Psychology P FT) - PSYR31

Module name:
PhD
Last updated:
07/01/2016

Department:
Psychology

Date application started:
Fri 18 December 2015 at 13:53

Applying as:
Postgraduate research

Research project title:
The relationship between multisensory integration processing patterns and dyslexia: an approach based on sensory integration theory.

Section B: Basic information

1. Supervisor(s)

Name	Email
Roderick Nicolson	r.nicolson@sheffield.ac.uk

2: Proposed project duration

Proposed start date:
Mon 1 February 2016

Proposed end date:
Tue 30 August 2016

3: URMS number (where applicable)

URMS number
- not entered -

4: Suitability

Takes place outside UK?
No

Involves NHS?
Yes

Healthcare research?
No

ESRC funded?
No

Involves adults who lack the capacity to consent?
No

Led by another UK institution?
No

Involves human tissue?
No

Clinical trial?
No

Social care research?
No

5: Vulnerabilities

Involves potentially vulnerable participants?
Yes
Involves potentially highly sensitive topics?
Yes

Section C: Summary of research

1. Aims & Objectives

The aim of this study is to characterise the relationship of multi-sensory processing in the symptoms of Developmental Dyslexia. The initial objective is to compare the patterns of multi-sensory integration processing in dyslexic children with a control group (normal development expected) and a group of children with developmental co-ordination disorder (typical motor handicap). The second objective is to identify the influence of multi-sensory processing patterns and deficits found in dyslexia, including difficulties in phonological, speed of processing and motor skills.

It is hypothesised that reading problems of dyslexic children may be caused, at least partly, by inaccurate multi-sensory integration which interferes with the process of obtaining information from the environment and thus affects cognitive processes. Likewise, it is expected that dyslexics have particular patterns of multi-sensory integration that are shared with DCD but differ from the normal developmental. Previous research has found evidence of difficulties integrating in auditory, visual, somato-sensory, motor and language skills in dyslexic children (Kruger, Hugo & Campbell,2001; Nicolson & Fawcett, 1994; Koizol, Budding & Chidekel, 2011; Magallon, Crespo-Eguilaz & Narbona, 2015).

2. Methodology

Design: Non experimental method, ex-post-facto, correlational scope.
Participants: Three groups of children between 8 and 10 years. The first group with diagnosis of Dyslexia, the second group with diagnosis of Developmental Coordination Disorders and a third group of controls.
Dependent variables include (i) skills performance measured by Dyslexia Screening Test - Junior (DST-J) (Nicolson, Fawcett, 2004). The DST-J is a battery that contains screening tests of attainment and ability, consists of 12 subtests: Rapid Naming, Bead Threading, One Minute Reading, Postural Stability, Phonemic Segmentation, Two Minute Spelling, Backwards Digit Span, Nonsense Passage Reading, One Minute Writing, Verbal Fluency, Rhyme and Vocabulary.
(ii) Patterns of multi-sensory integration processing evaluated with the Sensory Profile 2 (Dunn, 2014), questionnaire for parents. This is a questionnaire that evaluates child' sensory processing patterns in the context of home, school and community-based activities.
Analysis of data: Standard descriptive and inferential statistical measures will be used.

3. Personal Safety

Raises personal safety issues? No

Pesonal safety management

- not entered -

Section D: About the participants

1. Potential Participants

The study will be developed with a sample of children between 8 and 10 years old - a period important to reading acquisition. Children will comprise three groups: those with a diagnosis of dyslexia, those with diagnosis of developmental coordination disorder and a third group of children without a background of learning difficulties.

2. Recruiting Potential Participants

Recruiting will be undertaken by contacting specific centres which work with children with dyslexics or with developmental coordination disorder. For DCD it may be necessary to approach the Ryegate Clinic. I will also contact the Department of Human Communication Studies at the University of Sheffield, with regard to children with Specific Language Impairment. If necessary and advertisement will be circulated. Then, parents will be contacted to inform them about the aims and procedures of the research to follow with the assessments in the case that they agree to the participation of their children

2.1 Advertising methods

Will the study be advertised using the volunteer lists for staff or students maintained by CiCS? No

- not entered -

3. Consent

Will informed consent be obtained from the participants? (i.e. the proposed process) Yes

Parents of target children will be called to inform them about the research, those who are interested to participate will be summoned to a meeting where will be delivered the consent form personally. Also, before administration of the test, children will receive an oral explanation about the main objectives of the research.

4. Payment

Will financial/in kind payments be offered to participants? No

- not entered -

5. Potential Harm to Participants

What is the potential for physical and/or psychological harm/distress to the participants?

Some children may feel anxiety in the assessment situation.

How will this be managed to ensure appropriate protection and well-being of the participants?

Assessment will be conducted by a doctoral student with extensive prior experience of working with children and fully trained in the tests to be used.

Section E: About the data

1. Data Confidentiality Measures

A code will be assigned to participants at the moment of review assessment instruments and enter information into the data base, to avoid any personal identification about their performance.

2. Data Storage

All information collected during the present study will be stored securely by the main researcher and the academic supervisor.
The review of assessments instruments and follow analysis will be conducted by the main researcher who hand the information in the Department of Psychology of the University of Sheffield.

Section F: Supporting documentation

Information & Consent

Participant information sheets relevant to project?
Yes

Participant Information Sheets

- participant_information_sheet.docx
  (Document 017038)

Consent forms relevant to project?
Yes

Consent Forms

- Participant_Consent_Form.docx
  (Document 017040)

Additional Documentation

- RiskAssessmentChecklist.doc (Document 017042)
  Risck assessment checklist
- RiskAssessmentChecklist.doc (Document 017043)
  Risk assessment checklist
- Researcher_Safety_Form.docx (Document 017044)
  Safety form

External Documentation

- not entered -

Ethic: Approval letter

Downloaded: 31/03/2016
Approved: 01/02/2016

Stephanie Alejandra Armstrong Gallegos
Registration number: 150210566
Psychology
Programme: Psychology (PhD/Psychology P FT) - PSYR31

Dear Stephanie Alejandra

PROJECT TITLE: The relationship between multisensory integration processing patterns and dyslexia: an approach based on sensory integration theory.
APPLICATION: Reference Number 007264

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 01/02/2016 the above-named project was **approved** on ethics grounds, on the basis that you will adhere t the following documentation that you submitted for ethics review:

- University research ethics application form 007264 (dated 01/02/2016).
- Participant information sheet 1014594 version 3 (01/02/2016).
- Participant consent form 1014595 version 3 (01/02/2016).

If during the course of the project you need to deviate significantly from the above-approved documentatio please inform me since written approval will be required.

Yours sincerely

Thomas Webb
Ethics Administrator
Psychology

Information Sheet for parents

From: Stephanie Armstrong
Telephone: 07497 612589
Email: sarmstrong2@sheffield.ac.uk

Head of Department: Prof. G. Waller
Department of Psychology
University of Sheffield
Floor D, Cathedral Court
1 Vicar Lane, S1 2LT, Sheffield

Combining information from the senses

INFORMATION SHEET FOR PARENTS / CARERS OF PARTICIPANTS

Research Project Title: Combining information from the senses.

You and your child are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it involves. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

What is the project's purpose?

This study investigates the way that children are able to use all their senses (vision, hearing, touch) in everyday life, or whether they prefer to focus on just one. It also looks to see whether any of these sensory preferences is associated with their overall profile of abilities.

If you accept, we will collect information from two sources: first, will be sent a questionnaire for you about your child's sensory preferences; and second, a simple assessment for your child (the Abilities Profiling Test – Junior), which provides information about different skills (such as language, balance and memory skills).

We will complete the assessment child in one session, which should take no more than 30 minutes. It will be take place in the premises of the school. We will fix the suitable day and time with the school.

Do I have to take part?

It is up to you to decide whether or not to take part. If you agree, you will be given this information sheet to keep (and be asked to sign a consent form) and you and your child can still withdraw at any time. You do not have to give a reason.

There are no direct benefits to you for participating in this research. However in the longer term, we hope that this information will help to improve future treatments for learning disorders.

All information that you provide will be kept confidential and will be used only for academic purposes. The data will be encoded such that the identity of each participant is protected, and specific identities will never be divulged. We may use the anonymous data for publications or for future research related with the University of Sheffield. The data will be protected and will not be shared outside the immediate research team.

This study has been approved by the Psychology Research Ethics Committee at the University of Sheffield, and is supervised by Professor Roderick Nicolson. For any further information or questions about this study, please contact the main researcher:

With best wishes

Information sheet for children

CHILD'S SHEET  **INFORMATION**

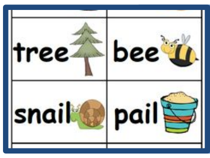
Hi, I'm part of the Psychology Department at University of Sheffield. As a psychologist, I work with people like you.... take a look at this letter.

You are probably used to thinking of the brain as something that is "scientific" and nothing to do with your daily life, but in fact it is working for you all the time. Your eyes are seeing, your nose

is smelling, your ears are hearing, your hands are touching, and your brain has to decide what all this means, so you can take the right actions.

In this study we are inviting <u>children aged 8 to 12 years old</u> to take part in some interesting activities.

These are some of the activities we are using:



How good are you at telling whether words rhyme or not?

How fast can you name pictures?

Can you balance on one foot?

The study will take about 30 minutes. We hope it will tell us how to help everybody to be really good with their senses. You don't have to take part. It is up to you and you can say don't want to carry on at any time.

Thanks for reading!

Stephanie Armstrong

Consent form

CONSENT FORM FOR PARTICIPANTS AND PARENTS/CARERS

Title of study: **Combining information from the senses**

Name of main researcher: **Stephanie Armstrong**

Please initial box

1. I confirm that I have read and understand the information for the above study and have had the opportunity to ask questions. ☐

2. I understand that my child's participation is voluntary and that I am free to withdraw him/her from the study at any time, without giving any reason or my legal rights being affected. ☐

3. I understand that all data will be treated confidentially. ☐

4. I agree to take part in the above study with my child. ☐

Participant´s name (child)	Participant signature (child)	Parent/Guardian signature

Date: ________________________

**Return this document to the school*