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Reading comprehension mechanisms in autism spectrum disorder: Metacognitive processes and executive function

Mecanismos de comprensión lectora en el trastorno del espectro autista: Procesos metacognitivos y función ejecutiva

Tesis Doctoral

MARTINA MICAI

Memoria de investigación presentada para la obtención del Grado de Doctor con Mención Internacional

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Professor David Saldaña, Professor Mila Vulchanova, Professor Holly Joseph, and I, jointly designed the Chapter 2. Professor David Saldaña, Professor Mila Vulchanova, and I, jointly designed the Chapter 3 and 4. The Chapter 2, 3 and 4 correspond to the experimental studies. I carried out the recruitment of participants (as well as Dr. Sobh Chahboun), data collection and data processing. I undertook the statistical analyses with input from all authors. All authors contributed to the drafts and the final version of the chapters. I wrote the Chapters 1 and 5 and all my supervisors, Professor David Saldaña and Professor Mila Vulchanova, contributed to the final version.

Abstract

This thesis aims to increase the understanding of the metacognitive processes and executive function underlying reading comprehension deficits in autism spectrum disorder (ASD). This aim was achieved using behavioural assessments and eye-tracker technology. Although the problems in reading comprehension in ASD have been broadly investigated, the reasons why they occur and the processes that are involved are still poorly understood. Chapter 1 of the thesis provides an overview of the literature related to the cognitive components that influence reading comprehension in typically developing and individuals with ASD. The next chapters present three experiments respectively exploring different components that may influence reading comprehension in ASD: inference generation (Chapter 2), reading monitoring (Chapter 3) and adaptation to reading goals (Chapter 4). In order to observe if differences in reading behaviour where present in absence of cognitive and language impairment, all the studies include children and adolescents with ASD carefully matched with individuals without ASD on chronological age, receptive oral language, non-verbal intelligence and reading speed. Chapter 2 confirmed the hypothesis that individuals with ASD and a high level of oral language show subtle differences in reading strategies compared to the control group. In order to see if differences in reading behavior could be due to top-down modulation strategies, we explored the adaptation to different instructions. Chapter 3 shows limited evidence that individuals with ASD can positively affect their ability to detect errors in reading in response to specific instructions. However, they still seemed to have a different reading pattern compared to controls showing to be less responsive to the type of error. Finally, since the error-detection task is an artificial task, with the next experiment, we further explored top-down modulation strategies using a more ecological

task. Chapter 4 reveals that individuals with ASD change their reading behavior according to the reading goals differently from controls, with less adaptation of their deep-level processing strategies when necessary. Planning, measured by the Tower of Hanoi, was the only executive component that predicted the strategy change between specific reading conditions. This pattern of behavior illustrates that reading comprehension problems may be partially explained by difficulties in adjusting the reading behavior according to the task and in planning. Taken together these studies confirm the already suspected differences in the online processing of reading materials for individuals with ASD, above and beyond oral language deficits, and reveal novel cognitive sources such as metacognition and executive function that may impact reading comprehension in ASD.

Resumen

Esta tesis tiene como objetivo explorar el papel de los procesos metacognitivos y de la función ejecutiva en la comprensión lectora en personas con trastorno del espectro del autismo (TEA). Para ello se han desarrollado experimentos conductuales y con eye-tracker. Los problemas de comprensión lectora en TEA han sido ampliamente investigados; sin embargo, las razones por la que se producen y los procesos que están involucrados en ellos todavía han sido poco explorados. El Capítulo 1 describe los componentes cognitivos que influyen en la comprensión lectora en personas de desarrollo típico y con TEA. Los capítulos siguientes exploran tres componentes que pueden influenciar la comprensión lectora: la generación de inferencias (Capitulo 2), la monitorización de la lectura (Capitulo 3) y la adaptación a los objetivos de lectura (Capitulo 4). Para observar si las diferencias en el comportamiento lector están presentes en ausencia de discapacidades cognitivas o lingüísticas, todos los estudios incluyen niños y adolescentes con TEA cuidadosamente emparejados con un grupo de individuos sin TEA en edad cronológica, lenguaje oral receptivo, inteligencia no verbal y velocidad lectora. El Capítulo 2 demuestra que los individuos con TEA, a pesar de tener un nivel equivalente de comprensión inferencial, muestran sutiles diferencias en las estrategias lectoras en comparación con el grupo de control. Con el fin de ver si las diferencias en el comportamiento de lectura podrían ser debidas a las estrategias de modulación *top-down*, hemos explorado la adaptación a diferentes instrucciones. El capítulo 3 muestra pruebas limitadas de que las personas con TEA pueden modificar positivamente su capacidad de detectar errores en la lectura en respuesta a instrucciones específicas. Sin embargo, todavía parecen tener un patrón de lectura diferente en comparación con los controles. Finalmente, dado que la tarea de detección de errores es

una tarea artificial, con el siguiente experimento, exploramos más las estrategias de modulación top-down usando una tarea más ecológica. El Capítulo 4 revela que las personas con TEA cambian menos su comportamiento lector de acuerdo con los objetivos de lectura, mostrando una menor tendencia a adaptar sus estrategias profundas de procesamiento a los requisitos de la tarea. La planificación, medida con la Torre de Hanoi, fue el único componente ejecutivo que predijo el cambio de estrategia entre condiciones específicas de lectura. Este patrón de comportamiento ilustra que los problemas de comprensión lectora pueden explicarse en parte por las dificultades para ajustar el comportamiento de lectura a la tarea y en la planificación. En conjunto, estos estudios confirman las ya sospechadas diferencias en el procesamiento on-line de materiales de comprensión lectura para individuos con TEA en comparación con un grupo de control, y también revelan nuevos procesos cognitivos, tales como la metacognición y la función ejecutiva, que podrían impactar en su comprensión lectora.

Conference presentations produced during the Ph.D.

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List of Abbreviations

ADOS	Autism Diagnostic Observational Schedule
ADHD	Attention Deficit Hyperactivity Disorder
AQ	Autism Quotient
APA	American Psychiatric Association
ASD	Autism Spectrum Disorder
ANOVA	Analysis of Variance
CCC	Cognitive complexity and control theory
CEG	Test de Comprensión de Estructuras Gramaticales - Grammatical Structures Comprehension Test
D-KEFS	Delis-Kaplan Executive Function System
DRC	Dual-route cascade model of reading
DSM	Diagnostic and Statistical Manual of Mental Disorders
EMLE TALE	Escala Magallanes de Lectura y Escritura - Magellan Scales of Reading and Writing
ESDM	Early start Denver Model
FA	False alarm
H	Hits probability
ICD	International Statistical Classification of Diseases and related Health Problems
ISI	Inter-stimulus interval
ITPA	Illinois Test of Psycholinguistic Abilities
M	Mean
MARS	Maudsley Attention and Response Suppression
NAC	National Autism Center
PPVT	Peabody Picture Vocabulary Test
PRI	Perceptual Reasoning Index
SD	Standard Deviation
TD	Typically Developing
TEACCH	Treatment and Education of Autistic and Communication Handicapped Children
ToH	Tower of Hanoi
ToM	Theory of mind
TROG	Test for Reception of Grammar
UCLA	Young Autism Project
WCC	Weak central coherence
WAIS	Wechsler Adult Intelligence scale
WCST	Wisconsin Card Sorting Test
WHO	World Health Organization
WISC	Wechsler Intelligence Scale for Children
WMI	Working Memory Index

Chapter 1

General Introduction

1. Autism spectrum disorder

1.1 Evolution of the concept and definition

The concept and definition of autism has changed widely throughout its history. Originally, autism spectrum disorder (ASD) was seen as a rare childhood disorder. It was generally associated with intellectual disabilities, scarcity of social awareness, and a lack of meaningful expressive language (Lotter, 1996). Today, ASD is recognized as a pervasive developmental disorder characterized by impairments in social interaction and communication, and a restricted repertoire of interests and behaviors (American Psychiatric Association, APA 2013; DSM-5, 2013, see Table 1.1).

The word autism was first used in 1911 by Bleuler (Wing, 1988) to refer to a thought disorder in schizophrenic patients. Later, the child psychiatrist Grunya Efimovna Sukhareva (1926) used the term "schizoid (eccentric) psychopathy" to describe autism. She then replaced this definition with "autistic (pathological avoidant) psychopathy" and, in her description of the disease, several correspondences with the current diagnostic criteria can be found (Manouilenko & Bejerot, 2015). Leo Kanner (1943) described and classified some of the components of ASD that are still valid, and anticipated many questions pertaining to the procedures for efficient diagnosis, the increase in prevalence, and best practice for treatment. Kanner observed "a deep lack of emotional contact with others, and obsessive desire for environmental invariance and extraordinary fondness for objects, communication difficulties and a very high cognitive potential" (p. 250). At the same time, the psychiatrist and pediatrician Asperger (1944), in line with Kanner, highlighted the social difficulties of individuals with ASD and, in addition, described individuals without delayed language, greater comorbidity with other diseases, and a later appearance of autistic traits compared to the traditional ASD profile. Asperger also noticed that the individuals that he examined presented delayed motor skills. He speculated a possible genetic source of the disease, noticing that similar traits were found in other family members, especially the father. Later, Bettelheim (1956) claimed that the cause of autism was the incapacity of the mother to establish an emotional link with the child. This theory was pervasive until Rimland (1964) assigned the origin of autism to neurobiological causes. Since then, the research focus has been on the genetic, biological, and neurological factors that may have a role in autism.

The epidemiology and the classification of the disease were further described by Wing and Gould (1979) and included three core deficits in social interaction, language, and behaviors (repetitive and stereotyped). The first appearance of autism in the Diagnostic and Statistical Manual of Mental Disorders (DSM) was in its third revised version in 1987. In 1994, with the publication of the fourth edition of the DSM, the Pervasive Developmental Disorders category included a more detailed description of the autism diagnostic criteria. Pervasive Developmental Disorders included autistic disorder, Asperger's disorder, pervasive developmental disorder not otherwise specified (including atypical autism), Rett's syndrome, and childhood disintegrative disorder. The same classification was maintained in the revised version of the DSM-IV (APA, 2000). In 1996, the World Health Organization (WHO) published the tenth edition of the International Statistical Classification of Diseases and related Health Problems (ICD-10), which included similar diagnoses within the category of Pervasive Developmental Disorders: childhood autism, Asperger syndrome, atypical autism, other pervasive developmental disorders, pervasive developmental disorders (unspecified), overactive disorder associated with mental retardation and stereotyped movements, Rett's syndrome, and childhood disintegrative disorder. One of the most important recent developments in the diagnostic criteria and definition of ASD occurred with the introduction of the fifth edition of the DSM (APA, 2013). Although individuals diagnosed with one of the pervasive developmental disorders from DSM-IV do not lose this condition, new criteria for ASD have been drawn in the DSM-5 (see Table 1.1).

Table 1.1

The full-text of the diagnostic criteria for ASD, as they appear in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5).

A. Persistent deficits in social communication and social interaction across multiple contexts, as manifested by the following, currently or by history (examples are illustrative, not exhaustive, see text):

1. Deficits in social-emotional reciprocity, ranging, for example, from abnormal social approach and failure of normal back-and-forth conversation; to reduced sharing of interests, emotions, or affect; to failure to initiate or respond to social interactions.

2. Deficits in nonverbal communicative behaviors used for social interaction, ranging, for example, from poorly integrated verbal and nonverbal communication; to abnormalities in eye contact and body language or deficits in understanding and use of gestures; to a total lack of facial expressions and nonverbal communication.

3. Deficits in developing, maintaining, and understanding relationships, ranging, for example, from difficulties adjusting behavior to suit various social contexts; to difficulties in sharing imaginative play or in making friends; to absence of interest in peers.

Specify current severity:

Severity is based on social communication impairments and restricted repetitive patterns of behavior (see Table 1.2).

B. Restricted, repetitive patterns of behavior, interests, or activities, as manifested by at least two of the following, currently or by history (examples are illustrative, not exhaustive; see text):

1. Stereotyped or repetitive motor movements, use of objects, or speech (e.g., simple motor stereotypies, lining up toys or flipping objects, echolalia, idiosyncratic phrases).

2. Insistence on sameness, inflexible adherence to routines, or ritualized patterns or verbal nonverbal behavior (e.g., extreme distress at small changes, difficulties with transitions, rigid thinking patterns, greeting

rituals, need to take the same route or eat food every day).

3. Highly restricted, fixated interests that are abnormal in intensity or focus (e.g, strong attachment to or preoccupation with unusual objects, excessively circumscribed or perseverative interest).

4. Hyper- or hyporeactivity to sensory input or unusual interests in sensory aspects of the environment (e.g., apparent indifference to pain/temperature, adverse response to specific sounds or textures, excessive smelling or touching of objects, visual fascination with lights or movement).

Specify current severity:

Severity is based on social communication impairments and restricted, repetitive patterns of behavior (see Table 1.2).

C. Symptoms must be present in the early developmental period (but may not become fully manifest until social demands exceed limited capacities, or may be masked by learned strategies in later life).

D. Symptoms cause clinically significant impairment in social, occupational, or other important areas of current functioning.

E. These disturbances are not better explained by intellectual disability (intellectual developmental disorder) or global developmental delay. Intellectual disability and autism spectrum disorder frequently co-occur; to make comorbid diagnoses of autism spectrum disorder and intellectual disability, social communication should be below that expected for general developmental level.

Note: Individuals with a well-established DSM-IV diagnosis of autistic disorder, Asperger's disorder, or pervasive developmental disorder not otherwise specified should be given the diagnosis of autism spectrum disorder. Individuals who have marked deficits in social communication, but whose symptoms do not otherwise meet criteria for autism spectrum disorder, should be evaluated for social (pragmatic) communication disorder.

Specify if:

With or without accompanying intellectual impairment

With or without accompanying language impairment

Associated with a known medical or genetic condition or environmental factor

(**Coding note:** Use additional code to identify the associated medical or genetic condition.)

Associated with another neurodevelopmental, mental, or behavioral disorder

(**Coding note:** Use additional code[s] to identify the associated neurodevelopmental, mental, or behavioral disorder[s].)

With catatonia (refer to the criteria for catatonia associated with another mental disorder, pp. 119-120, for definition) (**Coding note:** Use additional code 293.89 [F06.1] catatonia associated with autism spectrum disorder to indicate the presence of the comorbid catatonia.)

ASD is now recognized as a neurodevelopmental disorder with a large genetic component, but without a valid biological marker or biological test (Abrahams & Geschwind, 2008). Several genes or genetic mutations are thought to be responsible for the increasing the risk that a child will develop ASD. However, the identity and number of genes involved remain to be investigated. The genetics foundations of ASD are further demonstrated a recurrence rate in relatives of individuals with ASD. In a sample of 14,516 children with ASD, Sandin, Lichtenstein, Kuja-Halkola, Larsson, Hultman, & Reichenberg (2014), predicted the relative risk for ASD, compared to the general population, to be 153.0 [95 % confidence interval (CI): 56.7–412.8] for monozygotic twins, 8.2 (3.7–18.1) for dizygotic twins; 10.3 (9.4–11.3) for full siblings, 3.3 (95 % CI, 2.6–4.2) for maternal half siblings, 2.9 (95 % CI, 2.2–3.7) for paternal half siblings, and 2.0 (95 % CI, 1.8–2.2) for cousins. In addition, the genetic source of ASD is further confirmed by the finding that autistic traits in children and parents correlate (Costantino & Todd, 2005). However, there are several sources of evidence that show that genetics alone cannot explain the development of ASD, but that also environmental components play an important role. Environmental causes that have been found to be related to increased risk of ASD include advanced parental age of both parents at the time of conception (Croen, Najjar, Fireman, & Grether, 2007), parental illness during pregnancy, such as metabolic conditions (e.g., Krakowiak, et al., 2012; Xiang et al., 2015), toxic exposure (e.g., McCanlies, et al., 2012; Williams, King, Cunningham, Stephan, Kerr, & Hersh, 2001), extreme prematurity (for a review see, Limperopoulos, 2009), very low birth weight (Lampi et al. 2012), complications during birth such as periods of oxygen deprivation to the baby's brain (Gardener, Spiegelman, & Buka, 2011), infections (e.g., Fombonne, 1999), maternal influenza or fever (e.g., Zerbo, Iosif, Walker, Ozonoff, Hansen, & Hertz-Picciotto, 2013), and winter months of conception (e.g., Zerbo, Iosif, Delwiche, Walker, & Hertz-Picciotto, 2011).

The symptoms of people with ASD fall on a continuum from mild symptoms to severe symptoms (Table 1.2). The concept of ASD as a continuum was applied also in the interaction between the disease and the comorbidity with other disorders such as specific language impairment (Bishop, 2003), executive function deficits (Landa & Goldberg, 2005), and symptoms of anxiety and depression (Gillott, Furniss, & Walter, 2001; Meyer, Mundy, Van Hecke, & Durocher, 2006). It has been shown that ASD shares common underlying risk factors with other disorders more than being a separate category.

Table 1.2

Severity levels for ASD

Severity level	**Social communication**	**Restricted, repetitive behaviors**
Level 3 "Requiring very substantial support”	Severe deficits in verbal and nonverbal social communication skills cause severe impairments in functioning, very limited initiation of social interactions, and minimal response to social overtures from others. For example, a person with few words of intelligible speech who rarely initiates interaction and, when he or she does, makes unusual approaches to meet needs only and responds to only very direct social approaches	Inflexibility of behavior, extreme difficulty coping with change, or other restricted/repetitive behaviors markedly interfere with functioning in all spheres. Great distress/difficulty changing focus or action.
Level 2 "Requiring substantial support”	Marked deficits in verbal and nonverbal social communication skills; social impairments apparent even with supports in place; limited initiation of social interactions; and reduced or abnormal responses to social overtures from others. For example, a person who speaks simple sentences, whose interaction	Inflexibility of behavior, difficulty coping with change, or other restricted/repetitive behaviors appear frequently enough to be obvious to the casual observer and interfere with functioning in a variety of contexts. Distress and/or difficulty changing focus or action.

	is limited to narrow special interests, and how has markedly odd nonverbal communication.	
Level 1 "Requiring support"	Without supports in place, deficits in social communication cause noticeable impairments. Difficulty initiating social interactions, and clear examples of atypical or unsuccessful response to social overtures of others. May appear to have decreased interest in social interactions. For example, a person who is able to speak in full sentences and engages in communication but whose to- and-from conversation with others fails, and whose attempts to make friends are odd and typically unsuccessful.	Inflexibility of behavior causes significant interference with functioning in one or more contexts. Difficulty switching between activities. Problems of organization and planning hamper independence.

Approximately, the prevalence of ASD is 1 in 68 among all racial, socioeconomic, and ethnic groups (Centers for Disease Control and Prevention; Autism and Developmental Disabilities Monitoring Network, 2017).

ASD occurs 4.5 times more often in males than in females and, in a third of cases, ASD is associated with intellectual disability (Centers for Disease Control and Prevention; Autism and Developmental Disabilities Monitoring Network, 2017). Social deficits are most frequent in ASD, whereas restricted and repetitive behaviors and interests are more variable across individuals (Lord & Bishop, 2010).

1.2. Cognitive theories of ASD

Psychological researchers often explain the characteristics of the cognitive style of ASD using the following main three cognitive theories: *theory of mind (ToM) hypothesis*, *theory of executive dysfunction*, and *weak central coherence* (Rajendran & Mitchell, 2007).

Each of these theories proposes a main deficit as the primary cognitive explanation for autistic symptomatology. However, researchers have also considered a combination of the traditional approaches called *multi-deficit account*. The multiple-deficit account claims that ASD is a complex developmental disorder that includes all the previously described theories (Baron-Cohen & Swettenham, 1997). In addition, the authors suggest that each individual could be affected to a different level by the three cognitive styles.

In the following paragraphs, we are going to describe briefly the main characteristics these three approaches.

1.2.1. The theory of mind hypothesis

The proponents of the theory of mind (ToM) hypothesis claim that individuals with ASD have problems in attributing mental states to themselves and other people, thereby making it difficult to take into account the mental states of other people (Baron-Cohen, 1997; Baron-Cohen, Leslie, & Frith, 1985). Researchers have often used the false belief task (Wimmer & Perner, 1983) to measure the capacity to understand the mental states of others. The task consists of making a judgment about the mental state of a character represented by a doll regarding the location of an object, when this representation is incongruous with the real location. If the subject fails to identify the mental state of the doll, the false belief test is not passed. Several additional tests with different grades of difficulty have been developed to test false belief at various levels.

Baron-Cohen (1989) suggested that the ToM problem in ASD is an issue of delay rather than deficit, showing that the ability to infer the mental states of others increases with age. This position was supported by Happé (1995), who pointed out that the probability of success in the ToM task was predicted by verbal mental age. Bowler (1992) claims that the limitations in ToM are not universal in ASD, since not all individuals with ASD display it (Happé, 1994a). This theory was later re-conceptualized in the *enactive mind hypothesis* (Klin, Jones, Schultz, & Volkmar, 2003), that claims that individuals with ASD have "reduced salience of social stimuli and concomitant enactment of socially irrelevant aspects of the environment" (p.345). The preschool impairments in joint attention in ASD is strongly linked with poorer theory of mind skills observed in the childhood (Mundy, 2017).

1.2.2. Theory of executive dysfunction

The executive dysfunction hypothesis in ASD was advanced following correspondences between the ASD's symptoms and those observed in specific brain injury (Dysexecutive Syndrome; Baddley & Wilson, 1988). Similar symptoms between the Dysexecutive Syndrome and ASD were needed for sameness, difficulty switching attention, tendency to perseverate, and impulsiveness. Executive function is an umbrella term that includes initiation, sustaining, shifting and inhibition (Denkla, 1996). It has been observed that individuals with attention deficit hyperactivity disorder (ADHD), schizophrenia, obsessive-compulsive disorder, and Tourette syndrome perform similarly to individuals with ASD in some tasks involving executive functioning (Rajendran & Mitchell, 2007). The *cognitive complexity and control theory* (CCC, Frye, Zelazo, & Palfai, 1995; Zelazo & Frye, 1997) states that ToM and executive function are strongly intertwined because both involve higher order rules.

1.2.3. Weak central coherence theory

Weak central coherence theory (WCC, Frith, 1989, 2003; Frith & Happé, 1994; Happé, 1999) suggests that individuals with ASD lack a sense of global coherence. They tend to process information in a detailed, focused, or piecemeal way. Examples that support this theory are the superior performance of the individuals with ASD in the Embedded Figure and Block Design tasks (Shah & Firth, 1983; 1993, but see White & Saldaña, 2011, for a critical perspective) and the lack of susceptibility to visual illusions (Happé, 1996). An alternative approach to the WCC in the *reduced generalization* hypothesis (Plaisted, 2001). Plaisted argues that individuals with ASD are better at processing unique, rather than common features. Another alternative approach is the *hierarchization theory* (Mottron & Burack, 2001; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). According to this theory, individuals with ASD process hierarchical stimuli differently compared to individuals without ASD: global processing does not have any preference over local processing in ASD, in contrast to typically developing individuals (Mottron & Belleville, 1993). WCC is proposed to be independent of executive dysfunction in ASD. An example that supports this position is that both individuals with ADHD and with ASD have problems in planning, but only the group with ASD shows deficits in WCC. However, Burnette, Mundy, Meyer, Sutton, Vaughan, and Charak (2005) revealed that verbal WCC measures were correlated with ToM measures in ASD. In addition, Norbury (2005) observed that language skills seem to be more related to central coherence abilities, but not uniquely in ASD.

1.3. Impact of ASD on academic achievement

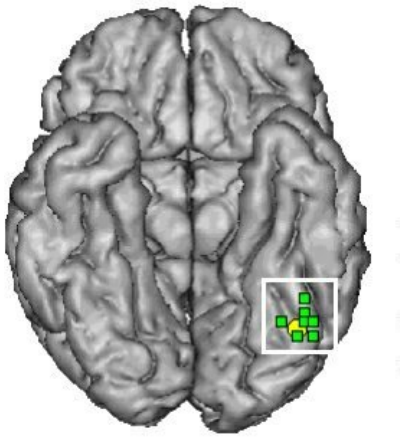
ASD is a developmental disorder that by definition impacts the person's everyday functioning (section D, Table 1.1). There is a link between social and academic competence that has been observed in typically developing children, but more research is needed to investigate the potential implications for children with ASD (Estes, Rivera, Bryan, Cali, & Dawson, 2011; Welsh, Parke, Widaman, & O'Neil, 2001). A longitudinal study on typically developing children showed that those with social deficits often experience inattention and distractibility at school, which leads to problems in the academic achievement. This poor academic achievement is associated with frustration in the classroom and engaging in socially disruptive behaviors, which also impact attitudes toward teachers and peers (Welsh et al., 2001). Although the findings concerning the academic achievement in ASD are variable (Griswold, Barnhill, Myles, Hagiwara & Simpson, 2002; Mayes & Calhoun, 2003), a problematic profile has been defined, especially for reading comprehension and mathematical skills (Jones et al., 2009; Nation, Clarke, Wright, & Williams, 2006). Individuals with ASD generally have problems in mathematical tasks that involve mathematical reasoning or inferential processing (Minshew et al., 1994; Troyb et al., 2014), despite an intact ability to perform basic arithmetic (Minshew et al., 1994). Reading comprehension is another aspect fundamental for academic achievement where individuals with ASD tend to find difficulties (e.g., Brown, Oram-Cardy, & Johnson, 2013; Nation et al., 2006). In the next paragraphs, we will present the typical and atypical process of reading, with a special focus on ASD. A paragraph will be dedicated to the eye-tracking, which is a technique widely used to study reading in typical and atypical populations.

2. Reading: From word up to comprehension

Literacy, which includes reading and writing, is an expert system that involves dedicated neural and cognitive architecture in the brain. It is a skill that derives from a core of other skills such as visual recognition, manipulation of sounds, learning, and memory. The human brain acquires, through experience, this dedicated neural structure for literacy as a result of the *ontogenetic development* of the individual (Ward, 2010). Due to its complexity, the reading process has not been defined by a unique theory, but has been described by several frameworks (Cain & Parrila, 2014; Perfetti & Stafura, 2014). In the following paragraphs, we give an overview of the most influence reading frameworks.

2.1. Cognitive models of word reading

In visual word recognition, it has been suggested that there is a word superiority effect (Carr, Posner, Pollatsek, & Snyder, 1979; Reicher, 1969), i.e. there are units of representation corresponding to letter clusters that influence the visual recognition of letters and words. This is taken as evidence of the existence of a top-down information process in visual word recognition: stored knowledge of the structure of known words can influence earlier perceptual processes (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). Functional imaging studies show a visual word form area (see Figure 1.1, e.g., Cohen & Dahaene, 2004) located in the left mid occipitotemporal gyrus (or fusiform gyrus), anterior to the other cortex dedicated to the visual processing of known letters and common letter patterns (Cohen, Lehéricy, Chochon, Lemer, Rivaud, & Dehaene, 2002). Some researchers have suggested that the visual word-form area does not respond only to letter patterns, but also to other types of familiar stimuli (e.g., visually presented objects and Braille reading) (Price & Devlin, 2003; Price, Winterburn, Giraud, Moore, & Noppeney, 2003). These findings support the idea that this area serves as computational hub linking together different brain regions, such as vision and speech, according to the task. Plaut (1997) and Seidenberg, and McClelland (1989) proposed that lexical decisions take place at a later semantic stage instead of at the visual lexicon level on the basis of the frequency and familiarity of words (Rogers, Lambon Ralph, Hodges, & Patterson, 2004).



R L

Figure 1.1. The visual word form area located on the rear under-surface of the brain, primarily in the left hemisphere.

2.2. Routes from spelling to meaning

Studies on homophones (words with the same phonology but different spelling) (Van Orden, 1987) suggest that the mapping between visual words and their meaning requires phonological mediation. However, the necessity of phonology has been much debated and some researchers have proposed that the meaning of visual words could be accessed directly (e.g., Baron & Strawson, 1976; Smith, 1973). Clinical evidence of this hypothesis was seen in an aphasic patient who made phonological errors, but could comprehend the meaning of the written words (Hanley & McDonnell, 1997). The phonological mediation and the direct access models are presented in the figure below (Figure 1.2).

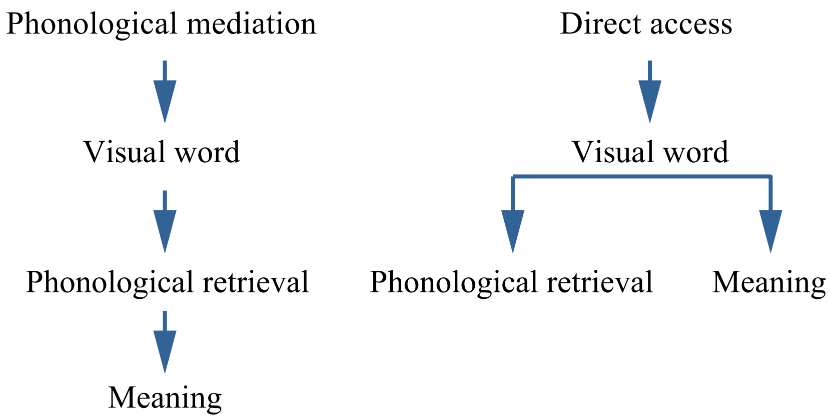


Figure 1.2. Phonological mediation and direct access models. In the phonological mediation model, the phonological retrieval is mandatory for word comprehension. In the direct access model, the phonological retrieval may accompany reading but is not essential.

The *dual-route model* (Figure 1.3) of reading aloud integrates both routes by including a semantically based reading route (visual words can access semantics directly) and a phonologically based reading route (it uses known regularities between spelling patterns and phonological patterns to achieve reading) (Marshall & Newcombe, 1973). The phonologically based route starts a procedure called grapheme-phoneme conversion where letter patterns are mapped onto corresponding phonemes. This process is fundamental to read nonwords, which do not have meaning or a stored lexical representation. However, in the case of words with irregular spelling, using this route would cause errors (e.g., YACHT read as 'yatched'). The semantically based reading route allows individuals to read words with meaning. The semantic route is faster and more sensitive to the word frequency. Within highly frequent words, reading times are fast irrespective of the sound-spelling regularity. In contrast, within the low-frequency words, regular words are read faster than irregular words (Seidenberg, Waters, Barnes, & Tanenhaus, 1984).

A *third route* has been proposed where the visual lexicon is linked with the phonological lexicon but does not go through semantics (e.g., Cipolotti & Warrington, 1995). Another alternative route is proposed by the *summation hypothesis* (e.g., Hills & Caramazza, 1991), which claims that lexical representations in reading are selected by summing the activations from the semantic system and the grapheme-phoneme conversion (Figure 1.3).

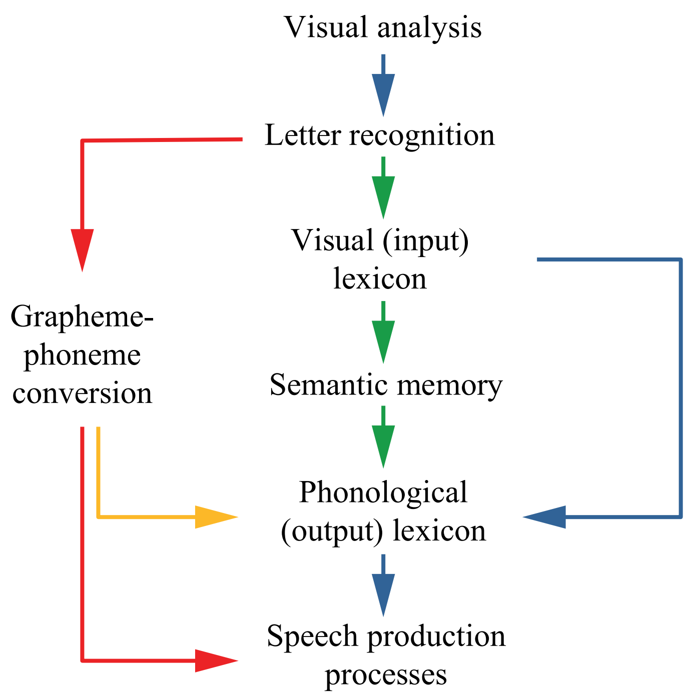


Figure 1.3. In red, the grapheme-phoneme route; in green, the semantic route; in blue, the third route, and in yellow, the summation hypothesis.

2.3. Computational models of reading

Seidenberg and McClelland (1989) proposed the main computational model that considers words have a distributed representation. They hypothesized a connectionist network where each node responds to several words. They suggested that a single route from orthography to phonology was sufficient to read.

A *dual-route cascade model* of reading (DRC), which contains a lexicon and interactivity between components, has also been proposed (e.g., Coltheart, Curtis, Atkins, & Haller, 1993). An example of a computational model that contains hybrid aspects of the DRC and Seidenderg and McClelland models is the Zorzi, Houghton, and Butterworth (1998) model, which claims that the pronunciation of nonwords and exception words are computed by two different routes. These routes interact without a need for a third route; grapheme-phoneme conversion works to extract statistical regularities during learning.

2.4. Reading comprehension as outcome of reading

Reading comprehension is the process that allows readers to extract meaning from the text, with the ultimate goal of understanding what is described in the text (Woolley, 2010). According to the *simple view of reading*, reading comprehension (R) is the outcome of two skills: Decoding (D) and language comprehension (listening ability, C) (R = D x C; Gough & Tunmer, 1986, Hoover & Gough, 1990).

On this basis, Hagoort and Gough (2000) identified three basic types of reading disorders: hyperlexia (decoding skills are intact but the understanding is impaired), true dyslexia (ability to understand the spoken language is intact, but the decoding is impaired) and garden-variety reading disorder (difficulty in both, decoding and understanding spoken language). The simple view of reading thus predicts "double dissociation" in the language deficits profiles of, on one hand, poor comprehenders or hyperlexics, who have problems in language comprehension despite unimpaired abilities in phonological processing and, on the other hand, poor decoders or dyslexics, who have deficits in phonological processing despite relatively good language comprehension. It has been observed that many children with dyslexia have advanced language processing skills that they use to compensate for poor decoding skills. They may be even better than individuals with normal skills in language comprehension, due to a compensation for their decoding deficits (Snowling, 2005). Catts, Adlof and Weismer (2006) confirmed that poor comprehenders have deficits in more general language comprehension and that these problems appear in the earlier grades. The authors suggest classifying poor comprehenders and poor decoders according to a system derived from the simple view of reading. This system categorizes individuals based on word recognition and language comprehension: *dyslexia* is characterized by deficits in word recognition, but normal language comprehension. *The specific comprehension deficit* affects readers that have problems in language comprehension, but not in decoding. *Mixed deficit* includes individuals who have problems with both word recognition and language comprehension. It is important to notice that these categories are dimensional and not categorical (Figure 1.4).

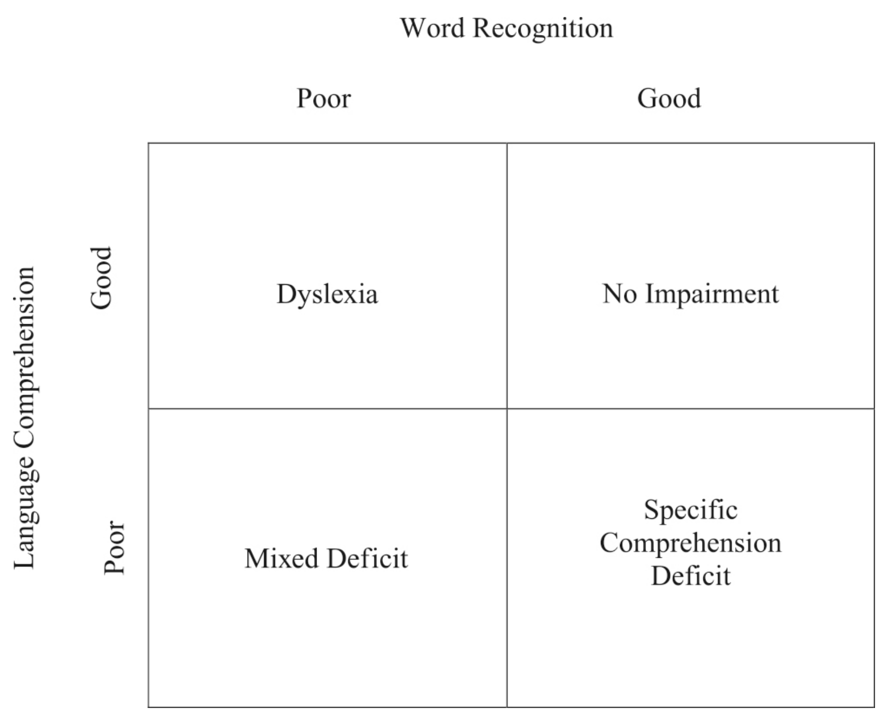


Figure 1.4. Classification system as appears in Catts, et al. (2006) based on the simple view of reading.

The simple view of reading was widely empirically validated as showed in the meta-analysis of García and Cain (2014), which found that decoding is strongly correlated with reading comprehension. However, this link becomes less strong when age increases, giving space to listening comprehension (e.g., Geva & Farnia, 2012; Lervag, Hulme, & Melby-Lervag, 2017; Verhoeven & van Leeuwe, 2012). More generally, vocabulary knowledge (e.g., Clarke, Snowling, Trulove, & Hulme, 2010; Protopapas, Mouzaki, Sideridis, Kotsolakou, & Simos, 2013), inferencing skills (e.g., Cromley & Azevedo, 2007; Oakhill & Cain, 2000, 2012; Perfetti & Stafura, 2014, Silva & Cain, 2014), and syntax (Perfetti & Stafura, 2014) also have crucial roles in reading comprehension. Figure 1.5 illustrates the interaction of word decoding and listening comprehension and their underlying skills (Hogan, Bridges, Justice, & Cain, 2011).

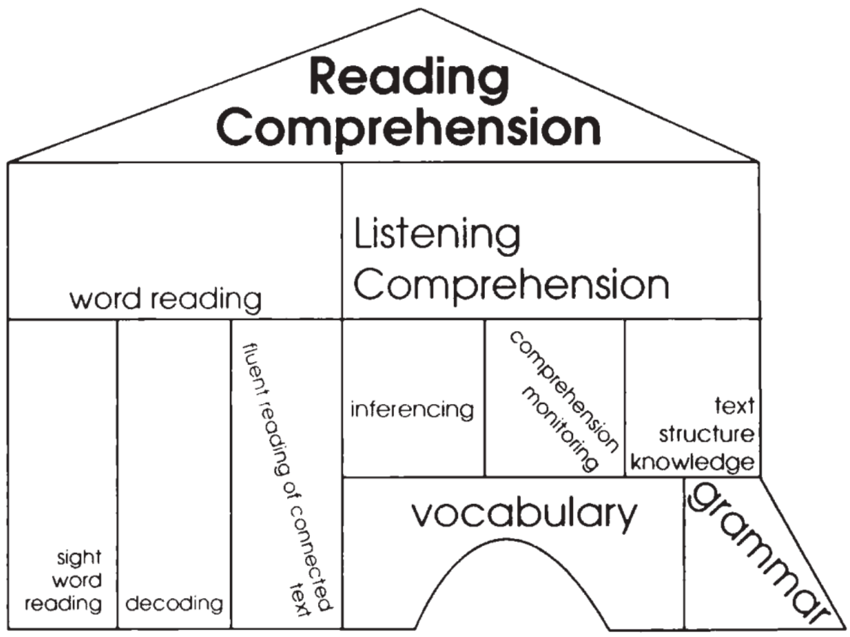


Figure 1.5. The Simple View of Reading as represented by Hogan et al. (2011).

Even though the simple model of reading may provide a solid starting point to describe reading comprehension, needs to be "filled out" with a number of relevant processes that mediate oral comprehension and text reading. The simple view of reading explains deficits such as dyslexia, specific comprehension deficit and mixed deficit, but it does not explain other important reading phenomena. Hoffman (2010) described some concerns about the simple view of reading. He claimed that the simple view of reading ignores the models or theories of comprehension which explain how listening processes work and under what conditions oral comprehension is successful (is it a constructivist or a socio-constructivist model?), the role that the engagement with texts has on cognitive and language skills (e.g., Storch & Whitehurst, 2002), how prosody mediates the process between decoding and comprehension, what happens when a reader approaches a challenging text, how does new literacy (electronic texts, maps) fit into the model, the role of explicit comprehension instructions on reading, and the progress made by individuals with reading difficulty.

Lervag et al. (2017) observed that decoding skills are the bottleneck for the development of reading comprehension, but additional oral language skills are involved in the comprehension process. This claim has important implications for intervention since poor comprehenders may benefit from a direct intervention on decoding skills, but it is necessary to assess and improve other oral language in the intervention protocols. There are no skills that are consistently associated with poor comprehension given the heterogeneity of poor comprehenders (Cain & Oakhill, 2006). However, it has been consistently evidenced that some skills (e.g., vocabulary knowledge and cognitive skills) influence reading comprehension (Cain, 2015; Cain & Oakhill, 2006). In the following paragraphs, we shall detail the most relevant higher oral and cognitive skills that are necessary to achieve successful comprehension.

2.4.1. Semantic analysis

Several models for various dimensions of reading comprehension have been proposed, such as the *construction-integration model* of Kintsch (1988, 1998), the *landscape model* (Van den Broek, Ridsen, Fletcher, & Thurlow, 1996), the *structure building theory* (Gernsbacher, 1990), the *event-indexing model* (Zwaan, Langston, & Graesser, 1995) and the Langston, Trabasso and Magliano (1999) model.

Most accounts of reading support the idea that the initial level of comprehension of a text is semantic analysis, which allows readers to "own" the text meaning. In the construction-integration model, propositions become linked in a network called the *microstructure* of the text. A coherent microstructure is made possible by the construction of inferences such as bridging inferences or pronoun identification (Kintsch & Rawson, 2008). The microstructures are organized in *macrostructures*, which are higher-order units and refer to the recognition of global topics and their interrelationships (Kintsch & Rawson, 2008).

Together, microstructure and macrostructure are called the *text-based*. Effective reading comprehension occurs when readers develop a text-based model, which is the mental representation of the text discourse. At a local level, comprehension requires the processing of symbolic representations of words, phrases and sentences. At a global level, during the text mental representation, readers may need to create a mental model by making inferences in order to link the content of the text across sentences (e.g. Johnson-Laird, 1983). Cain and Muijselaa (2017) recently illustrated that the local/global factors explain a small variance of inferencing and that these factors cannot be reliably measured separately. The authors interpret these results as the evidence for the necessity of both factors and external knowledge for successful comprehension, making difficult the creation of assessment tools that can measure separately the local/global inference generation.

Making inferences at a global level has been linked to knowledge about individual words, providing further evidence for the importance of vocabulary in reading comprehension (Cain & Oakhill, 2014). Inferencing was found to mediate the link between reading comprehension and vocabulary skills after controlling for working memory, but vocabulary was not a mediator for the link between inferencing and comprehension (Daugaard, Cain, & Elbro, 2017). These results, in line also with Currie and Cain (2015), suggest that working memory alone does not explain inferencing skills, but vocabulary has a key role in the success of this process.

The "from word up to comprehension" path is clearly pictured in the Reading System Framework (Perfetti & Stafura, 2014) that links the word identification with the word comprehension summarizing the comprehension system (Figure 1.6). The identification of a word is dependent on the text representation. Comprehension happens when a word is linked to a referent and included in an existing or extended mental model. The selection of the semantic units is influenced by the representation of the text.

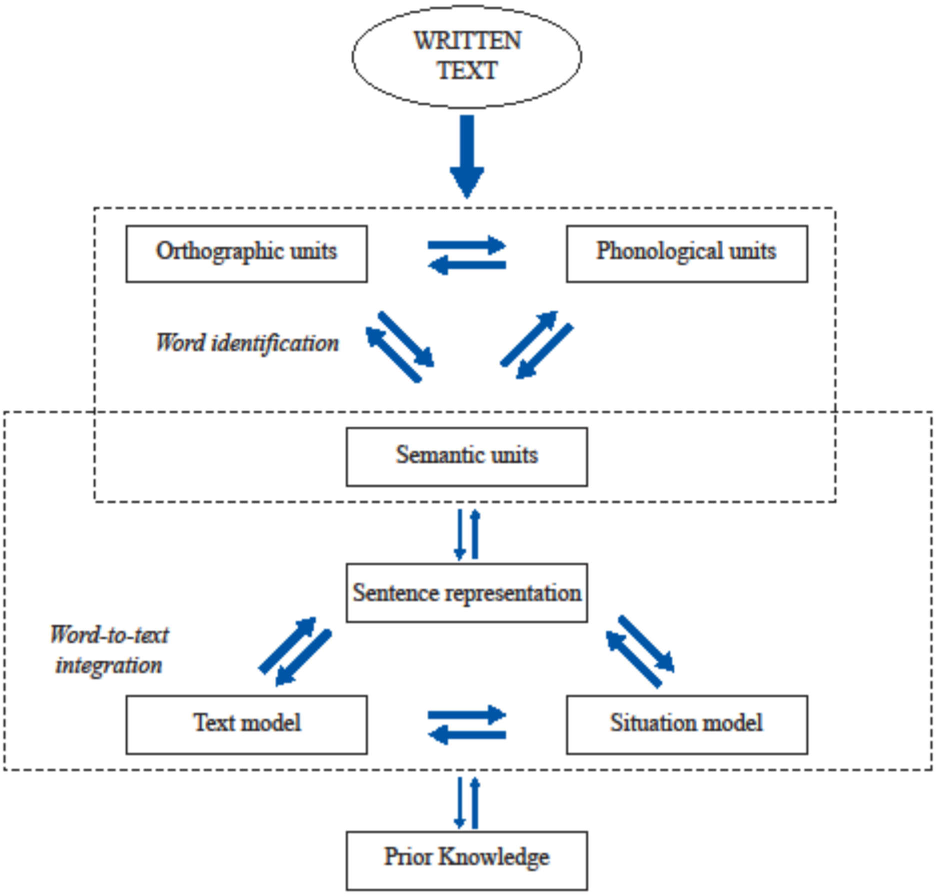


Figure 1.6. The Reading System Framework as appears in Stafura and Perfetti (2017, p. 24).

2.4.2. Situation model

The integration of the text-based information with previous knowledge, via the production of elaborative inferences, produces the *situation model* (Kintsch, 1998, Van Dijk & Kintsch, 1983). In contrast with the text-based model, the situation model includes a more flexible knowledge structure that supports the integration of visual and verbal representation (Snow, 2002; Stull & Mayer, 2007). Zwan, Radvansky, Hilliard, & Curiel (1998) suggested that situation models could include representations of the spatial locations of entities or events, the temporal relations between events, the causal relationships between actions or events, the goals and motives of the character, and the characters' characteristics. The same authors proposed a schema for the situation-model construction that included the current model (i.e., the part of the model being constructed at time T_n) and the integrated model (i.e., the situation model that has been build from time T_1 through time T_{n-1}). Updating refers to the process in the situation model construction where the current model is incorporated in the integrated model.

While building a situation model, readers need to coherently link local and global information and infer meaning that can be implied with the help of existing background knowledge. The situation model requires a larger amount of inferences compared to the text-based model, linking text-based information and integrating it with background knowledge (Nation, Clarke, & Snowling 2002); Taylor, 1992). The gaps, i.e., information not explicitly stated in the text, can be local (within the sentence) or global (involving the entire theme of the story). Inferences can be knowledge-based (involving information that is stored in background knowledge) or text-based (involving information that can be found only in the text).

As Cain and colleagues (2004) observed, despite word reading ability and verbal skills being a fundamental variable that plays a role in comprehension, they do not fully explain higher-level component skills of comprehension (i.e., inference-making ability, comprehension monitoring, and knowledge about story titles). Reading is a complex act that involves motivation and application of strategic behaviors to achieve goals. Building a coherent representation of the text also simultaneously involves several higher cognitive skills such as setting reading goals, monitoring meaning, reflecting upon the understanding (Cain & Oakhill, 2007), and imagining emotions and personal experiences (Kintsch & Rawson, 2008). It is an active, strategic, flexible, and self-regulating process (Hoffman, 2010). Metacognitive and self-control processes are essential in reading, and we shall devote the next section to reviewing their role.

3. Metacognitive processes as a tool of reading comprehension

Metacognition in reading is the conscious awareness and knowledge about the cognition, cognitive processes, and strategies used during reading (Baker & Brown, 1984; Flavell, 1979; Jacobs & Paris, 1987). Metacognition is a very important component of reading because it permits the adaptation of behavior pursuant to the task demands (Woolley, 2010). In order to successfully comprehend a text, readers need to think about the process of reading, learn from the monitoring of the reading, set goals, activate strategies, and assess goal progress and outcomes (Wolley, 2010; Zimmerman, 2002). Skilled readers are able to predict the content of the text, activating memories and testing themselves to see if they have sufficient knowledge about the reading material (Dole, Duffy, Roehler, & Pearson, 1991; Glazer, 1994). The ability to predict the content of the text promotes the understanding and commitment of a story and helps in verifying the comprehension of the text (Duke & Pearson, 2002). Skilled readers generally verify their predictions by monitoring meaning and using repair strategies (e.g., reading back when they find difficulties in the comprehension of the text or reading on when their predictions failed) (Zinar, 2000). Metacognitive comprehension strategies are used more often by skilled readers compared to less-skilled readers (e.g., Israel & Massey, 2005; Myers & Paris, 1978; Paris & Myers, 1981; Sadoski, 1983) and deficits in metacognition are correlated with reading comprehension difficulties (for review see Garner, 1987). Also, poor readers showed less than adequate knowledge about reading (Myers & Paris, 1978) and about cognitive processes (Papetti, Cornoldi, Pettavino, Mazzoni, & Borkowsky, 1992), and they had problems in controlling the reading process (Pazzaglia, Cornoldi, & De Beni, 1995).

Metacognition evolves with age (e.g., Flavell, Friedrichs, & Hoyt, 1970) and increases with training. Guthrie et al. (2004) explained that children become more cognitively engaged when they are taught to use metacognitive skills (e.g., asking themselves questions, monitoring their own response for understanding). This behavior leads individuals to become more goals directed and active in constructing meaning while reading (Afflerbach, Pearson, & Paris, 2008). Metacognitive skills can be improved with a positive impact on reading comprehension (e.g., Borduin, Borduin, & Manley, 1994, Oakhill & Patel, 1991; Pressley, 1976; Davey & McBride, 1986; Armbruster, Anderson, & Ostertag, 1987).

3.1. Comprehension monitoring

In the context of reading, comprehension monitoring is a central component of metacognitive skill, and has been extensively researched within the field of metacognition and self-regulation (Paris & Winograd, 1990; Zimmerman, 2002). Monitoring permits the students to achieve goals and to be more capable of assessing their own performance (Schunk, 2003). It refers to the conscious awareness of lack of understanding (Ruffman, 1996), and is used by a reader to assess whether he/she understands the text (Perfetti, Marron, & Foltz, 1996). Monitoring also refers to the ability of the readers to reconcile inconsistencies and restore meaning. It is activated when a person reads texts and he/she has certain background knowledge that can be applied to the reading material. Readers need then to make bridging inferences when information is missing and take the necessary information from long-term memory (Woolley, 2010). Monitoring includes three phases: planning activities prior to reading, self-evaluation, and revision during reading. This last phase is very important because it determines revision actions (Baker, 1989; Beal, 1990; Beal, Garrod, & Bonitatibus, 1990).

Skilled readers can self-regulate reading by setting their own monitoring understanding, and reading goals and reflecting on their learning outcomes. They also are aware of repair strategies that they can apply during reading and that they can use to regain meaning when it is lost (Zimmerman, 2002). For example, skilled readers tend to ignore a word when is difficult and continue to read to gain contextual cues, or they may reread by scanning back to the previous part of the passage when they lose the meaning of the sentence. It is possible to observe an example of self-regulating strategy during reading aloud. When readers make an error, they continue to read and then self-correct. In this case, the reader is predicting, reading for meaning, monitoring ongoing meaning, and applying online fix-up strategies. Ehrlich, Rémond and Tardieu (1999) found that skilled comprehenders spend more time reading parts of the text containing inconsistent anaphors compared to poor comprehenders. Good comprehenders also adopted the strategy of looking back to previous part of the text when they encountered an inconsistent anaphor. The anaphor resolution (influenced by pronouns, synonymous and repeated nouns) is the psychological process that allows for identification of a previously mentioned concept or referent when the referential relationships are not explicit.

Blunter (2002) observed that children who lack the ability to monitor their reading or use inappropriate or ineffective strategies often have low reading self-efficacy. They also have a tendency to make the same mistakes without reflection on the effectiveness of the strategies they have applied (Johns & VanLeirsburg 1994; Klassen, 2002). Readers can also have misconceptions about reading goals, believing that reading is about decoding words more than obtaining meaning from the text (Perfetti et al., 1996). Ruffman (1996) identified six sources of difficulties for children with comprehension monitoring tasks: 1) conceptual, 2) metacognitive, 3) low-confidence knowledge or nascent knowledge, 4) information-processing limitations, 5) a predisposition to derive an interpretation from the text, and 6) an absence of constructive processing. The conceptual source (1) refers to the knowledge about the characteristics of a difficult text. The metacognitive source (2) refers to the knowledge of reading comprehension processes and knowledge about the understanding of a text (comprehension monitoring). The knowledge about the understanding of a text includes the fact that the student recognizes if the text is wrong and why it is wrong. Low confidence or nascent knowledge (3) concerns the fact that the reader may be aware that the text is problematic, but does not report a problem because he/she has low confidence or nascent knowledge regarding the problems, and these can be unreported instead of undetected (Garner, 1987). Information-processing limitations (4) occur when the student lacks memory or working memory for the demand of the text. Predisposition to derive a conclusion (5) is the tendency of a reader to claim that he/she knows the conclusion of a text even if he/she does not have a clear conclusion in mind. Finally, constructive processing (6) consists of the ability to build a mental model of the text by connecting the individual propositions together; some children may fail in this last process.

Comprehension monitoring should be promoted by encouraging students to use flexible self-regulating behaviors that encompass a three phases process: forethought (pre-reading), performance (during reading), and self-reflection (after reading) (Wolley, 2010; Zimmerman, 2002). Forethought and goal setting are associated with the *forethought* phase. The *performance* phase is associated with organization and performance monitoring, and the *self-reflection* phase is linked with the reorganization phase that is associated with summarization and self-reflective appraisal (see Table 1.3). The features of reading will be different at each phase depending on the reader's purposes.

Table 1.3

The tree reading phases from Zimmerman (2002)

Phases	Processes
Forethought phase (Before-reading phase)	Task analysis:
	Goal setting and planning
	Self-motivation beliefs:
	Self-efficacy, outcome expectations, intrinsic interest/value, and learning goal orientation
Performance phase (During-reading phase)	Self-control:
	Imagery, Self-instruction, attention focusing, and task strategies
	Self-observation:
	Self-recording and self-experimentation
Self-reflection phase (After-reading phase)	Self-judgment:
	Self-evaluation and Causal attribution
	Self-reaction:
	Self-satisfaction/affect and adaptive/defensive

3.1.1. The forethought phase

The forethought phase (before-reading-phase) refers to the beliefs of the reader about the future reading performance (Eccles & Wigfield, 2002). This allows individuals to self-regulate their reading strategy and effort depending on their ability and task demand (Combs, 2002).

Goal setting is an important component of the forethought phase that involves the integration of cognition, motivation, and volitional processes (Cole, 2002; Pekrum, Goetz, Titz, & Perry, 2002). Schunk (2005) observed that setting a goal prior to reading helps readers to know what they are looking for. The selection of the reading goal is fundamental because it will influence the choice of strategies and the type and quality of meanings (Woolley, 2010). Horner and Shwery (2002) found that short-term goals are better than long-term goals, because they promote higher standards compared to long-term goals. Readers feel self-efficient when they can reach a reading goal (Bandura, 1978). Some strategies that can be used to reinforce goal setting are self-instruction and verbalizing (Woolley, 2010).

Planning is another ability that should be applied before reading. It is the ability to understand, organize, and apply appropriate processes and strategies in achieving a set goal (Jurado & Rosselli, 2007). In order to direct behavior, the reading goals need to be related to the task (Latham & Locke, 1991). Researchers have identified two types of achievement goals: achievement-oriented goals where the target is learning and understanding, and performance-oriented goals where the target is to improve execution of the ability in comparison with others (Combs, 2001; Hidi & Harackiewicz, 2000; Horner & Shwery, 2002; Linnenbrink & Pintrich, 2002; Pintrich, 2000; Schunk, 2003).

Individuals with reading comprehension problems tend to have lower performance in planning skills. Locascio, Mahone, Eason, and Cutting (2010) found that children with specific reading comprehension deficits performed more poorly than controls on the planning factor measured with Elithorn Mazes (WISC-III-PI; Kaplan, Fein, Kramer, Delis, & Morris, 1999), Trail Making (Delis-Kaplan Executive Function System; D-KEFS; Delis, Kaplan, & Kramer, 2001) and Tower (D-KEFS; Delis et al., 2001). This poor performance on the planning component remained significant after controlling for phonological processing. Cutting, Materek, Cole, Levine and Mahone (2009) found that children with specific reading comprehension deficits showed lower performance on traditional tasks to assess planning skills (i.e., Tower of London; Shallice, 1982, and Elithorn Perceptual Maze Test; Mazes;

Kaplan, et al., 1999) compared to both typically developing and general reading-disability groups, and had poorer performance than typically developing participants on mazes.

3.1.2. The performance phase

When efficient strategies are used during reading, they facilitate successful performance and raise efficacy and self-concept (Schunk, 2003; Tabassam & Grainer, 2002). Compensatory reading facilitates successful reading, if readers are able to apply strategies to compensate for a possible flaw during reading. One example of an efficient compensatory reading strategy is the one where readers re-read details of the text by choosing the chunks that are relevant for comprehension or that appear confusing. In contrast, a less efficient strategy may be to re-read the entire text. Other examples of compensatory strategies are slowing reading rate, or pausing or reading aloud to recover meaning when it is lost (Rapp & Kendeou, 2007). A necessary condition for the use of compensatory strategies is the ability to monitor reading comprehension.

Walczyk, Wei, Grifith-Ross, Goubert, Cooper, and Zha (2007) found that when less fluent seventh-grade students found a text interesting, they were more likely to use compensatory strategies and comprehend well. The authors suggest that compensatory skills can be taught even to children with reading difficulties.

3.1.3. The self-reflection phase

Successful reading comprehension needs to use self-reflection strategies, which consist of monitoring the progress and attributing the success to the effort invested in comprehension (Ames & Ames, 1984). The affective reactions to self-evaluations have an important role in the motivation to read (Combs, 2002). Self-satisfaction is a fundamental contributor to learning and development (Furrer & Skinner, 2003; Zimmerman, 2002).

Zimmerman (2002) showed that individuals who were more able to make judgments about their own abilities activated more challenging goals.

One technique to promote self-regulation and engagement is self-questioning, which consists of asking questions, being involved in the learning experience, and directing oneself to the pursuit of personal knowledge (Woolley, 2010). Self-questioning has a direct positive effect on motivation and task commitment, because it is influenced by the expectancy of answering questions successfully (Gambrell, Palmer, Codling, & Mazzoni, 1996). Self-questioning is also very useful for self-monitoring and for checking understanding (Boss & Vaughn, 1994).

4. Executive function as a tool of reading comprehension

Executive function can be defined as the neurocognitive processes that control and coordinate cognition and guide goal-directed behavior (Barkley, 1997; Denckla, 2007; Garner, 2009; Meltzer, Pollica, & Barzillai, 2007; Salthouse, 2005). Metacognition was defined as the knowledge of cognition and the regulation of cognition (Schraw & Dennison, 1994). Researchers have reported significant relations and commonalities between executive function and metacognition (Effeney, Carroll, & Bahr, 2013; Garner, 2009; Hofmann, Schmeichel, & Baddeley, 2012).

Executive control in reading involves the ability to control one's cognitive processes and allocate resources to handle cognitive tasks (Britton & Glynn, 1987; Garner, 1994). Reading comprehension is an example of balanced interaction between top-down and bottom-up processing, closely linked with executive function (Cantin, Gnaedinger, Gallaway, Hesson-McInnis, & Hund, 2016; Carretti et al., 2009; Locascio et al., 2010). Sesma, Palmer, Codling, and Mazzoni (2009) found that a large proportion (63%) of variance in reading comprehension is explained by executive function after controlling for individual differences in attention, basic decoding skills, reading fluency, and vocabulary. However, in this model, executive function skills, such as planning (i.e., Tower of London) and working memory, were not significant contributors to single word reading. Cutting et al. (2009) also found in a sample composed of typically developing children, children with word reading deficits, and with specific reading comprehension deficits, that deficits in executive function skills were associated with reading comprehension, specifically in planning and organization skills (excess moves on a Tower of London task).

In the following section, we are going to describe the specific contribution of different executive components to reading.

4.1. Cognitive flexibility

Cognitive flexibility, or attention shifting or switching, is one of the most important skills in reading comprehension (Gaskins, 2008; Kieffer, Vukovic, & Berry, 2013; van der Sluis, de Jong, & van der Leij, 2007). Reading requires the simultaneous and flexible use of multiple elements (Cartwright, 2008); a phenomenon called *cognitive juggling* (Pressley, et al., 2009). This process may be conscious or unconscious and interact with semantic processes (e.g., Crain-Thoreson, 1996). Cognitive flexibility is an aspect of executive control that involves the ability to coordinate simultaneously, and access flexibly multiple features of cognitively complex tasks and to conceptualize a task or situation in multiple ways and flexibly switch between those conceptualizations (Zelazo & Frye, 1998). Cartwright (2007) showed that reading-specific flexibility contributed significant unique variance to adults' reading comprehension in English, after controlling for other variables. The contribution of flexibility on reading comprehension is valid also for French, which is a language that has a more transparent orthography (Colé, Duncan, & Blaye, 2014). Cognitive flexibility was also found to be a fundamental precursor of metalinguistic abilities in pre-readers (Tunmer, Herriman, & Nesdale, 1988; Tunmer & Hoover, 1992).

In reading, there are three types of cognitive flexibility: Coordination of semantic features within and across texts, resolving inconsistencies, and making inferences. To comprehend a text, the readers must make connections between several semantic chunks of the text. The readers should be able also to identify individual inconsistencies between these semantic elements and, generally, the integration of inconsistencies requires longer processing times compared to consistent information (Hakala & O'Brien, 1995). The ability to resolve inconsistency requires that the readers keep in memory, coordinate, and compare text information that can be in different parts of the text (Markman, 1979). Less-skilled comprehenders are less able to detect inconsistencies compared to skilled comprehenders (August, Flavell, & Clift, 1984; Zabrucky & Moore, 1989). However, inconsistency detection can be trained (Reis & Spekman, 1983; Rubman & Waters, 2000).

Inferencing is another complex process that requires cognitive flexibility, in that readers need to consider multiple sources of information at the same time and relate these elements with prior knowledge (Cartwright, 2010). As we have indicated above, less-skilled readers are less likely to make inferences from the text (Oakhill, Yuill, & Parkin, 1986; Cain & Oakhill, 1999; Oakhill et al., 2003; Laing & Kamhi, 2002).

Cognitive flexibility improves with age (e.g., Inhelder & Piaget, 1964), support (Kirkham, Cruess, & Diamond, 2003; Kloo & Perner, 2003), and practice (e.g., Bigler & Liben, 1992). Clay (2001) observed that beginning readers seem to be "limited to one task at the time" (p. 56), while more proficient readers seem to use "several sources of information" (p.57) and they seem to process the material in a more automatic way. Flexibility can be taught effectively (Cartwright, 2002), even with children with deficits in reading (Rong &

Guo-Liang, 2006). Cartwright showed that training with a reading-specific flexibility task produced improvements in reading comprehension. In contrast, general training did not.

4.2. Inhibition

Clark (1996) defined inhibition as "any mechanism that reduces or dampens neuronal, mental, or behavioral activity" (p. 128). Inhibition suppresses or does not activate contextually irrelevant meanings, but does permit activation of context-appropriate meanings (Gernsbacher, 1990). Studies of lexically ambiguous words have provided an insight into the processes of meaning activation, suppression, and enhancement. The activation of contextually irrelevant meanings is suppressed and the activation of contextually relevant meanings is enhanced, so that only the relevant meaning contributes to the building of the text situation model (Gernsbacher & Faust, 1991; Seidenberg, Tanenhaus, Leimen, & Bienkowski, 1982). For example, SPADE which refers a playing card or to a shovel, prompts the activation of both meanings (SHOVEL and CARD), despite the presence of a contextual cue (e.g., *He dug with the spade*). However, inhibitory processes facilitate the selection of only one of the meanings in a given sentence.

Kieffer and colleagues (2013) showed that reading comprehension, in fourth grade students, had a unique direct association with both attention shifting and inhibitory control. Nouwens, Groen, and Verhoeven (2016) found that in fifth grade students, storage, inhibition, and cognitive flexibility contributed to listening span task performance, and so, indirectly to reading comprehension. However, Borella, Carretti, and Pelegrina (2010) observed that difficulties in reading comprehension are linked to specific inhibitory difficulties (i.e., resistance to proactive interference which is the ability to inhibit irrelevant information). Finally, inhibition deficits may negatively influence working memory performance while reading (Cain, 2006b; De Beni and Palladino, 2000; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998).

4.3. Working memory

Working memory has been described in the Baddeley and Hitch (1974) model, in which verbal information is stored in the phonological loop, and visual and spatial information in the visuospatial sketchpad. The authors described a central executive system that controls the communication of information from and to these two storage systems. The central executive system has been linked to multiple, domain-general, executive functions (Baddeley, 1996; Baddeley & Della Sala, 1996) such as updating, inhibition, cognitive flexibility, and planning.

It is well established that working memory has an important role in the growth of reading comprehension (e.g., Swanson & Jerman, 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010). A meta-analysis by Daneman and Merikle (1996) showed that the measures that assess working memory processing and storage capacity together (e.g., reading span, listening span) are more predictive of comprehension than the measures that assess only the storage capacity (e.g., word span, digit span). In addition, the meta-analysis revealed that working-memory span (e.g., storage of digits) is predictive of comprehension. Reading span, measured by asking participants to read a series of sentences and then recall the last word from each sentence, largely differs among individuals and ranges from two to six sentences. It is also a good predictor of reading comprehension and inferencing (Singer, Halldorson, Lear, & Andrusiak, 1992). Several studies found that reading comprehension is affected by the distance between the information required to produce inferences about a text and the subsequent consistent or inconsistent information with the deductions made on it (Ackerman, 1984a, 1984b; Zabrucky & Ratner, 1986). In addition, readers with specific comprehension problems showed increased difficulties with making inferences when the working memory load was higher in the text or sentence (Cain et al., 2003, 2004; Oakhill, Hartt, & Samols, 2005; Yuill, Oakhill, & Parkin, 1989; Yuill & Oakhill, 1988). Inferential revision is effortful in individuals that have low working memory (Pérez, Cain, Castellanos, & Bajo, 2015). The authors proposed that there may be a difficulty in the inhibition of less relevant information, revision of the situation model and full integration into the memory representation of the relevant information.

It has been suggested that the relationship between working memory and reading comprehension depends on domain-specific factors such as language (Cornoldi & Vecchi, 2003). A specific deficit to verbal working memory tasks but not nonverbal working memory tasks in poor comprehenders was observed by Pimperton and Nation (2010, 2012). Verbal working memory tasks are related to reading comprehension tasks since both are drawn by processes of a specific domain (i.e., verbal). In contrast, visuo-spatial working memory tasks are only moderately correlated to reading comprehension (Daneman & Tardif, 1987). Other authors suggested that the implication of working memory in reading comprehension is domain-general, in a way that is dependent on the attentional/executive control component of working memory (e.g., Engle, Kane & Tuholski, 1999; Turner & Engle, 1989). This is supported by data that showed that tasks requiring both maintenance and manipulation of information, or tasks associated with executive functions, correlated more strongly with reading comprehension regardless of the task modality (e.g. Daneman & Merikle, 1996). A meta-analysis from Carretti, Borella, Cornoldi, and De Beni (2009) illustrated that reading comprehension skills are better predicted by working memory tasks that need to implement higher attentional control compared to simpler tasks. These studies indicate that both the processing of verbal information, and the attentional control (storage processing) may have a role in the discrimination of poor comprehension.

4.4. Updating

Updating is an executive component that allows the continuous substitution of stored information that is no longer relevant with new information in working memory, based on a given criterion. The ability to update working memory is related to the functioning of various high-level cognitive processes, and in particular to reading comprehension (Carretti, Cornoldi, De Beni, & Romanò, 2005; Palladino, Cornoldi, De Beni, & Pazzaglia, 2001). Updating is closely related to the general level of intelligence (Friedman, Miyake, Corley, Young, DeFries, & Hewitt, 2006), probably because it is demanding in terms of the executive resources required. Updating is impaired in individuals with intellectual disabilities (e.g., Carretti, Belacchi, & Cornoldi, 2010) and in older adults (e.g., De Beni & Palladino, 2004; Pelegrina, Borella, Carretti, & Lechuga, 2012).

Pelegrina, Capodieci, Carretti, & Cornoldi (2015) showed that children with poor reading comprehension performed worse in an object updating task, compared to a number updating task, in contrast to the children with arithmetic disability who failed in a number updating task, but not in an object task. The authors suggested that the problem of working memory updating in children with learning disabilities may be due to a poor representation of the material to be updated.

The ability to update or revise the situation model of a text becomes necessary during the reading of a long text (e.g., Barnes et al., 2004) and occurs when information in the text conflicts with the interpretation that the reader had of the event. The ability to update situation models might continue to improve over the years (at least after 12 years of age). Pyykkönen and Järvikivi (2012) pointed out that 12-year-old children did not reach adult performance level to revise situation model of temporal order of events. However, Barnes, Raghubar, Faulkner, and Denton (2014) further explored this aspect for the spatial component and found that location and object information during reading are activated and updated from explicit text-based information and the mental model of the event described by the text. The authors showed that were no age differences for this pattern and that the capacity to update the text's situation model was predictive of reading comprehension after controlling for word, decoding.

5. Eye movements during reading

The recording of eye movements has been increasingly used to explore the reading process. Huey (1908) was one of the first researchers to measure the eye movements during reading. Since then, the eye tracking technique has been considered one of the most informative of the reading online processes. It allows us to tap into the underlying cognitive processes of reading and capture the readers' strategies.

During reading, eyes alternate between periods when they are relatively stable (*fixations* with a duration of 200-250 ms) and when they are rapidly moving (*saccades*, 20-40 ms) (Rayner, Juhasz, Pollatsek, 2008). Due to a constant tremor, called *nystagmus*, the eyes are never totally still (Rayner, 1998). The nystagmus is generally considered "noise" and reading researchers tend to ignore it (Rayner, 1998). Visual information is acquired during fixations because vision is suppressed during saccades (*saccadic suppression*, Matin, 1974; Wolverton & Zola, 1983). However, Irwin (1998) showed that some lexical processing occurs during saccades. Not all words are fixated during reading, but some of them are skipped. The skipping happens more in content words compared to function words (Rayner, 1998). A longer word also has a greater probability of being fixated upon compared to a shorter word. In English, most saccades are made from left to right. The approximately 15% of them in which this does not occur are called *regressions* (right-to-left movements along the text or movements back to previously read text). Regressions can be made because readers make too long a saccade, and it is necessary for efficient reading to make a saccade on the left, or because readers may have problems in understanding the text. In this last case, the regression is more than 10 letter spaces back along the text in the same or different line (Rayner, 1998). For example, when the readers encounter a word that indicates that their prior interpretation of the text was an error, they usually make a regression (Frazier & Rayner, 1982). Other regressions are short saccades and may be due to oculomotor errors (Rayner, 1998).

It has been shown that, quite accurately, the regressions go back to the place in the text where comprehension broke down (Frazier & Rayner, 1982; Kennedy, Brooks, Flynn, & Prophet, 2003; Meseguer, Carreiras, & Clifton, 2002). Skilled readers can accurately direct their gaze to the part of the text that caused difficulty (Frazier & Rayner, 1982; Kennedy, 1983; Kennedy & Murray, 1987a, 1987b; Murray & Kennedy, 1988). Poor readers do more backtracking through the reading material (Murray & Kennedy, 1988). We also infer from the readers' gaze whether they find the text difficult by observing increases in fixation duration, frequency of regressions, and decrease in saccade length (Jacobson & Dodwell, 1979, Rayner & Pollatsek, 1989, Rayner, Chace, Slattery, & Ashby, 2006). During reading comprehension, if the reader makes more regressions, it is likely that he/she is encountering difficulties during comprehension (Rayner et al., 2006).

Word characteristics also influence reading behavior. For example, words with lower frequency are fixated longer (longer gaze duration) compared to words with higher frequency (Inhoff, 1984; Inhoff & Rayner, 1986; Rayner & Duffy, 1986). Gaze duration is also affected by the predictability of the word in the context (Inhoff, 1984).

The measures that are traditionally analyzed for reading material and that reflect specific reading processing, are presented in Tables 1.4 and 1.5. In the following chapters, we will consider two types of measures. First, *global* measures that refer to the eye movement data collected during the reading of the entire paragraph (Chapters 2 and 4) and sentence

(Chapter 3) (Table 1.4). Second, *local* measures during the reading of targeted regions associated with different experimental conditions: target word in Chapter 2 (inferential vs. literal), error in Chapter 3 (semantic vs. orthographic) and target sentence in Chapter 4 (central vs. peripheral) (Table 1.5).

Table 1.4

Description of global eye movement measures and the reading processing that can be inferred for each measure.

Measure	Definition	Reading processing	References
Total reading time	The time spent in a region, both forward and regressive movements, given that the region was fixated	Total processing time spent on a region	Clifton, et al., 2007
Total number of fixations	The sum of fixations did in a region, given that the region was fixated	Processing effort spent on a region (i.e., easy words to identify and understand are fixated shorter than difficult words) and preview of the word prior fixating it	Clifton, et al., 2007
Average fixation duration	The average of the duration of all fixations did in a region, given that the region was fixated	Influence by the information density of the region (e.g., semantic and morphosyntactic characteristics)	Clifton, et al., 2007; Rayner, 1998
Number of forward fixation	Number of fixations following a forward (left to right) saccade	This measure reflects the initial encounter with the region	Hyönä, Lorch, & Kaakinen, 2002
Forward saccade length	The mean length of all saccades	Processing difficulty influences this measure. As reading skills increases	Rayner, 1998

		(reading difficulty decrease), saccade length increases	

Table 1.5

Description of local eye movement measures and the reading processing that can be inferred for each measure.

Measure	Definition	Reading processing	References
First fixation duration	The duration of the first fixation on a word provided that the word wasn't skipped	This measure indicates how long it takes to move the gaze from the region that is of immediate interest for the reader to another area of interest. This measure is sensible to word recognition difficulty and lexical factors	Clifton, et al., 2007; Norbury, 2016
Single fixation duration	The duration on a word when only one fixation is made on the word	This measure occurs when there the eyes land in a region of a word that is optimal (near the word's middle)	Clifton, et al., 2007
Gaze duration/total fixation time	The sum of all fixations on a word prior to moving to another word	This measure is influenced by word frequency (high-frequency words are fixated shorter than low-frequency word) and predictability (shorter for high predictable words than low predictable	Clifton, et al., 2007

Measure	Definition	Reading processing	References
		word)	
Go-past time/ Regression path duration	The sum of all fixations in a region from first entering the region until moving to the right of the region; fixations made during any regressions to earlier parts of the sentence before moving past the right boundary of the region are thus included in this measure, again given that the region was fixated	The cost of overcoming the difficulty of integrating a word when is fixated, which may well occur late in processing	Rayner, Sereno, Morris, Schmauder, & Clifton, 1989
Re-reading time	The total fixation duration in a region after having left the error to the right. The regression path reading time for a region less the first pass reading time for a region	This measure is an index of the time the reader spends re-reading the text after encountering a problem, but before he/she makes an eye movement to fixate words to the right of the problematic region	Liversedge, Paterson, & Pickering (1998)
Regression-out	The probability of regression out a region, usually limited to the first-pass reading of that region	Difficulty in integrating a word when is fixated	Clifton, et al., 2007
Regression-in	The probability of making a leftward eye movement into the error having already left that word to the right	Difficulty in integrating a word when is fixated	Clifton, et al., 2007
Skip	Probability of not reading the region	Contextual constraint, word frequency, and length:	Rayner, 1998

Measure	Definition	Reading processing	References
		words that are highly constrained by the previous context, more frequent and shorter are skipped more frequently compared to less constrained, less frequent and longer words	
Right bounded duration	The sum of all fixations within a region before the eye fixates any region to the right of the region	This measure is similar to gaze duration except the termination of right-bounded reading time does not occur until a region of the sentence progressive to the region is fixated. This measure assesses the immediate stage processing	Gordon, Hendrick, Johnson, & Lee, 2013
First pass regression	The sum of all fixations in a region from first entering the region until leaving the region, given that the region was fixated at least once	Word's representation, orthography, phonology, meaning and syntactic factors	Juhasz & Pollatsek, 2011; Clifton, et al., 2007

First fixation durations are reported, especially when the disambiguating region is short, but when regions are long and the disambiguating material is not likely to be included in the initial fixation, the first fixation measure is inappropriate. Measures such as first fixation time are often referred as "early" measures and measures such as total time are referred as "late" measures (Rayner et al., 1989). The go-past and the regression-out measures are considered in some cases early and in other later measures (Clifton et al., 2007). Early and late measures reflect the first v. the second stage processes of sentence comprehension (Rayner, Carlson, & Frazier, 1983; Frazier, 1987). Early processing eye movement measures refer to the first-pass measures that occur prior to any regression back to the word and are attributed to the word's representation, orthography, phonology, or meaning (Juhasz & Pollatsek, 2011). Later processing eye movement measures refer to the readers attempt to create a coherent situation model for a text and are affected for example by plausibility violations (Warren & McConnell, 2007).

It has broadly observed that reading skills influence eye movements. Skilled readers make shorter fixations, longer saccades and fewer regressions compared to less skilled readers (Rayner, 1978, 1998). The eye movements also change with age and reading experience. Fixation durations and the frequency of regressions decrease and saccade lengths increase (Rayner et al. 2008).

While reading, the reader makes two unconscious decisions: to where and when does the gaze move. The where decision is influenced by low-level word length and orthographic properties, and the when decision is related to the proprieties of the text, such as lexical, syntactic and discourse characteristics (Rayner et al., 2008).

6. Reading and ASD

The study of reading in ASD is of interest for two reasons. First, studying reading in ASD give us a view of atypical mechanisms that may be illustrative of the typical functioning of the reading processes. ASD can be considered a good model to study poor reading comprehension because often, in this population, a discrepancy is observed between reading comprehension and word recognition abilities (Jones et al., 2009). In the present studies, we additionally recruited participants with ASD comparable in language skills with controls. According to the Simple View of Reading, reading comprehension is the product of decoding skills and oral language skills. Based on this model, we would expect individuals with ASD to show unimpaired performance in reading comprehension and no difference in the reading strategy. It has to be noted that our participants were monolingual Spanish speakers. Linguistic comprehension is an important predictor for reading comprehension in transparent orthographies as Spanish, compared to decoding accuracy for beginner readers (Florit & Cain, 2011). However, in transparent orthographies, the influence of decoding skills in reading comprehension is determined by the assessment measures: decoding fluency has been observed to be equally important for reading comprehension as linguistic comprehension (Florit & Cain, 2011).

Second, reading comprehension deficits have been broadly recognized in ASD, and researchers and practitioners need to understand the underlying mechanisms that drive those flaws and to plan potential interventions.

6.1. Dissociation between decoding skills and reading comprehension

The profile of poor comprehenders is characterized by poorer performance in understanding the texts during reading (Nation & Norbury, 2005; Nation, 2005a), compared to higher decoding skills. Some disorders in which poor comprehension associated with relatively good decoding often appears are Turner syndrome (Temple & Carney, 1996), specific language impairment or developmental language disorder (Bishop & Adams, 1990), Williams syndrome (Laing, Hulme, Grant, & Karmiloff-Smith, 2001), attention deficit hyperactivity disorder (Cain & Bignell, 2014; Miller Keenan, Betjemann, Willcutt, Pennington, & Olson, 2013), and ASD (Ricketts, 2011).

Reading comprehension has been extensively investigated in ASD. However, to our knowledge, there is a lack of direct comparison of reading comprehension skills between ASD and other disorders, with the exception of language impairment and some work on

ADHD. It could be interesting to compare the performance between clinical groups in order to see if the processing of the reading material differs between groups. Some work has been done in the comparison between ASD and ADHD. Åsberg, Kopp, Berg-Kelly, and Gillberg (2010) study exhibited no difference in the reading comprehension patterns in girls with ASD and ADHD after controlling for oral vocabulary, word decoding, and nonverbal ability. Recently, McIntyre et al. (2017) described, using a larger sample and including males, a more severe impairment in the reading comprehension profile in high functioning individuals with ASD compared to the ADHD group. Also, in a comparison of groups with ASD, specific language impairment and pragmatic language impairment, the group with ASD was more likely to have inferential deficits (Norbury & Bishop, 2002).

The first observations about reading comprehension in ASD were written by Kanner (1943): "Reading skill is acquired quickly, but the children read monotonously, and a story or a moving picture is experienced in unrelated portions rather than in its coherent totally.*" (p. 250).* A large number of studies have since then attempted to describe the profile of reading comprehension in individuals with ASD (e.g., Ricketts, Jones, Happé, & Charman, 2013; Nation & Norbury, 2005; Norbury & Nation, 2011; Snowling & Frith, 1986; Wahlberg & Magliano, 2004). Nation and colleagues (2006), found that, despite a large heterogeneity of the group with ASD, the majority (65%) of the children and adolescents who participated in their study had reading comprehension problems, and another consistent portion (38%), had severe deficits (more than two standard deviations below the population mean). Nation and colleagues (2006) showed the dissociation between difficulties to understand reading material, despite a reading ability in word and nonword reading equivalent to their chronological-age matched peers. In addition, the novelty of this study was to highlight the consistent heterogeneity across the sample, showing performance ranging from floor to ceiling levels. Three reading patterns were observed in the ASD sample: i) hyperlexia (discrepancy between the level of decoding and comprehension), ii) impairment in reading words and nonwords and, iii) impairment in decoding nonwords, despite a reasonable level of word reading skill. In this context, individuals are considered to be hyperlexic when their ability to decode and pronounce single words is rather high in comparison to their comprehension level and/or cognitive development (Frith & Snowling, 1983; Newman, Macomber, Naples, Babitz, Volkmar, & Grigorenko, 2007). Snowling & Frith (1986) and Whitehouse & Harris (1984) identified a profile of hyperlexia in individuals with ASD. Later, Newman et al. (2007) showed that children with ASD and hyperlexia performed better on single-word reading and pseudoword decoding compared to children with ASD and without hyperlexia, and typically developing children matched on word-reading, but not on reading comprehension. Approximately 5 to 10 % of the persons with ASD have a profile of hyperlexia, according to some estimations (Burd & Kerbeshian, 1985; Wei, Christiano, Yu, Wagner, & Spiker, 2014). Hyperlexia is not an ASD -specific phenomenon, but has been observed also in advanced decoders with intelligence scores below the norm (Snowling & Frith, 1986). However, its prevalence does seem to be greater in ASD than in other developmental disorders (Newman, 1997). Nation (1999) observed that hyperlexia is one of the manifestations of reading profile associated with individual differences. Processes involved in decoding, on the other hand, seem to be similar to typically developing readers, with phonology playing a strong role (Saldaña, Carreiras, & Frith, 2009). Hyperlexia is a rare condition in transparent languages such as Spanish and it is generally observed accompanied by reading comprehension problems (Talero-Gutierrez, 2006).

A recent meta-analysis (Brown, Oram-Cardy, & Johnson, 2013) examined 36 studies and three moderators (semantic knowledge, decoding skill, and performance intelligence quotient) and two text types (high and low social knowledge) and found that reading comprehension in ASD was, on average, poorer than controls, with a mean difference between the ASD and typical development groups of 0.7 standard deviations. Individuals with ASD had more difficulty with texts containing high social contents compared to the low social content texts. Brown et al. (2013) also suggested that the decoding abilities in ASD, although extraordinary in some low-functioning readers with ASD, vary in a similar way as in the typical population, i.e., the word reading accuracy is distributed normally and the people that have hyperlexia fill the right tail of the distribution. These problems of reading comprehension in ASD even occur in individuals with a relative strength in decoding (Castles, Crichton, & Prior, 2010; Flores & Ganz, 2009; Goldstein, Minshew, & Siegel, 1994; Nation et al., 2006). Several studies reveal that the reading profile of people with ASD is similar to that of poor comprehenders without ASD, in that there is the discrepancy between decoding reading skills and text reading comprehension (e.g., Davidson & Weismer, 2014; Jacobs & Richdale, 2013). Minshew and colleagues (1994) found that participants with high functioning ASD, matched with typically developing subjects on general intelligence, gender, age, and economic status, had lower scores in the comprehension tasks. However, these differences were not found in decoding skills. One hundred children with dyslexia were compared with 384 participants with ASD. The latter group had problems in reading comprehension despite relatively intact decoding skills. In another study, the group with dyslexia showed the opposite pattern of stronger comprehension and weaker decoding (Huemer & Mann, 2010). Jones and colleagues (2009) studied a sample of 100 adolescents with high functioning ASD and found a significantly low score in a standardized reading comprehension task, despite unimpaired decoding and orthographic skills. Almost 40% of the participants showed reading comprehension scores lower than expected from their intellectual level. Recently, Solari, Grimm, McIntyre, Swain-Lerro, Zajic, and Mundy (2017) tested 68 participants with higher functioning autism that had lower performance in reading connected text or oral reading fluency (strongly related to decoding) compared to 38 matched on intelligence typically developing children and adolescents. These results are possibly due to the fact that deficits in structural language impede fluent text reading. They highlighted the importance of text reading fluency by observing that it was the most important predictor of reading comprehension, whereas single word decoding lost its effect.

Although there is a certain consensus on the poor comprehender profile in ASD, there is less agreement as to the cognitive and linguistic variables that could explain it. Ricketts (2011) reviewed reading comprehension problems in ASD, as well as in individuals with specific language impairment and Down syndrome, and found that the problems were statistically explained, to some extent, by factors such as word recognition, oral language, nonverbal ability and working memory.

The following section is dedicated to the analysis of the components that influence reading comprehension in ASD. The variables we are going to describe do not impact reading comprehension only in ASD, but also in typically developing individuals and in other disorders. Since the present thesis concerns ASD, we are only going to review the studies that took into consideration these variables in autism.

6.2. Variables that influence reading comprehension in ASD

6.2.1. Oral Language

Nation et al. (2006) found a strong correlation between oral language skills and reading comprehension: skilled comprehenders with ASD presented higher scores in oral language comprehension compared to the poor comprehenders with ASD, despite the two groups being matched on word recognition. Norbury and Nation (2011) also found that oral language explains variance in reading comprehension, after controlling for word recognition. Similarly, Ricketts et al. (2013) agreed that word recognition and oral language explain unique variance in reading comprehension. Lucas and Norbury (2014) showed that vocabulary knowledge was the strongest predictor of comprehension and decoding skills at a sentence and passage level. In addition, the same authors (Lucas & Norbury, 2015) found that one third of the children with ASD and unimpaired language, and half of the sample with language impairment, regardless the ASD diagnosis, had difficulties in inference generation that were predicted by oral language skills. The autistic symptomatology did not contribute to the variance in reading comprehension. Again, Eberhardt and Nadig (2016) found that structural language ability was the only significant predictor of sensitivity to context on both picture and sentence completion tasks. McIntyre et al. (2017) also observed a relevant role for oral language in reading comprehension in high functioning individuals with ASD. Specific higher order components of language (inference, narrative recall, sentence-level processing skills) mediated the effect of ASD-specific characteristics on reading comprehension.

6.2.2. Vocabulary

The contribution of various specific language skills has additionally been explored in studies in this field. Vocabulary is probably one of the most relevant. In the general reading literature, it is clear that the size of the lexicon has a positive impact on reading comprehension (e.g., Cain & Oakhill, 2011). Nation (2005) observed that children with poor comprehension have less vocabulary compared to their peers without comprehension difficulties. Finally, in their meta-analysis, Brown et al. (2013) showed that vocabulary explained 57% of the variance in reading comprehension, with decoding explaining 55% of the variance. The authors concluded that the autistic symptomatology alone does not predict reading comprehension difficulties.

Other studies have evaluated reading comprehension skills in the absence of problems in vocabulary skills. Whitehouse and Harris (1984) tested 20 children with ASD and found that the majority of them had an excellent vocabulary, together with a decoding ability significantly higher than the level that was expected based on their intellectual skills. Despite this, they had poorer scores on comprehension. Similarly, Newman et al. (2007) showed that the participants with hyperlexia and ASD did not display significant differences with the control group in vocabulary. However, the readers with ASD and hyperlexia had poorer reading comprehension than readers with ASD and without hyperlexia.

In summary, the importance of vocabulary knowledge in ASD has been confirmed to a passage level (Lucas & Norbury, 2014), but it has also been shown that is a necessary, but not a sufficient condition, to display unimpaired reading comprehension skills in ASD (Whitehouse & Harris 1984; Newman et al., 2007).

6.2.3. World knowledge

Some evidence suggests that individuals with ASD have difficulties to access and use world knowledge and that this might not permit them to comprehend adequately. Snowling and Frith (1986) asked participants to answer questions that could be solved by referring to general knowledge (e.g., “What makes hedgehogs wake up from their sleep?”) versus questions that referred to factual details provided by the text (e.g., “For how long had the hedgehog been in her underground nest?” The answer could be: days, week or months). In the control group, the questions referred to general knowledge were answered more correctly than the factual questions. This pattern was not found in the group with ASD. The authors suggested that the participants with ASD may have the relevant previous knowledge, but they are not able to activate it during reading. Wahlberg and Magliano (2004) investigated if their participants with ASD were able to apply previous knowledge in order to understand the content of what they read. The authors used two types of texts: the first type of texts–primer texts- were written in a brief encyclopedic form, and described well known historical event very explicitly, and a second type –ambiguous texts–, in which it was difficult to understand which events the text referred to without an informative title. Each ambiguous text referred to an event that was discussed in a primer text. The ambiguous texts were accompanied by either an informative or a noninformative title. These results tell us that the recall of the ambiguous texts in participants with ASD was not influenced by the presence of background knowledge, while the readers without ASD did benefit from previous cues. These results suggest that individuals with ASD benefit less from previous knowledge to understand the text.

However, Saldaña and Frith (2007), using the validation paradigm proposed by Singer's team (Singer & Halldorson, 1996; Singer, Halldorson, Lear, & Andrusiak, 1992), designed a task involving online processing to evaluate the performance of automatic bridging inferences (Haviland & Clark, 1974). Also, these authors explored whether the content of the text (physical or social) could exert some influence on the ability to produce a bridging inference. They developed experimental texts consisting of two sentences and a question of general knowledge related to the content of the bridging inference between these two sentences. In addition, they introduced irrelevant texts in which the inference was not related to the content of the question. Participants in both the control group and group with ASD responded more quickly to the questions where the text prepared the participants to evoke an inference. This indicates that individuals with ASD were appropriately primed by the bridging inference and had activated world knowledge. This study was later replicated by Sansosti, Was, Rawson, and Remaklus (2013). This sets of studies show that if the information is available, the individuals with ASD can activate it. However, it is still possible that they are lacking certain kinds of background knowledge necessary for the inferences.

6.2.4. Working Memory

Memory skills were first mentioned in relation to ASD by Kanner (1943), when he claimed that individuals with ASD show a “development of a truly phenomenal memory that enables the child to recall and reproduce complex ‘nonsense’ patterns, no matter how unorganized they are, in exactly the same form as originally construed” (p. 249). However, it has been observed later that high-functioning individuals with ASD have a performance within the norm in working memory tasks (e.g., Foley-Nicpon, Assouline, & Stinson, 2012). Also, several studies have found that despite good working memory skills, the impairment in reading comprehension in ASD is still present. Whitehouse and Harris (1984), for example, noted the prodigious memory of many of their participants with ASD, despite low scores in reading comprehension.

The influence of working memory on reading comprehension in ASD has been directly assessed in other studies. Assouline, Foley Nicpon, and Dockery (2012) pointed out that the Working Memory and Processing Speed Indices of the WISC-IV explained the majority of the variance in reading performance in high-functioning individuals with ASD. The role that working memory has on reading comprehension in ASD seems to be similar to typically developing individuals. Tirado and Saldaña (2016) manipulated the distance of the information in the text to determine how the working memory load affected story comprehension. They designed texts in which the participants could infer the emotions felt by the characters, and in which a series of neutral sentences were introduced before a target sentence with an explicit emotion, that served to measure if the inference about character’s emotions was being produced. The authors observed that the increase in working memory load affected the ability of children with ASD to build an adequate mental representation of the text, just like poor comprehenders (Cain, 2006a; Oakhill et al., 2005).

6.2.5. Contextual integration

The ability to integrate information in context is a critical component of reading comprehension and there is empirical evidence that illustrates that it can be challenging for individuals with ASD. For example, Frith and Snowling (1983), Snowling and Frith (1986) and Happé (1997) found that people with ASD have difficulties in the choice of the correct meaning and pronunciation of a homograph. Homographs are words with identical spelling that vary in the way in which they are read depending on their meaning, which can therefore only be inferred from the text or phrase in which they are embedded. Frith and Snowling (1983) presented participants with five homographs (*tear, row, bow, lead, read*) inserted in short texts. The authors found that the number of homographs read correctly by the children with ASD was significantly lower than typically developing controls. Moreover, the analysis of the errors showed that the ASD group had problems with using context to determine the pronunciation of the homographs. Later, Snowling and Frith (1986) replicated the results based on their original materials, introducing some modifications. The authors found similar results: the ASD participants had difficulties in using context in order to determine the meaning of homographs and to use context spontaneously to monitor their reading and detect errors in the text. Happé (1997) evaluated the role of theory-of-mind (ToM) and the position of contextual information —before or after a homograph—when inferring its meaning. The ASD group benefited significantly less from the position of the homograph, compared to the control group, who had a better performance when the contextual information preceded the homograph. The authors attributed these results to the lack of central coherence.

More recently, another study investigating performance in homograph reading was run by López and Leekam (2003), using the same stimuli. Their results replicated the difficulties in the ASD group that appeared in the original studies. They also studied the rectifications of their own pronunciation related to the homograph position. The typically developing children corrected their pronunciation in the 85 % of the occasions when they read the contextual facilitation words after the target, whereas this only occurred in the 60 % of the occasions for the ASD group. Brock, Norbury, Einav and Nation (2008) investigated the effect of semantic context on the processing of ambiguous linguistic information using eye movement analysis. The main purpose of the study was to investigate sensitivity to verb meaning as reflected in anticipatory looks towards the object that would be expected from the verb semantics. Two categories of verbs were included: constraining verbs where the verb was strongly associated with the target (e.g., "Joe stroked the *hamster* quietly") and non-constraining or neutral condition where the verb was always "chose" (e.g., "Sam chose the *hamster* reluctantly"). Two conditions were created: target-present and target-absent. In the target-present condition, the participant saw the target object (e.g., hamster), a phonological competitor (e.g., hammer), and two unrelated distracters (e.g., medal and medicine). In the target-absent condition, the phonological competitor (e.g., hammer) of the target word and three unrelated distracters (e.g., button, coffee and medicine) were present. For both conditions in this example, the constraining verb was "stroke". The authors recorded the eye movements of 24 individuals with ASD and 24 language-matched peers while participants were listening to sentences. Participants were instructed to press a button if any word in the sentence matched any of the pictures on the screen. The study revealed that participants looked less at the phonological competitor when the preceding verb made it an unlikely referent, even in the target-absent condition. Participants also looked more to the target object following a constraining verb, but not after non-constraining verbs. Reduced sensitivity to sentence context (and main verb lexical semantics) was found in individuals with poorer language profile, independently from the diagnosis of ASD. This study highlighted the importance of language competences and skills as a predictor of sensitivity to context and ability to anticipate upcoming speech information. In contrast, the diagnosis of ASD did not appear to be discriminant in shaping the ability to integrate information in the context. However, a more recent study indicates that the homograph task is not the best measure of contextual integration (Brock and Bzishvili, 2013). Using eye-tracking, this study shows that in the correct pronunciation of the homograph, various other factors are involved, such as the interference of the previous trial, the time between the visual fixation, the homograph pronunciation, and the ability to detect errors and to modify the strategy to avoid future errors. This sets of studies suggest that a certain difficulty in integrating information in the context may be present in ASD, although it seems to be modulated by oral language skills.

6.2.6. The production of inferences

The ability to produce inferences is at the core of the comprehension process (Schank, 1979). Hence, problems in producing inferences have been proposed as a possible explanation for poor comprehension (Cain & Oakhill, 1999). Jolliffe and Baron-Cohen's studies were some of the first to explore inferencing in readers with ASD (1999a, 1999b). They included three groups of adult participants: high-functioning ASD, Asperger syndrome, and typically developing individuals. In one of their studies, Jollife and Baron-Cohen (1999b) included a combination of short stories with and without mentalistic content, and asked participants to respond to inferential questions. Analyses revealed that the groups differed significantly on the justifications that they offered for the mentalistic texts: the ASD and Asperger groups provided less appropriate justifications than the control group. The authors also studied the ability to produce local inferences (Jollife & Baron-Cohen, 1999a). They used passages with two phrases that required a bridging inference. Participants were asked to respond to a question with three sentence options, each of which represented a potential bridging inference. Again, both the ASD and the Asperger groups had significantly more difficulties than the control group in producing bridging inferences. Participants also listened to brief texts (two phrases) that contained an ambiguous sentence, and they had to answer a multiple-choice question. The two groups with ASD had more difficulties than the control group. Taken together, these results suggest a deficit in local coherence in individuals with ASD.

In a different study, Jolliffe and Baron-Cohen (2000), focused on the global inferences generation. In one of their experiments, participants had to reorganize sentences in a text. They presented two types of passages: one type included temporal cues in order to order the sentence (temporal condition) and the other that did not (coherence condition). Results exhibited differences between groups only in the coherence condition: the accuracy rate of participants with ASD and Asperger syndrome in the reorganization of sentences was significantly lower. Also, the reorganization of sentences in the temporal condition was significantly easier for the ASD groups, which was not the case for typically developing adults. The best performance of the sample with ASD and Asperger syndrome in stories with temporal information was explained by the possibility of using temporal cues given at the beginning of sentences. In contrast, in the coherence condition, it was necessary for the participants to produce inferences which appropriately linked the corresponding sentences, and this might have been difficult for the individuals with ASD. In a second task, after reading texts, they had to answer three questions and recall the main ideas of the text. The first question was used to assess the performance of the global inference; the second was related to the protagonist's goal; and the last was of comprehension. No significant differences were observed between the three groups on recall, the comprehension question, or the character´s goal. However, participants with ASD and those with Asperger syndrome had significantly poorer performance on questions about a global inference. No differences were detected between groups with ASD, although there was a trend ($p < .06$) in the group with high-functioning ASD to present poorer performance in producing global inferences. In conclusion, these data point to difficulties of people with ASD to produce inferences about global coherence of the story.

Norbury and Nation (2011) adapted the materials of Snowling and Frith (1986) and evaluated the ability of readers with ASD to answer to inferential questions in comparison with questions about explicit content. The authors divided the sample of participants with ASD according to language skills and found the children with ASD and language difficulties had a significantly lower accuracy rate in inferential questions than participants with ASD and age-appropriate structural language and their peers in the control group. No significant differences were found between the latter two groups, but children with ASD were slightly less accurate than typically developing peers. In addition, the diagnosis of ASD predicted a further 10% of the variance of the ability to produce inferences, after accounting for word-level reading and oral language skills.

All the studies measure inferencing in off-line tasks, i.e., through responses to questions presented after a participant has read a text. However, it is interesting to study the ongoing process of reading, evaluating whether people with ASD can process information and produce inferences *during* reading. This was the aim of the study by Saldaña & Frith (2007), described above, who found that individuals with ASD were able to produce online inferences. Recently, Sansosti et al. (2013) included eye tracking in a replication of Saldaña and Frith's experiment, and found similar results. The novelty of the Sansosti et al. (2013) study was the collection of the eye movement data that gave a framework of the online reading behavior. They found that children with ASD made more fixations, had longer reading time, and more regressions in reading passages compared to the control group, despite being able to produce bridging inferences necessary for comprehension. From these results, we can conclude that the sample with ASD activated the necessary knowledge and produced relevant inferences automatically. However, the reading behavior during inference generation was different between groups suggesting that the group with ASD encountered more difficulty in the processing of the reading material.

The results from these two studies seem to contradict the previous findings of the more classic off-line experiments. Tirado and Saldaña (2016) explicitly contrasted performance on both kinds of tasks in the same participants. They analyzed the ability of participants to detect the coherence or incoherence of an emotion in a story, given the state or the perspective of the main character, and investigated if this performance was influenced by the distance between the phrases that are used to facilitate inference generation. Participants included three groups: typically developing individuals, poor comprehenders, and persons with ASD. The results from this study showed longer reaction times on a target phrase included in the text, when it was incoherent with the protagonists' emotions, as inferred from the text. Readers with ASD also exhibited this pattern, apparently producing the inference on the emotion of the main character. However, when explicitly asked for the character's emotion in a question after reading the text, their performance was poorer than typical controls, and more interestingly, also than non-autistic poor comprehenders. This study illustrated that the participants with ASD were capable of building a situation model that included the emotional perspective of the protagonist, but that this did not guarantee a correct response to a question about the emotional status of a certain character *after* the text. The authors proposed that the differences in performance in off-line versus online tasks were due to the additional processing necessary to respond to a question, and not to the production of the inference itself. The difficulties for readers with ASD seemed to result from their attempt to control and manage textual information once they were asked questions about the story.

6.2.7. Comprehension strategies

Reading comprehension can be limited because readers ignore many of the strategies useful to extract meaning from text or discourse (Graesser, 2007), or, even when they have the knowledge of the strategies, they can be ignoring their benefits or not understanding the application of the rules (Brown, 1980; Myers & Paris, 1978). Paris, Wasik and Tuner (1991) offered six reasons for why acquiring a strategic competence in reading comprehension is relevant: 1) the strategies allow the reader to process, organize, and evaluate the textual information; 2) reading strategy acquisition coincides and overlaps with the development of several cognitive strategies, such as the improvement of attention, memory, communication, and learning during the childhood; 3) strategies are controlled by the readers and are cognitive tools that can be used in a selective and flexible way; 4) comprehension strategies reflect metacognition and motivation, because the readers have to own the strategic knowledge and the flexibility to use them; 5) the strategies that promote the reading and the thought can be taught directly from the teachers; and 6) the strategic reading improves learning in all curricular areas.

Despite the importance of reading strategies, in my knowledge, there are only few studies that investigated this aspect in readers with ASD. O'Connor and Klein (2004) used three kinds of facilitation on reading comprehension. In one, they applied prior-knowledge activation, achieved by presenting a question to the participants before they began to read the text. In another, participants had to complete cloze sentences in a text. And a third strategy was to help them solve anaphoras by identifying relevant antecedents. The most successful strategy was training anaphora resolution, probably because it induced the re-reading of text parts and facilitated the localization of the relevant information.

In another intervention study (Whalon & Hanline, 2008), the effects of reciprocal questioning on question generation and responding in cooperative pairs —composed of three children with ASD and nine 7 and 8-year-old peers— were analyzed. The intervention showed that the students with ASD increased the numbers of questions they expressed and their accuracy in the answers to questions, when they used a story-map framework.

In a more recent study (Williamson, Carnahan & Jacobs, 2012), three reading comprehension strategies used by 13 individuals with ASD while extracting meaning from the text were described. A first group of participants was classified as *text bounded comprehenders*: they tended to focus on bringing meaning to the text without interpretation. Participants tended to give short responses to comprehension questions and present errors in syntax and semantics, and have an undeveloped use of expressive vocabulary and imprecise conceptual knowledge. In the second profile, called *strategic comprehenders*, participants proved to be successful at responding to comprehension questions regardless of the text features and background knowledge. Finally, the *imaginative comprehenders* were more successful in text supported by pictures, and organized and presented as individual sentences. The authors also found that the following factors influenced comprehension: construction-integration model of text comprehension (Kintsch, 1988), facilitative text, background knowledge, and language characteristics of the participants.

6.2.8. Comprehension monitoring

Self-monitoring refers to the capacity to monitor actions toward specific goals (Mundy et al., 2007) thanks to the supervisory attention system (Norman & Shallice, 1986). Being able to have control on activities such as academic and job achievements, and entertainment activities increase self-efficiency, self-monitoring and intrinsic motivation (Bandura, 1993). Self-monitoring has been considered as one of the modifier processes which characterize ASD and is linked with variability in intelligence quotient and social symptom severity (Mundy, Henderson, Inge, & Coman, 2007). Response monitoring (Bogte, Flamma, van der Meere, & van Engeland, 2007; Henderson et al., 2006; Russell & Jarrold, 1998) have been highlighted as contributing factors to ASD (Thakkar, et al. 2008). Comprehension monitoring while reading is one side of the general response monitoring and has been quite extensively studied in ASD. Snowling and Frith (1986) developed a task in which the participants had to detect anomalous words in the text. The error-detection paradigm is useful to evaluate reading comprehension and monitoring (Oakhill et al., 2005), and has been observed to discriminate between competent readers and poor comprehenders (Kolić-Vehovec, Rončević, & Bajšanski, 2008). Half of the errors in Snowling and Frith's study were inadequate in the immediate sentence context, but coherent with the story. The results varied as a function of the participants' verbal skills. The group with low-functioning ASD had a higher number of false alarms, indicating anomalous words as correct, and they could detect only a few errors. The highly-verbal readers and with high-functioning ASD obtained similar results to their typically developing peers. Norbury and Nation (2011) adapted this paradigm and introduced three types of errors in the text: contextual errors, grammatical errors (omitting the *–s* to the singular third person or the *–ed* for the past verbs), and orthographic errors. The results were consistent with the previous study: children with ASD and poor structural language skills found more difficulty in detecting errors. The participants with ASD but with a good language presented the same performance as the typically developing children.

Three recent studies (Koolen, Vissers, Hendriks, Egger, & Verhoeven, 2012; Koolen, Vissers, Egger & Verhoeven, 2013, 2014) investigated reading monitoring skills in adults with ASD using event-related potentials. The Koolen et al. group of studies suggests that individuals with ASD may implement differently the use of monitoring resources during reading compared to typically developing control groups. Koolen and colleagues (2012) asked individuals with ASD and control participants to focus their attention either on the syntactic level (high and single level), or on the orthographic level (low and single level), or on both (dual level), during a task that consisted of syntactic and orthographic error detection. Results showed that, in the dual-level condition compared to the single-level condition, the control group spent additional attentional effort (decreased speed of language processing) while processing the orthographic inconsistencies, but not the syntactic inconsistencies. However, participants with ASD did not show this attentional discrimination, and presented additional attentional cost (reduced speed of language processing) for both the orthographic-level and syntactic-level conditions. Another study from Koolen, Vissers, Egger, and Verhoeven (2013) found that participants with ASD showed a monitoring response to the semantically implausible input, signaled by a P600, a language relevant event-related potential component, only when they were instructed to attend to implausibility, compared to a free reading condition. By contrast, when orthographic errors were presented, the monitoring response was present in both instructed- and free-reading conditions. The typically developing group displayed a monitoring response for both incorrect semantic and orthographic input in both instructed- and free-reading conditions. Finally, a third study by Koolen, Vissers, Egger, and Verhoeven (2014) explored reading monitoring, also signaled by the P600 effect, during orthographic (local) and syntactic (global) errors after an instruction that alerted to the presence of one type of error (local *or* global and single level) and after an instruction that prepared the participants for the presence of both local and global errors (dual level). When presented with the instructions, individuals with ASD were able to monitor syntactic information, but only under simple circumstances, such as orthographic inconsistencies. In contrast, control participants monitored syntactic information under more complex circumstances, such as syntax inconsistency. These findings indicate that when reading, adults with ASD do not spontaneously control for possible semantic processing errors, or do not seem to mobilize additional attention for the adjustment of the contextual interpretation, unless they are instructed to do so.

6.2.9. Reading comprehension through general cognitive theories

This section is dedicated to the analysis of the general cognitive theories such as the weak central coherence, theory of mind deficits and executive function problems that we described in the 'cognitive theories of autism' section and how they could potentially impact reading comprehension.

WCC has been proposed as a potential explanation for some difficulties in academic abilities in ASD. Happé et al. (1996) found that children with Asperger syndrome showed poorer performance when reading stories compared to reading isolated phrases, something they attributed to a cognitive style focused on detail. Joliffe and Baron-Cohen (2000) also argued that WCC might explain the poor performance of individuals with ASD on tasks where it is necessary to infer at the level of global coherence. López and Leekam (2007) argue that the results of studies on homographs (Frith & Snowling, 1983; Happé, 1997; Jolliffe & Baron-Cohen, 1999a; López & Leekam, 2003; Snowling & Frith, 1986) constitute a clear example of one of the implications of WCC. Carnahan and colleagues (Carnahan & Williamson, 2010; Carnahan, Williamson, & Christman, 2011) have added that WCC could also explain the relative peaks in word decoding and vocabulary —relative to difficulties in concepts comprehension at the level of sentences and texts— sometimes observed in ASD.

Another prevailing cognitive theory in the field of ASD is the theory-of-mind (ToM) deficit perspective (Baron-Cohen et al., 1985; Happé, 1994a, 1994b, 1995; Happé & Frith, 1996), which has also been used to explain comprehension difficulties. Wahlberg and Magliano (2004) indicated that problems related to ToM could cause difficulties for the readers with ASD when trying to understand what the author of a given text is implying. In their work about the impact of prior knowledge in the comprehension of written narratives, they found that inadequate interpretation of the stories was related to ToM deficits. Moreover, Carnahan and Williamson (2010) and Carnahan et al. (2011) showed that limitations in ToM could not only affect the ability to infer the intention of the writer, but also disrupt the ability to adopt the perspective of the main character of a story, as well as the ability to infer his or her motivations or make predictions about events in a narrative.

Finally, there is the possibility that the poor results in comprehension tasks in ASD might be explained by executive function deficits. In my knowledge, no studies, except for the Koolen et al. group (2012, 2013, 2014) of studies that investigated reading monitoring skills in adults with ASD, have directly examined the influence of the executive function components on reading comprehension in ASD. However, as we discussed previously, executive function is very important for successful reading comprehension (for a review, see section 4).

7. The present thesis

The present thesis is comprised of three experimental studies that are presented respectively in three chapters. Each of the chapters compares the reading comprehension processes and the reading behavior of individuals with ASD with a matched control group, using eye-tracking technology.

The Simple View of Reading (Reading Comprehension = Decoding x Oral Language) does not fully explain the reading comprehension problems in individuals with ASD, since often they have unimpaired decoding and languages skills. However, differences in reading comprehension outcomes and reading strategies between individuals with ASD and control groups are still generally observed. In the present thesis, our overall aim was to explore if reading differed between individuals with and without ASD matched on decoding and language skills. Although reading off-line and outcome measures could be equivalent, we were especially interested in exploring the online processing to detect potential differences in the way readers with autism process text. Considering previous studies about online processing, our hypothesis was that eye movement measures and strategic reading behavior would differ between readers with and without autism, even after controlling for oral language and other relevant variables. A high-functioning group of participants with ASD with very good cognitive, decoding, and oral language skills took part in the studies. The aim was to control as much as possible for these variables, which clearly have a role in reading comprehension that is not being questioned in this thesis.

If differences in comprehension outcomes and/or strategies between groups were found between groups, we aimed to further explore the potential components that could play a role in comprehension, specifically metacognitive processes and executive function. I have explained the importance of these variables in reading, and how poor comprehenders and readers with autism often appear to have the relevant strategic and background knowledge, but also present difficulties in activating its use in a given reading task.

Our specific aims were thus:

1) To determine if differences in reading behavior, as observed with eye tracking measures, exist between readers with ASD and readers without ASD, over and above differences in chronological age, oral language comprehension, IQ, and other relevant variables. Our hypothesis was that differences would be apparent at the text-processing level, even in individuals with ASD and good oral and cognitive skills.
2) To explore the role of metacognitive processing and executive functions in the reading performance of individuals with ASD, with a special focus on comprehension monitoring and error detection, and on planning and reading

strategy selection (Locascio et al., 2010). We expected differences in both the ability to detect errors in comprehension and to adapt reading to comprehension demands of a task, with poorer performance in the ASD group.

An experiment, aimed at achieving the first objective, is explained in detail in Chapter 2. Chapters 3 and 4 include the studies focused on the second objective. More specifically, the study in Chapter 2 aimed to explore the accuracy in responding to inferential questions compared to factual questions, and reading behavior of participants for an entire paragraph and around a pre-defined target word needed for building an inference. We used inference generation because of its fundamental role in reading comprehension. It was hypothesized that no differences in accuracy and paragraph reading time (Saldaña & Frith, 2007; Sansosti et al., 2013) would be observed, given the verbal abilities of the high-functioning sample of individuals with ASD. However, we expected to observe differences between groups in the integration of the target word in the global context of the text, due to the greater difficulty in the individuals with ASD in building a situation model compared to the control group.

Chapter 3 aimed to explore reading monitoring by analyzing how reading behavior changes according to instructions and error types (semantic and orthographic) in individuals with ASD and in a control group. It was hypothesized that individuals with ASD would display poorer performance in detecting semantic errors compared to the control group, but we expected this performance would be improved by targeted instruction.

Chapter 4 aimed to explore how readers with and without ASD adapt to different reading goals (entertainment, study, and skim - read fast and search information for previously presented questions). It was hypothesized that the control group would show distinct levels of processing depth for a text which they were required to study, compared to both a text read for entertainment and one they were asked to skim. By contrast, we expected to find less response variability to different reading goals for the ASD group, due to a poorer ability to change strategies according to reading goals. In addition, we expected to find deficits in planning skills in ASD, and that these would relate to comprehension, in line with previous findings that displayed that poor comprehenders have poor planning skills (Locascio et al., 2010).

The individuals that participated in the studies were not the same across the different experiments. A large pool of participants was assessed and the recruitment was selected depending on the chronological age and the availability of participants.

Chapter 2

Strategies of readers with autism when responding to inferential questions: An eye movement study

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This chapter includes the post-print author's version:

Micai, M., Joseph, H., Vulchanova, M., & Saldaña D. (2017). Strategies of readers with autism when responding to inferential questions: An eye movement study. *Autism Research, 10,* 888-900. doi: 10.1002/aur.1731

Introduction

The influential model of reading comprehension proposed by Van Dijk and Kintsch (1983; Kintsch & Rawson, 2005) is characterized by two interactive levels of comprehension: a *text-based* or *propositional representation*, which includes comprehension involving a simple linguistic representation (e.g., word decoding), and a *situation model* or *mental model* that connects information and organizes it globally in a larger structure which also includes prior knowledge. When the information in the text is not directly connected, the reader may need to generate an inference in order to build a coherent situation model. During this process, the user fills in the missing links and creates a coherent flow of meaning units integrating them in the prior knowledge background (Kintsch & Van Dijk, 1978). The present study aimed to explore the ability of individuals with autism to make inferences which underlie the creation of situation models and, as such, have been shown to be essential for reading comprehension (Cain et al., 2001) and discourse comprehension (Snyder & Caccamise, 2010).

Among the clinical populations that show difficulties in reading comprehension (see, for example, Cain & Bignell, 2014, and Miller et al., 2013, for an example in Attention Deficit Hyperactivity Disorder), autism is one of the most extensively researched (Ricketts, 2011). Several studies have shown that, in particular, inference generation is impaired in autism. Initially, this impairment was observed as a difficulty in inferring the adequate meaning of a homograph (Frith & Snowling, 1983; Happé, 1997). More recently, Jolliffe and Baron-Cohen (1999a, 2000) reported difficulties in global coherence, exploring sentence rearrangement and global inference generation. They also found difficulties in achieving local coherence, using a homograph integration task, a task involving the generation of bridging inferences and a task for ambiguous sentence interpretation (Jolliffe & Baron-Cohen, 1999b). Later, Norbury and Bishop (2002), applying a categorical examination, showed inferencing deficits in individuals with pragmatic difficulties related to high-functioning autism. In addition, a strong relationship between story comprehension and recall was observed, showing that individuals who had higher scores in comprehension also performed better in recall.

However, other research has shown similar levels of reading comprehension skills in individuals with autism and typically-developing (TD) readers (Mayes & Calhoun, 2003; LaPointe-Speer, 2007; Mayes & Calhoun, 2008; Sansosti et al., 2013). It seems that individuals with ASD may reach the same level of comprehension as typical readers under specific conditions. Reading studies in autism spectrum disorders (ASD) vary considerably in the nature of the task administered and in participants' oral and language-related skills. Contradictory results in this field have sometimes been related to the use of off-line (i.e. question answering) or more online (usually response or reading time) measures, with greater differences typically appearing more in the off-line tasks (Jolliffe & Baron-Cohen, 2000; Norbury & Bishop, 2002; Nation, 2006), than in response time measures (Saldaña & Frith, 2007; Sansosti et al., 2013, Tirado & Saldaña, 2016). An exception to this appears in studies using eye-tracking. Sansosti et al. (2013), for example, found that while readers with autism showed similar accuracy and reaction times in responding to questions as a control group on a task requiring bridging inferences, they spent more time fixating the text, and made more fixations and regressions than the typically developing readers. Subtle differences in reading behavior have also recently been found by Howard et al. (2017), whose participants with autism made more regressions in a sentence reading task than controls. However, in their case, the task did not require the production of inferences, and their results are unlikely to relate to problems in inferencing itself. In any case, these eye-movement studies seem to indicate that the way in which readers with autism reach the same endpoint during text comprehension could be different and sensitive eye-tracking measures may help to uncover these different underlying processes.

The current study was designed to explore spontaneous elaborative inference making (McKoon & Ratcliff, 1992) during reading by monitoring participants' eye movements as they read texts that did, or did not require the generation of inferences. Monitoring a reader's eye movements gives an extremely accurate and detailed index of which words or phrases a reader is finding particularly difficult to process (Rayner, 1998), and thus permits the extraction of information about the time course in which disruption to processing occurs, and what the reader does on encountering difficulty (Vasishth et al., 2012). In addition, eye movement data have been shown to be sensitive to global text passage difficulty and inconsistency in texts (Rayner et al., 2009). Furthermore, eye movement data should provide us with an accurate insight into how inference-making unfolds in persons with ASD when they have to respond to a question about a text.

We also aimed to closely match participants on variables that have been shown to predict text comprehension. In particular, it is important to consider the oral language profile in individuals with ASD, because it has consistently been found to be a predictor of reading comprehension in general (Norbury & Nation, 2011; Ricketts et al., 2013), interpretative language ability (Minshew et al., 1995), use of linguistic context (Eberhardt & Nadig, 2016), and inferencing skill (Lucas & Norbury, 2015). It has been suggested that differences in reading comprehension between autism and control groups found in many studies could disappear with improved matching (Norbury & Bishop, 2002). For this reason, we included in the study individuals with high functioning autism displaying similar standardized receptive language, reading comprehension and fluency scores as our group of children and adolescents without ASD (control group). The sample of individuals recruited for this study may be not representative of the full scale of the autism spectrum, in that they are highly verbal and high-functioning. However, we consider it important to control for factors that have been observed to influence inferencing skill (e.g., structural language skills) and to study inferencing in the absence of impaired language in a sample of individuals that did not differ from controls on a relatively important number of background variables and in the presence of autistic symptomatology.

Against this back-drop, our study first aimed to explore whether there were any differences in accuracy in responding to inferential questions (inference condition) compared to questions requiring factual understanding (literal condition) between individuals with and without ASD matched on age, nonverbal intelligence scores, language, and reading skills.

Secondly, our study aimed to explore global paragraph reading behavior, as well as question-answering time while reading the texts and responding to the questions. Given the on-line nature of the task and the high cognitive and language skills of our clinical group, we expected no differences between the two groups in accuracy or global eye-movement measures while reading the text and answering the questions.

Finally, we conducted some more fine-grained analyses in order to investigate eye-movement behavior on predefined target words related to the paragraph assigned to the literal and inferential condition in the experimental texts in our two groups of participants. We expected to see a difficulty in the integration of the target word that supported the inference in the situation model that would translate into slower reading times in the inferential condition in the ASD participants compared to the control group (O'Brien et al., 1988; Cook & Myers, 2004; Garrod & Terras, 2000). This disruption of the integration of the target word into a coherent situation model was also expected to result in a higher number of eye movements such as regressions in the inferential condition for the ASD group (Sansosti et al., 2013). However, we expected that early processing eye-movement measures (i.e., first and single fixation durations) of the target word to be comparable between ASD and control groups, given the expectation of intact lexical processing. Early processing eye movement measures refer to the first-pass measures that occur prior to any regression back to the word and are found to be informative of a word's representation, orthography, phonology, or meaning (Juhasz & Pollatsek, 2011). Exploratory analyses were also conducted in order to distinguish general integration processes from those related to the task of answering the question itself, by comparing the percentage of regressions coming from the part of the text that followed the target word with the percentage of regressions coming from the question. This analysis was possible since both text and question were present on the screen at the same time. Additionally, the target word was present in each paragraph with other three critical words that changed depending on the paragraph condition (inferential and literal). We explored reading behavior also in relation to these critical words present in the text. One of the critical words provided the correct answer to the literal question in a literal condition, and the others were filler words. We expected to find similar reading behavior for these categories of words between the two groups, since none of them involved inferencing, showing that reading behavior in ASD may be atypical only during the situation model integration, rather than during the overall process of reading.

Method

Participants

Thirty-four children and adolescents with a diagnosis of autism spectrum disorder or Asperger's syndrome were recruited from local autism associations. Individuals with comorbidity with other developmental and acquired disorders or vision problems that impede reading, or bilingual families, were excluded from recruitment. Diagnoses were confirmed by a trained psychologist, using the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). All participants met the clinical cutoff on the ADOS with a total score > 7 (mean = 11.4, range = 7 – 16).

A control group of 36 native Spanish children and adolescents was recruited from local schools of middle-class neighborhoods. Exclusion criteria were the same as for the autism group. Three ASD participants were excluded because of low scores on nonverbal intelligence, defined as Perceptual Reasoning Index (PRI) and Working Memory Index (WMI) below or equal to 70. During the matching process, in which the ASD and control sample were statistically matched on chronological age (ASD mean age = 12.6 years, *SD* = 2.5, range = 9.9 – 17.2; control group mean age = 13, *SD* = 2.5, range 9.4 – 17.8; $p = .11$), gender (ASD: 3 females; control group: 7 females, $p = .25$), nonverbal IQ, raw scores on grammatical structure comprehension, vocabulary size, reading speed and comprehension accuracy, a further 9 participants with ASD and 14 controls were excluded, leaving a final sample of 44 individuals, all monolingual Spanish speakers from Andalucía in the South of Spain (ASD: $n = 22$; controls: $n = 22$). No statistical differences existed between groups on any matching variables (see Table 2.1).

Table 2.1

Background data of participants

	ASD (n = 22)		Control (n = 22)		
	Mean (SD)	Range	Mean (SD)	Range	*p*
Perceptual Reasoning Index	107 (18)	74–134	108 (14)	81–139	.85
Working Memory Index	107 (16)	79–137	106 (12)	79–130	.81
PPVT-III (Standardized Scores)	107 (18)	66–135	110 (12)	80–134	.62
CEG (Raw Scores)	73 (3)	66–79	75 (2)	68–80	.14
TALE Reading Speed (Words/Seconds Raw Scores)	125 (35)	63–181	141 (30)	80–195	.17
TALE Reading Comprehension accuracy (% Raw Scores)	57 (16)	28–100	65 (20)	28–100	.16

Note. n = number of participants. PPVT-III = Peabody Picture Vocabulary Test - Third Edition. CEG = Grammatical Structures Comprehension Test. TALE = Magellan Scales of Reading and Writing.

The Andalusian Regional Biomedical Research Ethics board approved recruitment and data collection procedures. Written informed consent was obtained from participants' parents or legal guardians prior to any testing.

Background assessment

Nonverbal intelligence. The PRI and WMI subscales from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2005) or Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV; Wechsler, 2012) were used, depending on the participant's age, to assess nonverbal intellectual ability.

*Receptive language***.** Receptive vocabulary size was measured using the Spanish version of the Peabody Picture Vocabulary Test - Third Edition (PPVT-III; Dunn et al., 2006). Receptive grammar was assessed using the Grammatical Structures Comprehension Test (CEG; Mendoza et al., 2005). The CEG test is a Spanish version of the Test for Reception of Grammar for English (TROG; Bishop, 1983). The CEG test shows a Cronbach's $\alpha = .91$. Its total scores correlate well with total scores from other tests such as PPVT-III ($r = .81$, $p < .001$), Illinois Test of Psycholinguistic Abilities (ITPA; Kirk et al., 1968) ($r = .64$, $p < .001$), and Digit Span from the Wechsler Intelligence Scale for Children Revised (WISC-R; Wechsler, 1999) ($r = .37$; $p = .003$).

Reading skills. The reading fluency and reading comprehension subtests of the Magellan Scales of Reading and Writing (EMLE TALE-2000; Toro et al., 2002) were used to assess reading speed and reading comprehension, respectively. The reading fluency subtest requires reading aloud one of three age-appropriate texts. Numbers and types of decoding errors and reading times were recorded, although only reading time was included in the matching analysis. Each participant, depending on their level of schooling, read one of the three texts. The reading comprehension subtest consists in reading one of the three age-appropriate texts and answering multiple-choice questions. The EMLE TALE, which has a test–retest reliability ranging from .76 to .85, for different ages, has been shown to agree with teacher ratings in the identification of poor comprehenders in 98% of the cases, and has a Kappa of .68 for overall classification of readers into poor and good comprehenders.

Apparatus

Stimuli were presented on a 18.5-inch monitor (41 x 23 cm) connected to a computer interfaced with an EyeLink 1000 eye tracker (SR Research, Ottawa, Ontario, Canada). The Eyelink 1000 is an infrared, video-based tracking system combined with hyperacuity image processing with a spatial resolution of 0.4 degrees, and a sampling rate of 1,000 Hz. While participants' viewing was binocular, only the movements of the right eye were recorded. Text was presented in black, Arial font size 20 on a light grey background. Participants were seated 55 cm from the monitor.

Materials and design

Paragraph creation. Five narrative stories in Spanish, divided into thirty paragraphs (6 per story), were created; at the end of each paragraph there was a question with three answer options. Each paragraph was presented with the corresponding question on a single screen. All paragraphs were 60 words long. We designed two versions of each paragraph, one which did not (literal condition) and one which did (inferential condition) require an inference to be made in order to answer the following question correctly. The paragraphs, questions and options in the two conditions were identical, except for one word: in the literal condition, a key word which enabled a correct response to the question without any need for an inference was present in the text (*correct answer word,* e.g., cat; Appendix 3). In the inferential condition the correct word was not present in the text, but replaced by another word (*replacement word*) that did not suggest the correct answer (e.g., little; Appendix 3). These words were matched on length and frequency (Real Academia Española) across conditions. In both conditions, a target word that allowed the participants to infer the correct answer (*target word,* e.g., mouse; Appendix 3), and a *distractor word* (e.g., parrot; Appendix 3) were also present.

A comprehension question was presented below the text with three possible responses. The response options were: (i) the correct answer (e.g., cat); (ii) a distractor that was present in the paragraph, but semantically distant from the correct option (In-text distractor; e.g., parrot), and (iii) a distractor that was absent in the text, but semantically close to the correct answer (Semantic distractor; e.g., dog). To permit the accurate analysis of eye-tracking data, the text was double spaced. The stories were developed such that minimal emotional (Bodner et al., 2015) and social understanding (White et al., 2009) were required.

Norming studies. We prescreened all possible responses, target words, and distractors with TD children and adults who did not participate in the main experiment. The semantic proximity of the correct answer to the In-text distractor (e.g., parrot) and Semantic distractor (e.g., dog) was judged by 20 TD children (mean age = 12.4, *SD* = 0.6; 9 females). In order to measure the semantic proximity for each correct option, four words were presented to the children. They were asked to judge which one was most different and which was most similar to the target word. We selected the words that the majority of the children judged to be similar (Semantic distractor) or different (In-text distractor) to the target. Secondly, ten university students confirmed that, in the inferential paragraphs, the selected target word was the only word in the text useful to answer the question. Any changes to the defined target words were derived from this last evaluation.

Counterbalancing and design. For both versions, fifteen paragraphs were assigned to the literal condition and fifteen to the inferential condition. Each story contained three literal and three inferential paragraphs. The order of the three answer options was randomized and held constant across participants. The order of presentation of the five stories was randomized, whereas the order of the paragraphs within each story was held constant.

For each paragraph, the In-text distractor was always in the first or second sentence of the text, then, in the middle of the text, participants encountered the correct answer (only for the literal condition). Finally, the target word was always the fifty-fifth word in the paragraph. Prior to the presentation of the experimental trials, participants read and answered two practice trials (one literal and one inferential paragraph type) that were excluded from the final analysis.

Procedure

Standardized tests were administered in the following order to all participants: nonverbal intelligence, verbal skills, and reading abilities. The diagnosis confirmation tests were administered only to the ASD participants on a different day and prior to any testing. The participants completed the test assessment in two (control group) or three sessions (ASD group) of one hour each on different nonconsecutive days. The eye tracking experimental task was performed in a single 30-minute session on a different day. Participants were tested individually, in a quiet room either in the university laboratory, at school, or at the local autism association. During eye tracking, chin and forehead rests were used to minimize head movements and ensure comfort. Participants undertook a nine-point calibration procedure.

Participants then looked at a fixation point in the upper-left corner of the screen and the paragraph appeared contingent on their gaze. Subjects were asked to fixate on a fixation point in the left top of the screen prior to the presentation of each paragraph in order to check the calibration validity. If the fixation did not meet the criteria (maximum point error < 1.5 degrees, average error < 1.0 degrees) of accuracy, the participants were recalibrated. Participants were asked to read each paragraph silently and to answer questions by choosing one of the three possible responses which were displayed at the bottom of each paragraph, and to respond by choosing one of three alternatives via a key press. The beginning of a new story was advised by a screen showing the message ‘New story’ presented in the middle of the screen, until the participant pressed the space bar.

Eye-movement data. First, five global measures are reported to assess the reading behavior during reading of the entire paragraphs and answering the question. Paragraph reading/question answering time is the total time spent for reading the text, the question and the possible answers; total number of fixations is the sum of all fixations; and average fixation duration is the mean length of all fixations. Number of forward fixations refers to fixation durations following a forward (left to right) saccade. Forward saccade length is the mean length of all saccades (Rayner, 1998, 2009) (see Table 2.2).

Table 2.2

Means (and SDs) of accuracy and global eye movement data in both, inferential and literal conditions for ASD and control groups, and overall conditions scores.

	ASD		Control		Both groups	
	Inferential n = 22	Literal n = 22	Inferential n = 22	Literal n = 22	Inferential n = 44	Literal n = 44
Percent correct	89 (10)	95 (4)	84 (15)	95 (7)	87 (13)***	95 (6)
Paragraph reading/question answering time	31,472 (13,730)	28,224 (11,459)	27,581 (10,559)	24,957 (8,511)	29,527 (12,263)***	26,590 (10,111)
Total number of fixations	115 (39)	103 (31)	107 (34)	97 (28)	111 (37)***	100 (29)
Average fixation duration	211 (35)	210 (37)	210 (28)	209 (29)	210 (32)	209 (33)
Number of	61 (27)	59 (27)	56 (25)	59 (24)	58 (25)	59 (25)

forward fixations						
Forward saccade length	4.10 (0.96)	4.10 (0.96)	3.99 (0.66)	3.95 (0.57)	4.05 (0.82)	4.03 (0.78)

Note. n = number of participants. Paragraph reading time and average fixation duration are in milliseconds; saccade length is in degrees of visual angle. **p* < .05; ***p* < .01; ****p* < .001.

Next, eight local eye-movement measures were explored in relation to the predefined target words (e.g. mouse*,* cat, parrot, and little; Appendix 3). First fixation duration is the duration of the initial fixation on the target word regardless of whether it is the only fixation or the first of multiple fixations, whereas single fixation duration is the duration of the initial fixation on the word when only one fixation was made on that word during first pass. Gaze duration is the sum of fixations on a word prior to moving to another word and go-past time is the sum of all temporally continuous fixations including fixations after a regressive eye movement to the left of the region, until the fixation point progresses to the region to the right. Total fixation time is the sum of all fixations on the target word. Re-reading time is the total fixation durations in a region after having left that region to the right. Finally, regressions-out refers to the probability of making a leftward eye movement out of the target word before leaving the word to the right, whereas regressions-in refers to the probability of making a leftward eye movement into the target word having already left that word to the right (Rayner, 1998, 2009). For all local measures, with the exception of regression probabilities, values of zero were excluded. Participants who had zero reading times in all items in one or both conditions were excluded from the analyses for the given six eye-movement measures. Consequently, the number of participants kept for each analysis varied between the eye-movement variables (see Table 2.3).

Table 2.3

Means (and SDs) of local eye movement data from the target words in both, inferential and literal conditions for ASD and control groups, and overall conditions scores.

		ASD		Control		Both groups	
	n (ASD/TD)	Inferential Mean (SD)	Literal Mean (SD)	Inferential Mean (SD)	Literal Mean (SD)	Inferential Mean (SD)	Literal Mean (SD)
Target Word							
First fixation duration	21/20	224 (51)	210 (59)	213 (42)	210 (81)	218 (47)	210 (69)
Single fixation duration	13/17	213 (53)	227 (68)	233 (52)	210 (41)	224 (52)	217 (54)
Gaze duration	21/20	323 (207)*	257 (87)	282 (97)	299 (129)	303 (162)	278 (110)
Go-past time	21/20	375 (208)	324 (126)	347 (144)	348 (209)	361 (178)	336 (170)
Total fixation	22/22	568 (298)	470 (299)	503 (237)	330 (188)	536 (268)***	450 (248)

time							
Re-reading time	15/13	1436 (2291)	1121 (950)	883 (1296)	1626 (3428)	1179 (1883)	1355 (2399)
Regression-out (%)	22/22	9.12 (10.29)	7.10 (10.90)	11.18 (13.56)	12.96 (13.51)	10.15 (11.94)	10.47 (12.39)
Regression-in (%)	22/22	22.05 (23.90)*	20.29 (24.28)	15.99 (18.40)*	24.12 (19.96)	19.02 (21.30)	22.20 (22.05)
Correct answer Word/Replacement Word							
First fixation duration	21/21	212 (62)	211 (53)	207 (51)	224 (53)	210 (56)	218 (52)
Single fixation duration	16/16	183 (53)	236 (108)	200 (53)	212 (66)	192 (53)	224 (89)
Gaze duration	21/21	253 (79)	276 (84)	265 (107)	279 (76)	259 (93)	277 (79)
Go-past time	21/21	304 (127)	343 (146)	350 (168)	343 (98)	327 (149)	343 (122)
Total fixation time	22/22	437 (240)	381 (179)	404 (183)	389 (147)	420 (212)	385 (162)

Re-reading time	8/11	100 (78)	352 (463)	141 (120)	330 (386)	124 (104)*	340 (408)
Regression-out (%)	22/22	16.73 (15.76)	18.96 (11.63)	22.78 (17.23)	28.03 (15.44)	19.75 (16.60)	23.49 (14.26)
Regression-in (%)	22/22	34.89 (13.94)	28.86 (14.88)	30.28 (18.73)	26.75 (13.79)	32.79 (16.45)	27.80 (14.22)
				Distractor word			
First fixation duration	21/21	234 (81)	217 (58)	208 (42)	205 (47)	221 (65)	211 (52)
Single fixation duration	14/17	279 (82)	300 (232)	229 (49)	245 (97)	252 (69)	270 (171)
Gaze duration	21/21	278 (92)	302 (119)	268 (86)	273 (91)	273 (88)	288 (105)
Go-past time	21/21	369 (183)	385 (164)	315 (106)	333 (124)	342 (150)	359 (146)
Total fixation time	22/22	529 (333)	450 (242)	430 (201)	391 (153)	480 (276)	421 (202)
Re-reading time	17/17	607 (688)	502 (487)	592 (709)	689 (791)	599 (688)	596 (654)

Regression-out (%)	22/22	20.14 (11.92)	23.67 (10.50)	24.24 (16.90)	22.67 (18.87)	22.19 (14.60)	23.17 (15.10)
Regression-in (%)	22/22	34.10 (18.35)	36.66 (15.69)	30.07 (19.54)	29.93 (19.42)	32.08 (18.84)	33.29 (17.78)

Note. The first part illustrates the eye movement measures from the target word (e.g., mouse), the second from the correct answer present in the text of the literal paragraphs (e.g., **cat**) compared to the word that replaced the correct answer in the inferential paragraphs (e.g., little), the third from the option that was present in the text as a distractor (e.g., *parrot*). n = number of participants. First fixation duration, single fixation duration, gaze duration, go-past time, total fixation time, and re-reading time are in milliseconds. *p < .05; ***p < .001.

Statistical analyses

All global eye-movement data and all log-transformed local eye-movement data, except for regressions, were analyzed using mixed (group x condition) ANOVAs across subjects (F_1) and items (F_2). Bonferroni correction was applied in order to allow multiple comparisons. Nonparametric analyses across subjects and items were performed on accuracy in answering the question and the proportion of regressions made out of and into the target word. Main effects of condition and group were assessed using Wilcoxon Signed-Rank Test (z_1, z_2, across items and conditions, respectively), or Mann-Whitney U Test (U_1, U_2), respectively. The condition by group interaction was probed using Wilcoxon Signed-Rank Test separately for each group and Mann-Whitney U Tests separated for condition. The effect sizes were interpreted in terms of Fritz et al. (2012) guidelines, with values of .10, .24, and .37 representing small, medium, and large effect sizes, respectively.

Results

Accuracy. In the whole sample, significantly lower accuracy was observed in the inferential than in the literal condition, $z_1 = -4.02$, $p < .001$, $r = .43$; $z_2 = -3.03$, $p = .002$, $r = .39$. No main effect of group or interaction was observed (see Table 2.2).

Eye-movement data recording and outlier exclusion. The velocity threshold was set to 30 degrees/sec and the acceleration threshold to 8,000 degrees/sec^2 to detect saccades of 0.5 degrees of visual angle or greater. Any sample that was not in a saccade was considered to be in a fixation. Fixations less than 80 ms and longer than 800 ms were excluded from the dataset. Data from each paragraph were visually inspected and those containing excessive blinks or track losses were excluded from the final analyses, resulting in data loss of 1.8% and 0.2% for ASD and control groups, respectively. Outliers for each eye-movement measure

(> 2.5 SDs below or above the subject mean for each condition) were excluded from the analyses. This resulted in the exclusion of a total of 23.3% of the data across all analyses and did not differ across groups or conditions.

Eye-movement measures

Global eye-movement analyses. The inference condition showed a longer paragraph reading/question answering time, F_1 (1, 42) = 32.53, $p < .001$, $\eta^2 = .44$; F_2 (1, 29) = 33.25, $p < .001$, $\eta^2 = 1$, and a greater total number of fixations, F_1 (1, 42) = 36.62, $p < .001$, $\eta^2 = .47$; F_2 (1, 29) = 37.11, $p < .001$, $\eta^2 = 1$. No main effect of condition (all *ps* > .19), group (all *ps* > .46) or interaction (all *ps* > .36) between group and condition were found for the average of fixation duration, number of forward fixations and forward saccade length (see Table 2.2).

Local eye-movement analyses. First, eye-movement measures on the target word (e.g., mouse) that allowed the participants to infer the correct answer were explored. The reading behavior on the target word when it was in the inferential paragraphs was compared with the reading behavior on the target word when it was in the literal paragraphs. The aim was to observe if the reading behavior in relation to the target word changed between the literal condition, where the correct answer was already available in the text, and consequently the target word was an additional, but not necessary cue, and the inferential condition, where the only cue to answer to the question was the target word. A significant interaction of group and condition was found in gaze durations on the target word, F_1 (1, 39) = 5.22, $p = .03$, $\eta^2 = .12$; F_2 (1, 29) = 8.85, $p = .01$, $\eta^2 = .82$. Posthoc analyses showed that the ASD group, but not the control group, displayed significantly longer ($p = .02$) gaze durations on the target words in the inferential than literal condition (Figure 2.1).

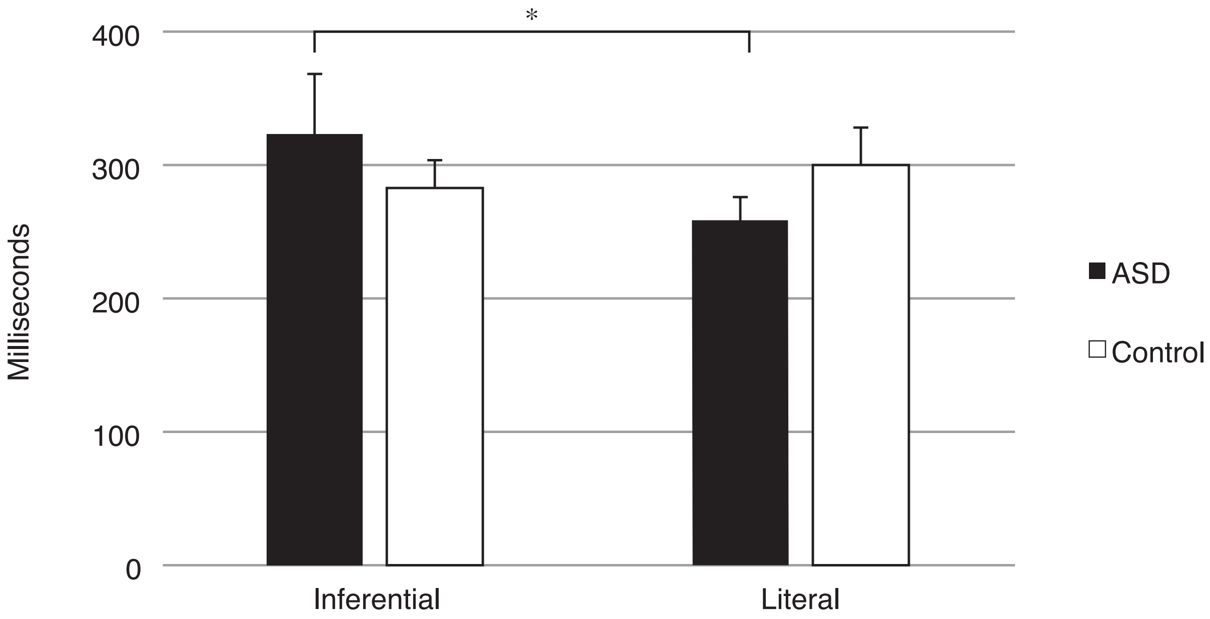

Figure 2.1. Mean gaze duration on the target word in both, inferential and literal conditions for ASD and control groups. Error bars indicate standard errors. *$P < .05$.

Furthermore, the ASD group made overall more regressions-in to the target word, $U_1 = 149$, $z = -2.18$, $p = .03$, $r = .33$, $U_2 = 201$, $z = -3.68$, $p < .001$, $r = .56$, compared to the control group. The inference condition showed longer total fixation times, F_1 (1, 42) = 14.84, $p < .001$, $\eta^2 = .26$; F_2 (1, 29) = 20.12, $p < .001$, $\eta^2 = .99$. No main effects of condition (all *ps* > .18), group (all *ps* > .67) or interaction (all *ps* > .24) between condition and group were found in any of the early measures of processing: first fixation duration, single fixation duration and gaze duration. No main effect of condition (all *ps* > .11), group (all *ps* > .37) or interaction (all *ps* > .37) between condition and group was observed in any other eye-movement measures (Table 2.3 shows mean reading times/probabilities and SDs in parentheses). Apart from regressions-in, it was not possible to conduct analyses from the target separately for the instances in which the word was visited from the text vs. when the word was visited from the question, due to the paucity of the extracted data.

The analyses above showed that readers in the ASD group made more regressions into the target word. We therefore proceeded to analyze in greater detail the possible origin of these regressions. The percentage of total number of regressions made into the target word from within the remaining part of the *text* after the target word (from the fifty-sixth word to the sixtieth word) and the percentage of regressions made into the target word from within the *question* were compared. Overall, the target word was visited significantly more from the text (M = 31.52, SD = 16.07), than from the question (M = 10.64, SD = 8.89), z_1 = -5.38, $p <$ .001, r = .81, z_2 = -4.78, $p <$ .001, r = .62. The target word was also visited from the text more in the inferential condition (M = 37.08, SD = 19.39) than the literal condition (M = 25.94, SD = 19.65), z_1 = -3.51, $p <$ .001, r = .53, z_2 = -2.76, p = .01, r = .36. This was not the case for regressions into the target word from within the question (p = .52). There was an interaction of origin of the regressions by group (see Figure 2). Overall, the ASD group made significantly more regressions into the target word from within the question (M = 13.99, SD = 7.56), U_1 = 118.0, z = -2.93, p = .003, r = .44, U_2 = 221, z = -3.41, p = .001, r = .51, compared to the control group (M = 7.28, SD = 9.91). This was the case in both the inferential (M = 15.34, SD = 11.06), U_1 = 118.0, z = -2.98, p = .003, r = .45, U_2 = 247, z = -3.05, p = .002, r = .39, and the literal conditions (M = 12.82, SD = 10.28), U_1 = 149.5, z = -2.25, p = .02, r = .34, U_2 = 328, z = -1.88, p = .06, r = .24 (inferential: M = 7.88, SD = 13.43, literal: M = 6.67, SD = 8.97, for the control group). No significant difference (p = .33) was found between groups (ASD group: M = 34.02, SD = 18.42, control group: M = 29.03, SD = 13.27) for the regression into the target word from within the text.

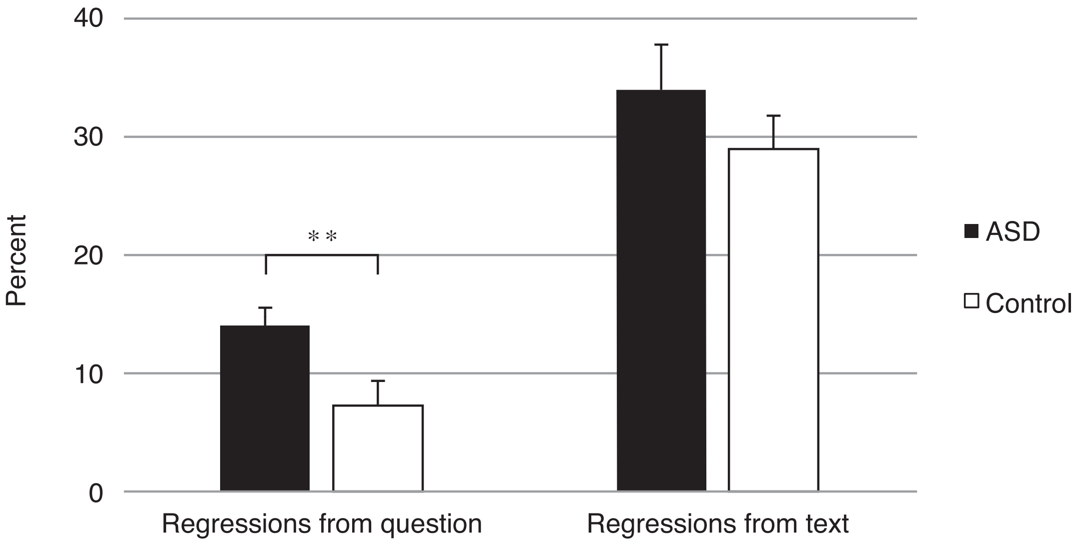

Figure 2.2. Percentage of total number of regressions-in to the target word from within the question and the text, for ASD and control group. *$P < .05$.

Second, the local eye-movement data from the word that contained the correct answer present in the text of the literal condition paragraphs (correct answer word*,* e.g., cat; Appendix 3) were compared to the word that replaced it in the inferential paragraphs (replacement word, e.g., little; Appendix 3). The replacement word, present in the inferential paragraph, was considered a control for the correct-answer word, present in the text in the literal paragraphs. The replacement word showed longer re-reading times, F_1 (1, 17) = 10.17, p = .01, η^2 = .37; F_2 (1, 23) = 7.04, p = .01, η^2 = .23, compared to the correct answer word, but all other effects were nonsignificant. No main effect of condition (all *ps* > .07), group (all *ps* > .74) or interaction (all *ps* > .27) were found for any of the other eye-movement variables (see Table 2.3).

Third, the local eye-movement data from the target word (e.g., mouse; Appendix 3) were compared with the replacement word (e.g., little; Appendix 3) only within the inferential paragraphs. A main effect of condition was found for gaze duration, but all other effects were nonsignificant. The target word received longer gaze durations, F_1 (1, 39) = 5.45, $p = .03$, $\eta^2 = .12$; F_2 (1, 29) = 5.17, $p = .03$, $\eta^2 = .15$, compared to the replacement word. Go-past time showed a significant interaction effect between condition and group, F_1 (1, 39) = 5.82, $p = .02$, $\eta^2 = .13$, F_2 (1, 29) = 3.53, $p = .09$, $\eta^2 = .05$. No main effects were significant. Posthoc analyses showed a significant difference ($p = .01$) between conditions in the ASD group; proportions of go-past time on the target word were higher compared to go-past time on the replacement word for the ASD group, and not for the control group. However, F_2 analyses showed no significant interaction in go-past time. Therefore, the results concerning the interaction effect on go-past time remain inconclusive. A main effect of condition was observed for the proportion of regressions made out of, and into the target and replacement words. More regressions-out of the replacement word were observed compared to the target word, $z_1 = -3.08$, $p = .002$, $r = .46$, $z_2 = -3.53$, $p < .001$, $r = .46$, for both contrasts. More regressions-in to the replacement word were observed compared to the target word, $z_1 = -4.10$, $p < .001$, $r = .62$, $z_2 = -2.52$, $p = .01$, $r =. 33$. No main effect of condition (all *ps* > .10), group (all *ps* > .16) or interaction (all *ps* > .09) between condition and group were found for any of the other eye-movement variables (see Table 2.3).

Fourth, the reading behavior on the correct answer word (e.g., cat; Appendix 3) was compared with the target word (e.g., mouse; Appendix 3), only within the literal paragraphs. A main effect of condition was found for regression-out, $z_1 = -4.51$, $p < .001$, $r = .68$, $z_2 = -2.79$, $p = .01$, $r = .36$. More regression-out from the correct answer word was observed compared to the target word. No main effect of condition (all *ps* > .06), group (all *ps* > .16) or interaction (all *ps* > .43) between condition and group were found for any of the other eye-movement variables (see Table 2.3).

Finally, the analyses of the option that was present in the text as a distractor (distractor word, e.g., parrot; Appendix 3) showed a significant interaction between condition and group in the regressions-out from the distractor, F_1 (1, 42) = 4.53, p = .04, η^2 = .09. Posthoc analyses showed a marginal difference (p = .08) between groups in the literal condition and indicated a close to significant difference (p = .08) between conditions for the control group; proportions of regressions-out from the distractor were higher in the literal condition compared to the inferential condition for the ASD group, and the control group showed the opposite behavior. F_2 analyses showed no interaction (p = .48) between condition and group in the regressions out of the distractor. Therefore, the results concerning regression-out from the distractor word are considered inconclusive. A main effect of inference condition was observed in the proportion of regressions into the word, F_1 (1, 16) = 4.42, p = .04, η^2 = .09, with more regressions-in for the literal paragraphs compared to the inferential paragraphs. Again, F_2 analyses showed no significant main effect of condition (p = .56) in the proportion of regressions into the distractor. Therefore, the results concerning the regression into the distractor word are considered inconclusive. No main effect of inference condition (all *ps* > .33), group (all *ps* > .19) or interaction (all *ps* > .27), between condition and group in any of these eye-movement measures were observed (see Table 2.3).

Discussion

This study aimed to explore inference generation skills and reading strategies in a group of children and adolescents with ASD compared to a closely-matched group of control peers. The first aim was to determine performance when responding to literal and inferential comprehension questions. Results showed that participants with ASD were as accurate as the control group in responding to both questions present in the paragraph assigned to the literal and inferential condition. The result that accuracy in the inferencing task was comparable across ASD and control participants is in agreement with some (LaPointe-Speer, 2007; Saldaña & Frith, 2007; Sansosti et al., 2013), but not all previous studies (Jolliffe & Baron-

Cohen, 1999b, 2000; Norbury & Bishop, 2002; Loukusa et al., 2007). The lack of differences in our study is perhaps not surprising, given that the current group of participants was composed of individuals with ASD, all comparable to the control group, both with respect to language skills and overall reading comprehension. Studies reporting differences in inferencing skill between ASD and TD have often included participants with poorer language abilities (Norbury & Bishop, 2002). These results support the idea that a great proportion of poorer performance of readers with autism is the result of their lower level of language abilities (Ricketts et al., 2013; Lucas & Norbury, 2014).

Alternatively, this lack of differences could be explained by the limited emotional (Bodner et al., 2015) and social (White et al., 2009) content of our stories. Bodner and colleagues (2015) found that when emotional content was the object of the inference, individuals with ASD performed worse than TD controls. Also, our text and questions were presented simultaneously on a single screen. Oakhill (1984) reported that, in skilled comprehenders, there is a facilitation effect provided by the presence of the text during question-answering. In our study, it is possible that the presence of the text on the same screen as the question and possible answers brought the accuracy performance of the ASD group to control standard. We had specifically aimed at reducing the working memory demands, as our research focus was on reading comprehension differences between control and ASD groups, and not on the role of working memory during the task. In any case, the results on accuracy do suggest that ASD individuals with good oral language skills are able to respond to simple global coherence inferences.

The current study also examined reading behavior during inferencing and question-answering by monitoring readers' eye movements. Results showed a similar reading pattern between the groups in global reading of the entire paragraph. However, fine grained analyses on the target words showed that the two groups exhibited subtly different reading patterns that seem indicative of greater effort in producing the inferences. Gaze durations on the target word were longer for participants with autism in the inferential condition, but not in the literal condition. The control participants apparently had no similar difficulty, judging by their similar gaze durations in both conditions. The longer gaze duration may be due to the fact that when the participants with autism encountered the target word, it was less expected in that context (Rayner & Well, 1996).

It should be noted, though, that individuals with ASD had comparable first and single fixation durations to the control participants indicating that the early processing of the target word and lexical access are intact (Rayner & Pollatsek, 1987). These results are consistent with the lack of differences in the early measures in the non-inferential sentence-processing tasks presented by Howard and colleagues (2017). The lack of differences between groups in both reading behavior for the entire paragraph and the early processing of the target word, could be indicative of similar ability in the ASD group in constructing the text-based comprehension or propositional representation (Van Dijk & Kintsch, 1983; Kintsch & Rawson, 2005). In the present study, our ASD group appeared to have no difficulty processing the meaning of the text as such, prior to integrating background knowledge and generating inferences to build the situation model.

Our data are in line with the study by Sansosti et al. (2013) which showed similar accuracy in responding to questions for ASD and control groups – replicating also the Saldaña and Frith, (2007) results. Similar findings in accuracy, albeit with materials tapping different kinds of inferences, were observed in the current study and the study by Sansosti and colleagues. We explored global spontaneous elaborative inferences in short passages. These are inferences that develop and enrich the interpretation of a text by filling in details such as the framework of a typical situation or the causes of a character's actions (McKoon & Ratcliff, 1992). On the other hand, Sansosti and colleagues explored local bridging inferences using short sentences. These are inferences that are essential for comprehension and provide connections between the different propositions underlying the discourse (Haviland & Clark, 1974). Still, in line with our results, Sansosti et al. (2013) demonstrate that the ASD group spent more time fixating the text, made more fixations overall, and made more regressions while reading short sentences that needed psychological or social bridging inferences and knowledge interpretation for comprehension, compared to a control group. Howard and colleagues (2017) did not find any differences in first pass or global reading measures, but their tasks are less comparable, as they did not require the production of inferences.

In addition to spending more time processing the target word, individuals with ASD made more regressions into the target word compared to control readers. A larger number of regressions is consistent with both Sansosti et al. (2013) and Howard et al.'s (2017) results. In our case, due to having the text and question present simultaneously on the screen, we could analyze where these regressions to the target word were coming from. Further analyses showed that for both groups more regressions into the target word from within the remaining part of the text (after the target word) were made compared to the regressions made into the target word coming from the question. However, when only the regressions from the question were explored, the ASD group showed more regressions compared to the control group for both the inferential and the literal condition. Hence, it is possible that ASD participants had a greater needed to re-inspect the target word in order to answer the question, whether an inference was necessary or not. ASD participants may find initial attempts to construct a situation model unsuccessful, thus requiring subsequent regressions into the relevant word to re-check and re-process pieces of information highlighted by the question (Just & Carpenter, 1978; Ehrlich, 1983; Shebilske & Fisher, 1983; Blanchard & Iran-Nejad, 1987; Vauras et al., 1992). The lack of differences between groups in both reading behavior for the entire paragraph and the early processing of the target word may suggest that the early cursory processing, defined as text-based comprehension or propositional representation of text in our ASD sample is similar to typical readers. However, in our ASD group, difficulties emerged during the situation model or mental model representation (Van Dijk & Kintsch, 1983; Kintsch & Rawson, 2005). Individuals with autism may have an underspecified situation model (Tirado & Saldaña, 2016), that lacks sufficient detail to respond to the question even when the response is actually presented in the text. Another explanation comes from previous studies that have shown that re-reading reflects attempts to re-engage working memory of prior text segments which are important to readers' reading goals (Kaakinen et al., 2003; Kaakinen & Hyönä, 2005, 2008). Similar behavior is seen in poor readers, dyslexic readers, and beginner readers (Adler-Grinberg & Stark, 1978; Lefton et al., 1979; Elterman et al., 1980; Martos & Vila, 1990; Eden et al., 1994; Blythe & Joseph, 2011). Hence, more regressions back toward the target word may reflect a backtracking technique of reading or ineffective use of text, as Murray & Kennedy (1988) found in poor readers. An alternative, although not totally incompatible, explanation is provided by Howard and colleagues (2017). They attributed increased second pass reading in their participants to a more cautious reading strategy. In our particular task, this approach could actually be justified if they were finding subtle difficulties in some of the texts. Readers with autism could have more difficulties in constructing the situation model and also be extra-cautious when responding to questions about a text.

Conclusion, limitations, and future prospects

In conclusion, results from the current study support the idea that readers with ASD may have a less specified situation model than their control peers even when they have relatively high levels of receptive language, nonverbal IQ, reading speed and comprehension skill. Despite registering as many correct responses to comprehension questions as the control group, the ASD group had longer gaze durations while reading texts that required inferencing. It appears that readers with ASD had to work harder during the reading process to reach the level of comprehension of the control participants. In addition, they seemed less sure about how to respond to questions about the text, even when the answer was explicitly presented. Although the present study yielded some novel and relevant findings, they need to be interpreted in the light of some limitations. First, the standardized tests used to assess language and reading skills in the present study may not have been sensitive to differences between the two groups in other important cognitive functions involved in reading. For example, higher cognitive and linguistic components such as executive control could play a relevant role in shaping the differences in reading behavior between groups. In addition, higher-level linguistic components such as passage-level listening comprehension and story recall were not assessed in the present sample. These linguistic comprehension challenges could impact on the creation of a coherent situation model and possibly explain why individuals with ASD appeared to work harder to reach the level of comprehension of the control group. Future studies should aim to explore broadly the cognitive and linguistic profiles of participants in order to examine the possible influence of these variables on reading behavior. Also, due to the amount of time required to complete testing in each session, we recruited a relatively small sample. We urge researchers to replicate the present findings in other samples. Future studies should also seek to replicate these results using different materials, for example, texts with social context or emotional content, and in different samples of ASD individuals with varying skills levels.

Chapter 3

Error monitoring and responsiveness to instruction in individuals with ASD

Introduction

In the previous experiment, we observed that highly verbal and high-functioning children and adolescents with ASD had similar performance in responding to inferential and literal questions to language-, nonverbal intelligence-, and reading-skill matched controls. However, thanks to the participants' gaze recording, we found that individuals with ASD showed subtly different reading strategies, possibly indicating additional effort or hesitancy while making inferences. With this previously described experiment, we showed that individuals with ASD and matched controls were similar in their behavioral outcome (in responding to inferential and literal questions), but the way they reached it could be different.

Although weakness in oral language is one of the main variables that explains poor reading comprehension in readers with ASD, but it does not fully account for all their difficulties. It certainly does not seem to explain the differences found in the previous chapter, since even in a very specific high-functioning orally competent group with ASD, reading behavior is subtly different.

In this second experiment, we aim to further explore potential sources of these differences. We are specifically interested in the role of executive function and top-down modulation strategies such as the adaptation to different instructions and error detection, as an indicator of comprehension monitoring.

Reading monitoring plays an important role in the optimization of language comprehension (Van de Meeredonk et al., 2009), in conflict detection, and in attentional control adjustment (Kolk, Chwilla, Van Herten, & Oor, 2003). In this chapter, we focus on linguistic conflict detection, i.e. the ability to identify inconsistencies encountered in the text, such as sentences that are scrambled, are contradictory, or are in conflict with world knowledge. Linguistic conflict detection only becomes possible if a coherent representation of the text has been built during reading, and in turn, it contributes to the construction of the text representation (Cain, Bryant, & Oakhill, 2004). For this reason, it is of great relevance to reading comprehension. Reading monitoring has been shown to be predictive of reading comprehension skills (e.g., Oakhill & Yuill, 1996; Perfetti, Marron, & Foltz, 1996; Ruffman, 1996). In particular, children with reading comprehension difficulties seem to perform poorly in inconsistency detection tasks (Ehrlich, 1996; Ehrlich, Remond, & Tardieu, 1999; Yuill & Joscelyne, 1988; Yuill & Oakhill, 1988). More specifically, some studies have found that poor readers have problems in detecting errors that violated the internal consistency of the text, despite unimpaired nonsense-word detection (Baker, 1984; Zabrucky & Moore, 1989). Similar results were found in less skilled 7-8 years-old children: they did not spend a greater amount of time on inconsistent sentences and detected less inconsistences in comparison to skilled children (Yuill & Oakhill, 1991).

One of the methods used to investigate linguistic conflict detection is the error detection paradigm, in which participants are asked to locate irregularities or anomalies in a text. This paradigm is not free from criticism because it violates the maxim of relevance, according to which the reader assumes that the text is coherent. However, although reading is transformed into a rather artificial task (Grice, Cole, & Morgan, 1975), the paradigm allowed us to explore the ability of readers to adapt reading behavior to a specific context and respond to particular instructions, as well as to explore the ability to monitor reading for errors.

Forrest-Pressley and Waller (1984) found that older and skilled readers were more capable of adapting their reading behavior to a given instruction compared to younger and poorer readers. In addition, Cataldo and Cornoldi (2011) showed that knowledge of reading strategy could be improved using instructions, especially in poor comprehenders. Similarly, some promising results were found in people with learning disabilities (Lucangeli, Galderisi, & Cornoldi, 1995).

We aimed to investigate if this improvement with instruction can be observed also in children and adolescents with ASD. Previous studies have investigated the role of instructions in different reading tasks in autism. For example, it has been shown that the pronunciation of homographs improved after instruction (Jolliffe & Baron-Cohen, 1999; Snowling & Frith, 1986). More recently, Koolen et al. (2012) warned participants about the presence of higher-level linguistic violations (syntactic), or lower-level linguistic violations (orthographic), or both levels (dual-level condition). The authors found that controls did not elicit a monitoring response (P600, usually found in semantic violation tasks; e.g., Kolk, Chwilla, Van Herten, & Oor, 2003; Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006) in the single-level condition (the participants knew that in the sentences they would encounter only one type of violation), but they did in a dual-level condition (when participants expected either type of violations, orthographic and syntactic) for the orthographic errors. However, adults with ASD showed an atypical monitoring response to both, syntactic and orthographic errors in the single and dual conditions. These results are in line with the Koolen et al. (2014) study, where the authors presented local (orthographic) and global (syntactic) violations in a single level (one type of error present in the sentences) and in a dual level task instruction (both types of errors can be present in the sentences). The authors found that individuals with ASD had monitoring responses in all cases: in both local and global linguistic violations under single and dual level condition. In contrast, the control group had monitoring response only during the presentation of local inconsistencies in single- and dual-level conditions. These results indicate that individuals with ASD tend to monitor global aspects of language already under simple circumstances and this may reflect their need for more executive resources during language comprehension. Finally, Koolen et al. (2013) showed higher-level (semantic) linguistic violations and lower-level (orthographic) linguistic violations in a free reading condition and in an instructed condition. People with ASD did not show a P600 effect in response to the semantically implausible sentences in the free-reading condition, unlike the control group. However, when participants with ASD were instructed to read sentences for semantic implausibility they exhibited the P600 response of monitoring. These findings indicate that when reading, adults with ASD do not spontaneously control for possible semantic processing errors, or do not seem to mobilize additional attention for the adjustment of the contextual interpretation, unless they are instructed to do so. This group of three studies suggests that the deployment of monitoring resources during reading in ASD could be implemented differently compared to typical readers.

In the present study, we aimed to explore how readers with and without ASD change strategies according to instruction and error type using eye-tracking technology. First, we explored accuracy in detecting semantic and orthographic errors. We expected to find overall poorer performance in semantic error detection for the ASD group compared to the control group. Second, we wanted to explore the modulation of specific instructions in detecting semantic and orthographic errors and if accuracy could be modulated by specific instructions to find certain errors. We expected higher accuracy scores for the ASD group in semantic errors detection after presenting the instruction that focused on semantic errors detection compared to the scores in semantic error detection after presenting the orthographic instruction. It was unclear what could happen in the orthographic condition, since we did not expect differences between groups in accuracy on orthographic-error detection. Third, we aimed to explore if the reading behavior as observed with eye-tracking was influenced by instructions and error types in both ASD and control groups. We expected an overall different reading behavior depending on error types, as found in Rayner et al. (2004). We also expected differences in the reading behavior on error types depending on the instruction type. For example, when an instruction focused on semantic errors was presented, we predicted deeper processing in the semantic errors (indicated by longer gaze) compared to the orthographic errors. We expected the opposite pattern when an instruction focusing on orthographic errors was presented.

The present study has novel aspects compared to previous ones investigating reading monitoring in ASD. First, we compared two different types of instruction instead of comparing free and instructed reading as in Koolen et al. (2013), because free reading might inhibit error detection (Ehrlich et al., 1999). With the presence of two different instructions, we wanted to modulate the attention towards specific type of errors. Second, we used eye-movement technology instead of an event-related potentials technique. Gaze behavior can show if the reader is finding the processing of a word particularly difficult (Rayner, 1998) and, similarly to the event-related potentials technique, it also provides a fine measure of the time course in which disruption to processing occurs (Vasishth, von der Malsburg, & Engelmann, 2012). Third, we had a between-subjects design that allowed us to exclude influences from previous instructions. Finally, the present study included children and adolescents, instead of adults.

Method

Participants

Twenty-one children and adolescents, all native speakers of Spanish with a diagnosis of ASD or Asperger's syndrome were recruited from local schools and ASD associations of middle-class neighborhoods. Individuals with comorbidity with other developmental and acquired disorders or vision problems that impede reading and bilingual families were excluded from recruitment. One participant with ASD registered a score on the Perceptual Reasoning Index (PRI) from the Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2005) or Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV; Wechsler, 2012) below 70 and was excluded from the analyses. A trained psychologist confirmed the diagnosis of the participants with ASD using the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). All participants met the ADOS criteria for autism spectrum with a total score greater than seven (*M* = 11.05, range = 7 – 19).

Twenty-six typically developing children and adolescents, all native Spanish speakers, were recruited from local schools of middle-class neighborhoods as a control group. The same exclusion criteria as for the ASD group were used for the control group. Four participants were excluded from the analyses in order to match the control group and the participants with ASD on chronological age (ASD mean age = 13.3 years, *SD* = 2.5, range = 10.6 – 18; control mean age = 13.5, *SD* = 2.3, range 10.3 – 17.8, *p* = .98), and gender (ASD: 4 females; control: 9 females, *p* = .74).

Twenty individuals with ASD and twenty-two control peers all monolinguals from Andalucía in the South of Spain composed the final sample. No statistical differences were observed between groups on their non-verbal intelligent quotient, vocabulary size, grammatical structure comprehension, reading speed, or number of decoding errors (hesitations, rectifications and repetitions). The ASD group showed lower performance on working memory, reading comprehension, and theory of mind (ToM) skills compared to the control group (see Table 3.1).

Children in both groups were randomly assigned to one of the two instruction conditions: semantic or orthographic. Within the semantic-instruction condition, the ASD group and control group did not differ on any of the background tests, except for the ToM task, where the ASD group had lower scores than the control group as expected. The ASD group randomly assigned to the orthographic-instruction condition showed lower performance on working memory, vocabulary size, grammatical structures comprehension, reading comprehension and ToM tasks, compared to the control group. The control group randomly assigned to the semantic instruction showed poorer performance in vocabulary size than the control group assigned to the orthographic instruction. The ASD group randomly assigned to the orthographic instruction had poorer performance in vocabulary size compared to the ASD group assigned to semantic instruction (means, standard deviations and ranges are provided in Table 3.1).

The regional Andalusian Biomedical Research Ethics Committee approved recruitment and data collection procedures. Written informed consent was obtained from participants' parents or legal guardians prior to any testing.

Table 3.1

Background data of the participants in semantic- and orthographic-instruction conditions for ASD and control groups.

	ASD		Control					
	Semantic Instruction	Orthographic Instruction	Semantic Instruction	Orthographic Instruction				
	Mean ± SD [range] n =10	Mean ± SD [range] n = 10	Mean ± SD [range] n = 11	Mean ± SD [range] n = 11	*p* between groups in the semantic instruction	*p* between groups in the orthographic instruction	*p* between instructions in the ASD group	*p* between instructions in the control group
PRI	102 ± 11 [83-120]	100 ± 17 [81-131]	107 ± 14) [83-134]	108 ±10 [100-139]	.41	.22	.85	.80
WMI	100 ± 17 [73-130]	102 ± 15 [75-127]	112 ± 9 [97-127]	115 ± 10 [100-141] [b]	.06	.03	.86	.53
PPVT-III (Standardized Scores)	109 ± 24 [85-164]	96 ± 22 [61-121]	107 ± 7 [95-119]	117 ± 11 [103-141] [a, b]	.76	.01	.01	< .001
CEG (% Raw Scores)	92 ± 4 [67-78]	90 ± 6 [61-79]	92 ± 6 [62-80]	96 ± 3 [74-80] [b]	.75	.02	.34	.18
TALE RS	137 ± 45 [66-	138 ± 37 [82-	138 ± 28	147 ± 27	.95	.54	.35	.54

(Words/Seconds Raw Scores)	195]	212]	[101-191]	[111-195]				
TALE RC (% Raw Scores)	58 ± 16 [22-79]	48 ± 16 [28-89]	66 ± 19 [42-100]	68 ± 13 [50-92] [b]	.35	.01	.35	.84
ToM (% Raw Scores)	61.4 ± 20.3 [2-7]	57.1 ± 17.9 [2-6] [b]	84.4 ± 14.9 [4-7]	88.3 ± 16.7 [3-7] [b]	.01	.001	.58	.63

Note. n = number of participants. PRI = Perceptual Reasoning Index. WMI = Working Memory Index. PPVT-III = Peabody Picture Vocabulary Test - Third Edition. Scores are standardized for the PRI, WMI and PPVT. CEG = Grammatical Structures Comprehension Test. TALE RS = Magellan Scales of Reading and Writing – Reading Speed subtest. TALE RC = Magellan Scales of Reading and Writing – Reading Comprehension subtest; correct answers' scores are in percentage. [a] denotes significant difference within group and between instructions. [b] denotes significant difference within instruction condition and between groups.

Background assessment

Nonverbal intelligence. Two indexes from the WISC-IV (Wechsler, 2005) or WAIS-IV (Wechsler, 2012), depending on participant's age, were used to measure working memory skills (Working Memory Index, WMI) and perceptual reasoning (Perceptual Reasoning Index, PRI) abilities.

Receptive language. The Spanish version of the Peabody Picture Vocabulary Test - Third Edition (PPVT-III; Dunn, Dunn, & Arribas, 2006) assessed receptive vocabulary size. The Grammatical Structures Comprehension Test (CEG; Mendoza, Carballo, Muñoz, & Fresneda, 2005) was used to measure receptive grammar. CEG is a Spanish version of the Test for Reception of Grammar for English (TROG; Bishop, 1983). This test explores receptive grammar status in children between 4 and 11 years of age, and targets certain structures specific to Spanish grammar. Raw scores for all participants were used for matching the two groups. CEG has a Cronbach's $\alpha = .91$ (Mendoza et al., 2005). Other tests such as PPVT-III ($r = .81$, $p < .001$), Illinois Test of Psycholinguistic Abilities (ITPA; Kirk, McCarthy, & Kirk, 1968) ($r = .64$, $p < .001$) and Digit Span (Wechsler Intelligence Scale for Children Revised; WISC-R; Wechsler, 1999) ($r = .37$; $p = .003$) correlate well with the CEG total scores (Mendoza et al., 2005).

Reading skills. Reading speed and reading comprehension abilities were measured using two subscales of the Magellan Scales of Reading and Writing (EMLE TALE-2000; Toro, Cervera, & Urío, 2000): reading fluency and reading comprehension. The reading fluency subtest requires the participant to read aloud one of three age-appropriate tests. Reading time and number of decoding errors were recorded. The reading comprehension subtest assesses the ability to extract text meaning, to understand the characters' role, and temporal sequences and to answer multiple-choice questions. Three different texts were presented depending on participant's level of schooling. The EMLE TALE has been shown to agree with teacher ratings in the identification of poor comprehenders in the 98% of the cases, and has a Kappa of .68 for overall classification of readers into poor and good comprehenders. This test has a test–retest reliability ranging from .76 to .85 for different ages.

Theory of mind. ToM was assessed by an experimenter that told and acted out with dolls four different stories. Two stories measured the first-order false beliefs (*Sally-Ann* test, Baron-Cohen et al., 1985 and *Smarties* test, Perner, et al. 1989) and other two stories the second-order false beliefs (*Ice-cream Van,* Peter & Wimmer, 1985, and *Birthday Puppy* test, Sullivan et al., 1994). Participants were required to answer to open questions regarding the protagonists' actions and thoughts. Scores on this task ranged from 0 to 7.

Apparatus

The sentences were presented on a 18.5-inch monitor (41 x 23 cm) connected to a computer interfaced with an EyeLink 1000 eye-tracker (SR Research Ottawa, Ontario, Canada). EyeLink 1000 is an infrared, video-based tracking system combined with hyperacuity image processing with a spatial resolution of 0.4 degrees, and a sampling rate of 1,000 Hz. Participants' viewing was binocular and only the right eye movements were tracked. Sentences were presented in black, Time New Roman font size 20 on a light grey background. The monitor was positioned at a 55 cm distance from participants' eyes.

Materials and design

Sentence creation

One hundred and forty-four sentences, divided into eight stories (18 per story), in Spanish, were created. Forty-eight sentences belonged to the semantic-error condition, forty-eight to the orthographic-error condition, and forty-eight to the condition without errors. All sentences were from 17 to 20 words long and were presented individually on the screen. Each story was composed of six sentences containing semantic errors, six sentences containing orthographic errors, and six sentences were correct. Each sentence had one word replaced either by semantic- or orthographic-error words, or had no word replacement. Half of the orthographic errors consisted in the replacement of one of the middle letters of the word by an incorrect letter (Koolen et al., 2013), and the other half were an inversion of two adjacent letters in the middle of the word. Semantic errors consisted in the substitution of a word in the sentence with another word that did not make sense in the context of the sentence. The word used as semantic error was chosen so that it had similar frequency (Real Académica Española, 2015) and length as the word that was originally used in the sentence (the stories are presented in Appendix 4). Sentences were double spaced to permit the accurate analysis of the eye-tracking data. The stories contained minimal emotional (Bodner, Engelhardt, Minshew, & Williams, 2015) and social content (White, Hill, Happé, & Frith, 2009) in order to avoid potential differences in the behavioral and gaze results due to poorer ToM skills of individuals with ASD compared to the control group.

Norming studies

Ninety-eight undergraduate students from the University of Seville in Spain confirmed the grammatical correctness and content coherence of the stories. Any changes to the selected target words were derived from this last evaluation. Predictability (Sheridan & Reingold, 2012) of the selected target word to be replaced by either an orthographic or semantic error was measured. We presented the sentences including a blank space corresponding to the target word to sixty-five adults. Participants were asked to provide in the blank space the word that seemed most likely to come next in the sentence. The target words selected for replacement with errors had a large variability in predictability, with a mean cloze probability of .61 (range = 0.01 to 1). We decided to keep this broad range of predictability in order to have a broader spectrum of difficulty in detecting errors.

Counterbalancing and design

The presentation of the eight stories was randomized among participants. Sentence conditions (semantic, orthographic and no-errors) were presented in a fixed random order between stories. To ensure that each sentence appeared in every condition, we designed two versions for each sentence, where the sentences contained alternately orthographic or semantic errors. Sentences that did not contain errors were constant between the two versions. Prior to any testing, each participant was assigned to a semantic-instruction or an orthographic-instruction condition and to one of the two versions of a sentence, based on chronological age and group status (ASD group or control group). The entire sample was divided in four groups (ASD group assigned to the semantic instruction, ASD group assigned to the orthographic instruction, control group assigned to the semantic instruction, and control group assigned to the orthographic instruction).

Procedure

Background information was obtained in the following order: working memory, nonverbal intelligence, verbal skills and reading abilities. Subjects completed the test assessment in two (control group) or three sessions (ASD group) of 1 hour each. The ADOS was administered only to the ASD group in order to confirm the diagnosis of ASD on a different day and prior to any testing. Then the eye-tracking experimental task was performed in a single 45-minute session. Participants were tested individually, and in a quiet room either in the university laboratory or at school. Participants' parents and participants themselves were informed that the study concerned reading stories displayed on a computer screen, and that eye gaze would be recorded. After the participants verbally declared that they understood the aims of the study, they were seated in front of the computer screen and the eye-tracker camera. Participants wore a small sticker on their forehead, which enabled the eye tracker to monitor head position, as is common in this type of eye-tracking technology. Nine-point calibration and validation procedures were used for each participant. If calibration and validation were successful, participants read one of the two instructions. The semantic instruction was as follows: 'You are going to read some stories divided in short sentences. In some of these sentences, there could be some errors. These errors can be of different types, but I am especially worried I made an *error of meaning, which consists in words that do not make sense in the context of the sentence.* You should help me to change the sentences so that they are correct, and especially so that the sentences have a coherent and complete meaning. At the end of each sentence, you will have time to tell me if you found any error and, if so, which one'. The orthographic instruction was the same as the semantic instruction except for the following sentence: 'I am worried that I made *an error of orthography, which consists in errors where I made mistakes in writing some of the letters of the words'.* When participants finished reading the instruction, they pressed the space bar on a keyboard, and were asked to fixate on a fixation point in the left center of the screen prior to the presentation of each sentence, in order to check the calibration validity. If the fixation on the fixation marker was appropriately accurate (maximum point error < 1.5 degrees, average error < 1.0 degrees) the next sentence began; if not, the subject was recalibrated. Subjects were asked to read each sentence silently, and to press the space bar on the keyboard when they finished reading the sentence. They were told that after each sentence they had to report orally if an error was present and if so which one it was. Participants were also free to report a possible correction for the error. The experimenter recorded the participant's error detection, and spontaneous corrections and comments. A screen showing the message "New story" in the middle of the screen advised the beginning of a new story, until the participant pressed the space bar. Prior to the presentation of the experimental trials, participants read and detected errors from six practice trials (two sentences containing orthographic errors, two with semantic errors, and two correct sentences) that were excluded from the final analyses.

Eye-movement data

First, we report five global eye movement measures that include the time during which the participants read the sentence and pressed the space bar to report if an error was present. Sentence reading time is the total time spent reading the sentence and pressing the space bar; total number of fixations is the sum of all fixations during that time; and average fixation duration is the mean length of all fixations. Number of forward fixations refers to number of fixations following a forward (left to right) saccade. Forward saccade length is the mean length of all saccades (Rayner, 1998, 2009) (see Table 3.2).

Next, we explored nine local eye-movement measures in relation to the errors contained in the sentences. First fixation duration is the duration of the initial fixation on the error regardless of whether it is the only fixation or the first of multiple fixations. Single fixation duration refers to the duration of the initial fixation on the error when only one fixation was performed on that error during first pass. Gaze duration is the sum of fixations on the error prior to moving to another word, and go-past time is the sum of all temporally continuous fixations including fixations after a regressive eye movement to the left of the region, until the fixation point progresses to the error to the right. Total fixation time refers to the sum of all fixations on the error. Re-reading time is the total fixation duration in a region after having left the error to the right. Regressions-out refers to the probability of performing a leftward eye movement out of the error before leaving the word to the right, whereas regressions-in refers to the probability of making a leftward eye movement into the error having already left that word to the right. Finally, skip referred to the probability of not reading the error (Rayner, 1998, 2009, see Table 1.5).

For all local measures, with the exception of regressions and skip, values of zero were excluded. Participants who had zero reading times in all items in one or both conditions were excluded from the analyses for the given six eye-movement measures. Consequently, the number of participants kept for each analysis varied between the eye-movement measures (see Table 3.3).

Results

Statistical analyses

Across all variables, both normal and non-normally distributed data were retained for analysis. Hence, non-parametric statistical tests were employed for accuracy in detecting errors and parametric statistical tests for all log-transformed global and local eye movement measures. Main effects of error were assessed with the Friedman Test, main effect of group and instruction with the Mann-Whitney U Test. Error X Instruction interaction was analyzed using the Friedman Test separately for each error, Instruction X Group and Group X Error interactions using the Mann-Whitney U Test separately for each instruction and group, respectively. Finally, Instruction X Error X Group interactions were analyzed with the Friedman Test separately for each instruction and group. All global and log-transformed local eye-movement measures were analyzed using a 2 (Group) x 2 (Instruction) x 3 (Error) repeated measures ANOVA. Bonferroni corrections were carried in normal and non-normally distributed data in order to allow multiple comparisons in posthoc comparisons.

Accuracy in detecting errors. An error was considered correctly detected if the participant reported, i) the error, ii) the error and the error correction, or iii) only the error correction. The error was considered incorrectly detected if the participant, i) did not respond, ii) identified a different word as error, or iii) mentioned the presence of an error, but did not remember or identify the error. Sentences without errors were considered correctly reported if the participant said that no errors were present in the sentence. Over the whole sample, a Friedman Test revealed a main effect of error for accuracy, χ^2 (2, n = 42) = 17.53, $p < .001$. A Wilcoxon Signed Rank Test comparing the error conditions with each other, revealed significant higher accuracy in the detection of no errors (*M* = 91%, *SD* = 9) compared to semantic errors (*M* = 78%, *SD* = 23), $z = -3.39$, $p = .001$, $r = .52$, and orthographic errors (*M* = 83%, *SD* = 10), $z = -3.77$, $p < .001$, $r = .58$. No statistical difference was observed overall between semantic and orthographic error detection ($p = .49$). No main effect of instruction ($p = .73$; semantic instruction, *M* = 85%, *SD* = 7; orthographic instruction, *M* = 84%, *SD* = 12) and no main effect of group ($p = .08$; ASD group, *M* = 81%, *SD* = 11; control group, *M* = 87%, *SD* = 7) were observed for accuracy.

No main Errors X Instruction interaction for any of the error conditions was observed over the whole sample (all *ps* > .27). In the semantic instruction condition, participants correctly detected 81% (*SD* = 14) of the semantic errors, 82% (*SD* = 8) of the orthographic errors, and 91% (*SD* = 11) of the sentences without errors. In the orthographic instruction condition, participants correctly detected 75% (*SD* = 29) of the semantic errors, 84% (*SD* = 13) of the orthographic errors, and 92% (*SD* = 8) of the sentences with no errors. No Group X

Error interaction for any of the error conditions was observed (all *ps* > .13). ASD participants correctly detected 71% (*SD* = 28) of the semantic errors, 80% (*SD* = 12) of the orthographic errors, and 92% (*SD* = 9) of the sentences without errors. The control group correctly detected 85% (*SD* = 14) of the semantic errors, 86% (*SD* = 9) of the orthographic errors, and 91% (*SD* = 10) of the sentences with no errors. No significant Instruction X Group interaction was observed in error detection after reading the semantic instruction (*p* = .04; ASD group, *M* = 84%, *SD* = 10; control group, *M* = 85%, *SD* = 5) and after reading the orthographic instruction (*p* = .92; ASD group, *M* = 78%, *SD* = 12; control group, *M* = 89%, *SD* = 8). No Instruction X Group X Error interaction was found to be statistically significant after the Bonferroni correction (ASD group, semantic instruction, *p* = .01; ASD group, orthographic instruction, *p* = .06; control group, semantic instruction, *p* = .23; control group, orthographic instruction, *p* = .20) (for means and standard deviations see Table 3.2).

Table 3.2

Accuracy in detecting errors and global eye movement measures, in sentences containing semantic and orthographic errors and in correct sentences, in semantic and orthographic instructions for ASD and control groups.

	ASD			Control		
	Semantic Instruction					
	Semantic errors Mean ± SD	Orthographic errors Mean ± SD	No errors Mean ± SD	Semantic errors Mean ± SD	Orthographic errors Mean ± SD	No errors Mean ± SD
Percent correct	80 ± 18	80 ± 7	93 ± 10	83 ± 10	84 ± 9	89 ± 13
Sentence reading time	10222 ± 4343	9390 ± 3630	10520 ± 5542	9916 ± 3869	9244 ± 3861	11064 ± 7473
Total number of fixations	26 ± 6	23 ± 5	28 ± 9	30 ± 11	27 ± 10	34 ± 21
Average fixation duration	329 ± 67	339 ± 77	49 ± 65	309 ± 50	320 ± 57	83 ± 121
Number of forward fixations	0.84 ± 0.22	0.79 ± 0.21	0.83 ± 0.14	0.78 ± 0.15	0.83 ± 0.15	0.78 ± 0.19
Forward saccade length	3.85 ± 0.97	3.79 ± 0.88	3.75 ± 0.83	3.37 ± 0.54	3.34 ± 0.53	3.36 ± 0.53
	Orthographic Instruction					
Percent correct	62 ± 34*	81 ± 15*	91 ± 9	87 ± 17	88 ± 9	93 ± 7

Sentence reading time	11000 ± 3027	9862 ± 3051	10805 ± 3559	9334 ± 3313	8372 ± 2542	11147 ± 5407
Total number of fixations	30 ± 4	25 ± 5	30 ± 6	32 ± 12	28 ± 9	37 ± 16
Average fixation duration	304 ± 62	329 ± 76	31 ± 6	276 ± 62	285 ± 70	108 ± 117
Number of forward fixations	0.63 ± 0.19	0.68 ± 0.11	0.58 ± 0.23	0.66 ± 0.51	0.61 ± 0.49	0.67 ± 0.49
Forward saccade length	3.74 ± 0.65	3.74 ± 0.58	3.79 ± 0.55	3.45 ± 0.60	3.45 ± 0.57	3.50 ± 0.67

Note. Percent correct is referred to the percentage of the errors correctly detected. Paragraph reading time and average fixation duration are in milliseconds; saccade length is in degrees of visual angle. * = Denotes main effect of group between errors, p = .05.

Eye-movement measures

Eye-movement data recording and outlier exclusion. The velocity threshold was set to 30 degrees/sec and the acceleration threshold to 8000 degrees/sec^2 in order to detect saccades of 0.5 degrees of visual angle or greater. Any sample that was not in a saccade was considered to be in a fixation. Fixations less than 80 ms and longer than 800 ms were excluded from the dataset. Data from each sentence were visually inspected and those containing excessive blinks or track losses (> 2.5 SDs below or above the subject mean for each condition) were excluded from the final analyses, resulting in data loss of 0.31% and 0.35% for ASD and control groups, respectively. Outliers for each eye-movement measure (> 2.5 SDs below or above the subject mean for each condition) were excluded from the analyses. This resulted in the exclusion of a total of 6.13% of the data across all analyses and did not differ across groups or error and instruction conditions.

Global eye-movement analyses. A main effect of error condition was observed for sentence reading time, F (2, 37) =, 11.61, $p < .001$, $\eta^2 = .39$, total number of fixations, F (2, 37) = 18.52, $p < .001$, $\eta^2 = .50$, average fixation duration, F (2, 37) = 89.74, $p < .001$, $\eta^2 = .83$. Compared to both the sentences containing semantic and the sentences with orthographic errors, the sentences without errors had longer reading time (Semantic: M = 10,118, SD = 566; Orthographic: M = 9,217, SD = 511; No error: M = 10,884, SD = 882), more fixations (Semantic: M = 29, SD = 1; Orthographic: M = 26, SD = 1; No error: M = 32, SD = 2), and shorter fixation duration (Semantic: M = 305, SD = 9; Orthographic: M = 318, SD = 10; No error: M = 68, SD = 14). Compared to the sentences containing orthographic errors, the sentences containing semantic errors had more but shorter fixations. No main effect of error was observed for the number of forward fixations (p = .84) and the forward saccade length (p = .75).

No main effect of group (all *ps* = .08) and no main effect of instruction (all *ps* = .07) were found for any of the global eye movement measures.

No Error X Instruction interactions (all *ps* = .06), Group X Error interactions (*p* = .07), or Instruction X Group interactions (all *ps* = .70) were observed for any of the global eye movement measures.

No Instruction X Group X Error interactions (all *ps* = .28) were showed for any of the global eye movement measures, except for the forward fixations, F (2, 37) =, 6.99, p = .003, η^2 = .27. Posthoc analysis did not show any statistically significant effects, although differences were close to significance (p = .07) in the orthographic instruction, where the ASD group made more forward fixations in the sentences containing orthographic errors (M = 0.68, SD = 0.09), compared to the sentences without errors (M = 0.58, SD = 0.09) (Table 3.2 displays means and standard deviations).

Local eye-movement analyses. Local eye-movement measures on semantic and orthographic errors were explored. A main effect of error was observed for first fixation duration, F (1, 38) = 22.07, p < .001, η^2 = .37, single fixation duration, F (1, 31) = 15.97, p < .001, η^2 = .34, gaze duration, F (1, 38) = 47.80, p < .001, η^2 = .56, re-reading time, F (1, 37) = 35.38, p < .001, η^2 = .49, regressions-out, F (1, 38) = 59.31, p < .001, η^2 = .61, and regressions-into, F (1, 38) = 8.71, p = .005, η^2 = .19. Compared to the semantic errors, orthographic errors had longer first fixation duration (Semantic: M = 360, SD = 102; Orthographic: M = 469, SD = 217), longer single fixation duration (Semantic: M = 447, SD = 244; Orthographic: M = 774, SD = 437), longer gaze duration (Semantic: M = 547, SD = 200; Orthographic: M = 761, SD = 291), and significantly shorter re-reading time (Semantic: M = 720, SD = 462; Orthographic: M = 501, SD = 357), less regressions-out (Semantic: M = 40.74, SD = 10.40; Orthographic: M = 29.73, SD = 9.78) and less regressions-into the error

(Semantic: *M* = 45.26, *SD* = 9.99; Orthographic: *M* = 39.22, *SD* = 11.97). There was no main effect of error for the go-past time, the total fixation time and the skip probability (all *ps* > .23).

A main effect of group was observed for the percent of skip, F (1, 38) = 9.25, p = .004, η^2 = .20, where the ASD group did more skipping (*M* = 19.81%, *SD* = 11.30) compared to the control group (*M* = 11.39%, *SD* = 6.75). No main effect of group was displayed for any of the others eye movement measures (all p > .15).

No main effect of instruction was observed for any others local eye movement measures (all p > .11).

A main Error X Group interaction for the regression-out was observed, F (1, 40) = 4.25, p = .04, η^2 = .10. Posthoc analyses showed that the ASD group displayed significantly more regressions-out on semantic errors (*M* = 38.48, *SD* = 7.21) compared to orthographic errors (*M* = 30.55, *SD* = 8.10). The control group showed the same pattern (Semantic: *M* = 42.80, *SD* = 12.43; Orthographic: *M* = 28.98, *SD* = 11.24). In order to calculate the mean difference of the regressions-out between groups, we subtracted the regression-out mean of the semantic errors to the regression-out mean of the orthographic errors. Using an independent-samples t-test, we compared the calculated mean and we found a significant difference in the mean difference of the regressions-out for ASD and control groups, t (40) = -2.06, p = .04, two-tailed. The ASD group mean difference (*M* = 0.08, *SD* = 0.09) was significantly smaller than the control group mean difference (*M* = 0.14, *SD* = 0.10, Figure 3.1).

No Error X Instruction interactions (all *ps* > .09), Group X Error interactions (all *ps* > .15), Instruction X group (all *ps* > .12), and Instruction X Group X Error interactions (all *ps* > .10) were observed for any of the other local eye movement measures (for means and standard deviations see Table 3.3).

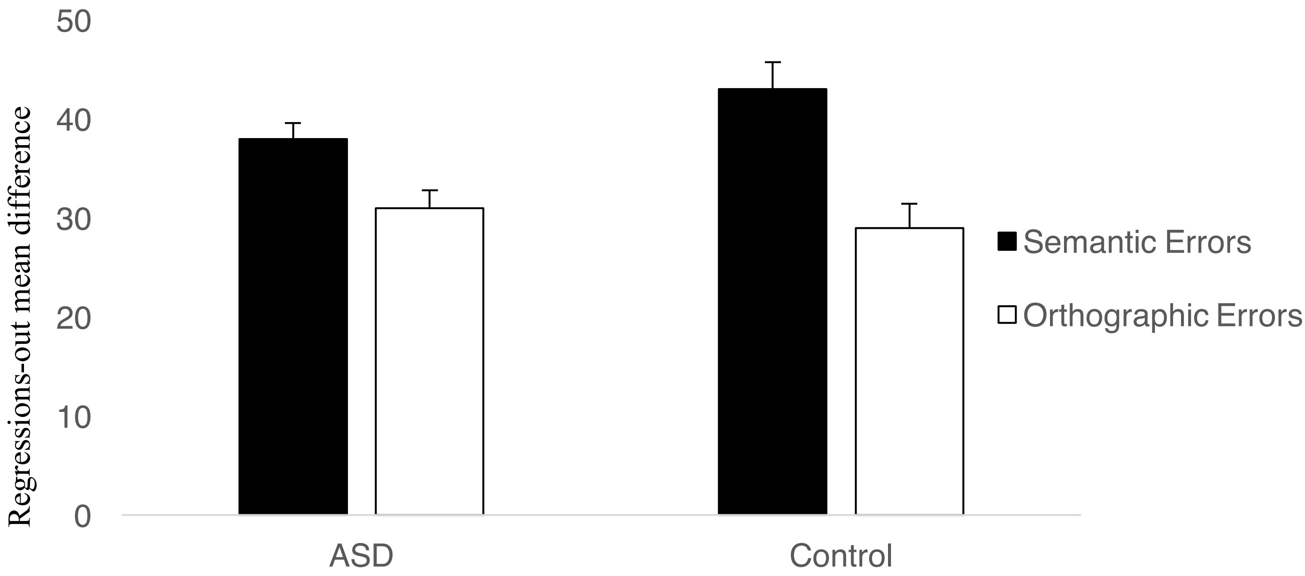

Figure 3.1. Regressions-out for the ASD and the control groups. Analysis on the regressions-out mean difference between errors showed that the ASD group mean difference was smaller compared to the control group mean difference.

Table 3.3

Local eye movement measures from the semantic and orthographic errors in semantic and orthographic instructions for ASD and control groups, and the overall error condition scores in semantic and orthographic instructions.

		ASD		Control		Both groups	
		Semantic Instruction					
	n (ASD/Control)	Semantic errors Mean ± SD	Orthographic errors Mean ± SD	Semantic errors Mean ± SD	Orthographic errors Mean ±SD	Semantic errors Mean ± SD	Orthographic errors Mean ± SD
First fixation duration	10/11	377 ± 103	486 ± 185	393 ± 116	447 ± 160	385 ± 107	466 ± 169
Single fixation duration	8/9	513 ± 287	571 ± 204	591 ± 286	823 ± 266	554 ± 280	704 ± 265
Gaze duration	10/11	546 ± 202	748 ± 307	604 ± 236	738 ± 183	576 ± 217	743 ± 243
Go-past time	10/11	1355 ± 586	1361 ± 611	1287 ± 554	1278 ± 450	1319 ± 556	1317 ± 521
Total fixation time	10/11	1536 ± 676	1530 ± 711	1397 ± 563	1414 ± 353	1463 ± 608	1470 ± 542
Re-reading time	10/11	433 ± 723	500 ± 286	635 ± 517	457 ± 360	677 ± 469	477 ± 320

Regression out (%)	10/11	37.98 ± 8.56	33.16 ± 6.64	38.89 ± 13.79	27.83 ± 11.52	38.93 ± 10.55	30.37 ± 9.68
Regression into (%)	10/11	44.53 ± 10.79	35.64 ± 7.83	45.16 ± 11.70	37.11 ± 14.48	44.86 ± 10.10	36.41 ± 11.53
Skip (%)	10/11	15.87 ± 7.29	15.06 ± 9.72	11.76 ± 10.62	11.31 ± 6.32	13.71 ± 9.20	13.10 ± 9.55
				Orthographic Instruction			
First fixation duration	10/11	357 ± 98	527 ± 318	315 ± 88	421 ± 197	335 ± 93	471 ± 260
Single fixation duration	8/9	405 ± 118	922 ± 677	405 ± 242	760 ± 423	405 ± 185	841 ± 554
Gaze duration	10/11	530 ± 101	851 ± 437	507 ± 182	713 ± 212	518 ± 182	779 ± 337
Go-past time	10/11	1426 ± 534	1555 ± 575	1284 ± 473	1174 ± 391	1351 ± 495	1355 ± 513
Total fixation time	10/11	1509 ± 492	1751 ± 703	1449 ± 559	1486 ± 646	1478 ± 516	1612 ± 670
Re-reading time	9/11	854 ± 451	661 ± 462	695 ± 480	415 ± 318	767 ± 462	526 ± 399
Regression out (%)	10/11	37.98 ± 8.56	27.94 ± 8.9	46.72 ± 10.03	30.13 ± 11.38	42.56 ± 10.16	29.09 ± 10.08
Regression into (%)	10/11	44.59 ± 10.04	40.92 ± 21.67	46.65 ± 8.61	43.02 ± 7.54	45.67 ± 9.14	42.02 ± 10.09
Skip (%)	10/11	21.78 ± 10.08	26.42 ± 16.32	9.13 ± 4.16	13.45 ± 6.63	15.15 ± 9.81	19.62 ± 13.64

Note. n = number of participants. First fixation duration, single fixation duration, gaze duration, go-past time, total fixation time, and re-reading time are in milliseconds.

Discussion

The present study aimed to explore the ability of individuals with ASD to detect errors when asked to do so, and more specifically, if instructions would impact on their ability to detect semantic and orthographic errors. In addition, it aimed to explore if reading behavior changed with different instructions and error types.

We did not find significant differences between the performance of the ASD and the control groups in semantic or orthographic error detection. The ASD group that received orthographic instructions showed the tendency to have poorer performance in the detection of semantic errors compared to the orthographic-instructed control group; when they were instructed to search for semantic errors, their performance on semantic-error and orthographic-error detection tended to reach the level of the control group. However, none of these differences reached significance. The small differences can probably be attributed to small differences in oral language levels: the orthographic-instruction ASD group had lower scores on working memory, vocabulary size, grammar structure comprehension, and reading comprehension, to the corresponding control group; but the semantic-instruction ASD group was comparable to the corresponding control group, except for poorer performance on reading comprehension. Overall, it is safe to assume that differences in error-detection accuracy are very small or non-existent between the autism and control groups once oral language is taken into account.

In addition to accuracy measures, we had also monitored readers' eye movements. Results on the reading measures concerning the entire sentences containing the semantic or orthographic errors and the entire correct sentences showed that the sentences that contained semantic errors received more and shorter fixations compared to the sentences containing orthographic errors. These results reflect participants' efforts to integrate the semantic errors in the context of the different sentences. Longer fixations in the sentences containing the orthographic errors compared to the sentences containing the semantic errors could be due to the need to inspect longer the error due to its visual nature. During the reading of the sentences that contained orthographic errors compared to the semantic condition, participants did more and shorter fixations probably because the detection of the orthographic error was more immediate. Participants took longer, had more fixations, but shorter fixations duration during the reading of the correct sentences compared to both the sentences containing semantic and orthographic errors. The fact that sentences without errors received more and shorter fixations and longer reading time compared to the sentences containing semantic and orthographic errors suggests that participants were alerted to the need to monitor for errors and were most probably prone to spend more time on the correct sentence trying to find a potential error. The reading strategy between conditions was also different: participants used a scanning strategy (indicated by more and shorter fixations) while reading the correct sentences and a deeper reading processing (less, but longer fixations) for the sentences containing the errors. It is plausible that the fixations behavior in the sentences containing errors is given by the fact that participants saw the error and continued to read the sentence normally. Different instructions did not modulate the participants' global reading behavior, suggesting that the presence of the instruction may create a general alert on the reading behavior that does not depend on the content or nature of the instruction.

Further local analyses on the errors showed that the orthographic errors received longer first fixations, single fixations, and gaze duration, compared to semantic errors. Participants needed more time to inspect orthographic errors, compared to semantic errors, probably due to the visual nature of the orthographic errors. On the other hand, semantic errors were re-read for longer, received more leftward eye movements out of the error before leaving the error to the right (regressions-out) and leftward eye movements into the error having already left the error to the right (regressions-into) compared to the orthographic errors. These results may reflect the participants' need to re-visit the semantic error more often, in an attempt to integrate the semantic error in the sentence context. These results are in line with previous research documenting that readers tend to make regressions back to earlier parts of the text (and longer fixations) during the processing of difficult texts containing anomalous words (Rayner, Warren, Juhasz, & Liversedge, 2004) or garden-path syntactic ambiguity (Frazier & Rayner, 1982).

The eye movements related to error detection indicate no overall significant difference in reading behavior between the ASD and control groups. This is consistent with the results by Howard, Liversedge, and Benson (2017), who found no differences on most eye-tracking measures. However, the control group in our study showed a greater difference in regressions-out between semantic and orthographic errors in comparison to the ASD group. This result may indicate that the ASD group exhibits less discrimination in reading behavior between the types of errors. These subtle differences in regressions-out between groups suggest that error types affected the reading behavior of the ASD group to a lesser degree. This result could reflect a weaker tendency in ASD individuals to adapt their reading to the nature of the error. These findings are in line with the study by Koolen et al. (2012) where the ASD group did not modulate their attentional effort depending on the presence of low- or high-level inconsistencies, whereas the control group did.

In summary, the validity of the present task is supported by the error condition effects found in error detection accuracy, in global eye movement measures and in error reading behavior. However, the instruction manipulation did not show any changes in behavioral responses and reading behavior. The presence of instructions could have a general alert effect on error detection, but no specific effect on changing reading behavior according to the instruction content. However, there is an indication that readers with autism may have difficulties in adapting their reading behavior to task demands. Our next experiment explores this issue specifically by manipulating the objectives of a reading task.

Chapter 4

Individuals with autism do not change reading strategies as a function of reading goals: A matter of planning

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Introduction

In the previous experiments, we have shown that highly verbal and high-functioning children and adolescents with ASD performed as well as a language-, intelligence-, and reading-skill matched control group in responding to inferential and literal questions. Nevertheless, reading behavior, measured using eye-tracking, differed between groups, indicating a possible additional effort on the part of the ASD group in reading the word that was necessary to make the inference. This suggests that individuals with ASD may adopt different reading strategies, even though they arrive at the same comprehension endpoint. In the second experiment, we explored the possibility that the differences in reading behavior could be related to different top-down modulation of reading strategies. Although they showed the same accuracy in detecting orthographic and semantic errors, they also seemed to be less responsive to instructions aimed at orienting their reading behavior. Although this experiment was useful to explore the ability of individuals with ASD to modify their reading when explicitly told to do so, it is a relatively unnatural task. In the current experiment, we further explore the differences in reading behavior between individuals with ASD and control group by manipulating the reading context in a series of more ecological reading tasks, specifically aimed at detecting the ability to adapt to different reading aims. We intend to observe if individuals with ASD adopt different reading strategies as a function of various reading goals, as would occur in real-life reading situations. We also aimed to explore which components of executive function are instrumental in adapting reading behavior.

Reading goals. Several studies have analyzed the impact of reading purposes on reading outcomes by manipulating reading context. Narvaez, van den Broek and Barron-Ruiz (1999) found that off-line and coarse online measures (reading time, recall, or answers to comprehension questions) were not influenced by the reading purpose. However, their participants had poorer online processing, as measured with inferencing thinking-aloud protocols (repetitions, acknowledgments of knowledge breaks, and evaluations), when they read for entertainment. This behavior was more pronounced during the reading of expository compared to narrative texts. Similarly, van den Broek, Lorch, Linderholm and Gustafson (2001) showed that under a study condition, readers produced more coherence-building inferences, whereas under an entertainment condition, more associations and evaluations were made. In addition, the study condition leads to better memory for the text compared to the entertainment condition.

It seems that the way different readers respond to goals is subjective. Linderholm and van den Broek (2002) showed that in a study condition, readers with low working-memory capacity produced fewer metacognitive comments and had poorer recall than high-working-memory readers, despite adopting a text-repetition strategy. In addition, Linderholm and Zhao (2008) observed that readers with poor working-memory were slower in reading and overconfident, but also more accurate in their estimates of comprehension in a study condition compared to an entertainment condition. In contrast, readers with high working-memory capacity did not differ in reading speed, accuracy and were under-confident across reading purposes. Working-memory capacity and reading goals thus seem to influence the time spent reading, which in turn mediates the degree of confidence and accuracy in comprehension.

Cain (1999) has shown that less-skilled comprehenders have less explicit knowledge about reading and reading strategies compared to skilled comprehenders of the same age, but not compared to a younger group of children of equivalent comprehension ability. However, the ability to adapt reading style to achieve different goals was poorer for the less-skilled comprehenders compared to both control groups. These results support a relationship between comprehension skills, knowledge about reading, and reading strategies.

Information centrality. Changes in reading for different purposes does not affect uniformly all reading behavior. In particular, attention to information essential for the construction of a mental model of the text (*central information)* could be allocated differently from attention to less relevant details (*peripheral information)* under different goal conditions. Irrespective of specific goals, previous studies of typical populations indicate that central information is more important than peripheral information for text understanding (e.g., Britton, Meyer, Hodge & Glynn, 1980; Brown & Smiley, 1977). Consistent with this, the *selective attention hypothesis* posits that more attention is allocated to central information, resulting in better memory for central than for peripheral information (Britton, Meyer, Simpson, Holdredge, & Curry, 1979; Goetz, Schallert, Reynolds, & Radin, 1983; Gomulicki, 1956; Meyer, 1975). Information centrality also affects reading times. In studies using the self-paced, sentence-by-sentence reading paradigm, central information was read more slowly than peripheral information (Cirilo & Foss, 1980; Britton, Muth, & Glynn, 1986), supporting the selective attention hypothesis. Later, using eye movement technology, Hyönä and Niemi (1990) report longer initial reading and more re-reading times for central compared to peripheral information.

Reading goals modulate this centrality effect. Bower (1976) and Mandler (1978) found more salient effects for central than for peripheral information in the story grammar structure. The experimental design of the present study has been inspired by recent research that explored the effect of reading goals on eye movement behavior and memory of central and peripheral information (Yeari, van den Broek, & Oudega, 2015). The authors compared the participants' reading behavior in four different reading-goal conditions: entertainment, presentation, study for a multiple-choice test, and study for an open-ended test. The variables explored were the reading time of central and peripheral information and the overall reading time of the expository texts. Results showed that centrality affected readers' early processing of the text (fixations duration), whereas reading goals influenced the subsequent processing (re-reading behavior).

The centrality effect has also been tested on atypical readers. Miller and Keenan (2009) showed that although children with word-reading deficits recalled more central than peripheral information, they showed a greater deficit relative to controls in recalling central information than peripheral information (*centrality deficit)*. However, this centrality deficit disappeared in poor decoders that were familiar with the topic of the text. The interaction of reading goals and the centrality effect, however, has not been closely studied in atypical readers.

In the present study, we explored how central and peripheral information is processed during reading and whether processing different types of information is influenced by different reading purposes in readers with ASD. We were particularly interested in applying this paradigm to a group of individuals with ASD to test the application of the *weak central coherence* theory (Frith, 1989) to the reading of long texts. During text reading, readers have to establish conceptual connections between central information in order to build a global text representation, whereas peripheral information can be locally integrated (Cirilo & Foss, 1980; Lorch & Lorch, 1986; Thorndyke, 1977, Trabasso & Sperry, 1985; van den Broek, 1988). We hypothesized that individuals with ASD would have trouble integrating central information in the global context of the text, showing disrupted reading behavior and information recall. No deficits were expected during the reading and recall of peripheral information. We also expected differences among reading goals in the reading behavior and recall in the control group, but none or less difference in the ASD group.

Executive function and reading comprehension. As we indicated above, executive function is a potential contributor to individual variability in reading, over and above word reading and oral language skills. Among the cognitive processes potentially involved in executive function (abstract reasoning, attentional control, cognitive flexibility, hypothesis generation, inhibition, response sequencing, set shifting, strategic goal planning, and use of information in working memory - Stuss & Knight, 2002), only a few have been explored in relation to reading comprehension.

One of the most extensively analyzed has been working memory (for meta-analyses, see Carretti, Borella, Cornoldi, & De Beni, 2009; Daneman & Merikle, 1996). Other less explored components of executive function related to reading comprehension include planning (Chiarenza, 1990; Cutting, Materek, Cole, Levine, & Mahone, 2009; Levin, 1990; Locascio, Mahone, Eason, & Cutting, 2010; Sesma, Mahone, Levine, Eason, & Cutting, 2009), updating (Barnes, Raghubar, Faulkner, & Denton, 2014; Iglesias-Sarmiento, López, & Rodríguez, 2015; Pelegrina, Capodieci, Carretti, & Cornoldi, 2014), inhibition (Barnes, Faulkner, Wilkinson, & Dennis, 2004; Kieffer, Vukovic, & Berry, 2013; Nouwens, Groen, & Verhoeven, 2016, Savage, Cornish, Manly, & Hollis, 2006) and cognitive flexibility (also known as well as task switching or shifting; Colé, Duncan, & Blayne, 2014; Kieffer et al., 2013). Planning and organization skills (excess moves on the Tower of London) appear to be particularly influential on reading comprehension (Cutting et al., 2009).

Although the experiment described in our previous chapter addresses indirectly the role of executive functions in reading comprehension, we did not include specific measures of general processes beyond the reading task. Here we intend to explore whether general planning, working memory, shifting, and inhibition skills are related to reading behavior and the ability to adapt to different reading goals. To our knowledge, except for the Koolen et al. group (2012, 2013, 2014) of studies that investigated reading monitoring skills in adults with ASD, no studies have examined the influence of the executive function components on reading comprehension in ASD.

Aims and hypotheses

We have shown that individuals with ASD adopt different reading strategies compared to a control group during inference generation showing to work harder to reach the same comprehension end. However, it is still unclear which cognitive functions drive this difference. In order to explore these reading differences in a controlled experimental setting, we manipulated the reading context. It is important to explore how readers adapt to different reading goals because potential poor performance in this task can be one of the causes of problems in reading comprehension. The present study aimed to explore reading behavior, using eye-tracking, under different goals conditions (entertainment, study, and skim - read fast and search information for a previously presented question). Two groups were recruited for the study, a group of highly verbal and high-functioning children and adolescents with ASD and a control group of typically developing individuals. As in the previous experiments, the group with ASD and the control group were closely matched on variables that have been observed to influence text comprehension in ASD, such as oral language skills (Norbury & Nation, 2011; Ricketts et al., 2013). In addition, we carefully matched participants for working memory skills, since Linderholm and van den Broek (2002) and Linderholm and Zhao (2008) have shown that working memory skills influence reading performance under different goals conditions.

In this study, we aimed to: 1) explore if readers with ASD are able to modulate their reading behavior in response to different reading goals, and 2) determine if general executive function skills are related to individual variability in adaptation to reading goals.

We explored the reading of: 1) multiple-choice questions; 2) entire text and 3) target sentences. For each analysis, we explored the main effect of reading goals (entertainment, study, and skim), the main effect of information centrality (central and peripheral information), the interactions between reading goal and group, reading goal and centrality,

centrality and group, and reading goal, centrality and group. Additionally, we explored the participants’ confidence in responding to the questions and in their reading performance (how well they read during study and how fast during skim). Finally, several executive function components were assessed in order to find the predictors of the participants' ability to dedicate different reading times to different reading goals.

We expected the control group to show different global and local eye movements, and confidence patterns depending on the reading goals. In particular, we expected to find in the control group longer text reading times and higher perception of confidence in responding to questions presented after under a study-aim condition, compared to both entertainment-aim and skim conditions. In contrast, we expected to find less sensitivity to different reading goals for the ASD group in any of the eye movement variables and confidence ratings. We also expected to find a relationship between the ability to plan behavior and shift attention and differences in reading behavior among goal conditions.

Method

Participants

Twenty-two native Spanish children and adolescents with a diagnosis of ASD or Asperger’s syndrome were recruited from local ASD associations. Diagnoses were confirmed by a trained psychologist, using the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). All participants met the clinical cutoff on the ADOS with a total score over seven (mean = 10.2, range = 7 – 14). A control group of twenty-two children and adolescents was recruited from local schools of middle-class neighborhoods. Both groups consisted of native Spanish monolingual speakers from Andalucía, in the South of Spain. Individuals with other developmental and acquired disorders or vision problems that impede reading were excluded from recruitment in both groups. The ASD and control samples were statistically matched on chronological age (ASD mean age = 14.7 years, *SD* = 2.9, range = 11.1 – 20.2; control group mean age = 15.1, *SD* = 2.8, range 11 – 19.6; $p = .66$), gender (ASD: 5 females; control group: 9 females, $p = .19$), verbal comprehension, perceptual reasoning, working memory, total intelligence score, grammatical structure comprehension, vocabulary size, reading speed and comprehension accuracy. The ASD group performed significantly lower in processing speed and a theory-of-mind task compared to the control group (means, standard deviations, ranges and statistical significances of differences are provided in Table 4.1).

Table 4.1

Background data of participants, with significance testing of comparison of means.

	ASD (n = 22)		Control (n = 22)		
	Mean ± SD	Range	Mean ± SD	Range	*p*
Verbal Comprehension Index	115 ± 19	68–147	114 ± 14	87-150	.71
Perceptual Reasoning Index	104 ± 19	74–134	112 ± 11	91–139	.12
Working Memory Index	105 ± 17	73–137	107 ± 17	69–140	.67
Processing Speed Index	97 ± 17	73–138	110 ± 11	92–134	.007
Total Intelligence Quotient	108 ± 18	81–145	115 ± 14	86-154	.19
PPVT-III (Standardized Scores)	108 ± 17	66–135	109 ± 10	84–120	.93
CEG (% Raw Scores)	92 ± 5	62–79	96 ± 2.5	72–80	.62

TALE Reading Speed (Words/Seconds Raw Scores)	136 ± 31	82–195	146 ± 27	106–191	.26
TALE Reading Comprehension accuracy (% Raw Scores)	59 ± 19	22–100	67 ± 17	35–100	.14
Theory of Mind (% Raw Scores)	70 ± 21.4	2–7	94.3 ± 10	5–7	< .001

Note. PPVT-III = Peabody Picture Vocabulary Test - Third Edition. CEG = Grammatical Structures Comprehension Test. TALE = Magellan Scales of Reading and Writing.

The Andalusian Regional Biomedical Research Ethics board approved the recruitment and data collection procedures. Written informed consent was obtained from participants' parents or legal representatives prior to any testing.

Background assessment

Intelligence. The Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV; Wechsler, 2005) or the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV; Wechsler, 2012), depending on the participant's age, were used to assess total intelligence scores.

*Receptive language***.** Receptive vocabulary size was measured using the Spanish version of the Peabody Picture Vocabulary Test - Third Edition (PPVT-III; Dunn, Dunn, & Arribas, 2006). Receptive grammar was assessed using the Grammatical Structures Comprehension test (CEG; Mendoza, Carballo, Muñoz, & Fresneda, 2005). The CEG test is a Spanish version of the Test for Reception of Grammar for English (TROG; Bishop, 1983). The CEG test shows a Cronbach's $\alpha = .91$. Its total scores correlate well with total scores from other tests such as PPVT-III ($r = .81$, $p < .001$), Illinois Test of Psycholinguistic Abilities (ITPA; Kirk, McCarthy, & Kirk, 1968) ($r = .64$, $p < .001$), and Digit Span from the Wechsler Intelligence Scale for Children Revised (WISC-R; Wechsler, 1999) ($r = .37$; $p = .003$).

Reading skills. Reading speed and reading comprehension were assessed using the reading fluency and reading comprehension subtests of the Magellan Scales of Reading and Writing (EMLE TALE-2000; Toro, Cervera, & Urío, 2002). The reading fluency subtest requires reading aloud one of three age-appropriate texts. Numbers and types of decoding errors and reading times were recorded, although only reading time was included in the matching analysis. Each participant, depending on their level of schooling, read one of the three texts. The reading comprehension subtest consists in reading one of the three age-appropriate texts and answering multiple-choice questions. The EMLE TALE, which has a test–retest reliability ranging from 0.76 to 0.85 for different ages, has been shown to agree with teacher ratings in the identification of poor comprehenders in 98% of the cases, and has a Kappa of .68 for overall classification of readers into poor and good comprehenders.

Theory of Mind. We measured first (*Sally-Ann* test; Baron-Cohen et al., 1985 and *Smarties* test; Perner, et al. 1989) and second order false belief tasks (*Ice-cream Van* test; Peter & Wimmer, 1985 and *Birthday Puppy* test; Sullivan et al., 1994). False beliefs were assessed using dolls by an experimenter that told and acted four stories. At the end of each story, participants were asked to answer open questions about the protagonists' actions and thoughts. Scores on this task ranged from 0 to 7.

Executive function

Tower of Hanoi. The Tower of Hanoi (ToH) task is traditionally a measure of planning, which is the ability to decide which processes are necessary to efficiently reach and complete a goal (Cartwright, 2009; Georgiou & Das, 2016) and recently it has been observed to reflect also inhibition (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000), defined as the ability to suppress automatic responses and ignore or suppress irrelevant information (Friedman & Miyake, 2004). A computerized and modified version of the ToH from Borys, Spitz and Dorans (1982) was implemented. Participants had to solve three different problems: a one peg problem (one minimum move), two pegs problem (three minimum moves) and three pegs problem (seven minimum moves). Participants read the instruction on a computer screen and started to play by moving the pegs using the mouse. Each problem had to be solved twice in order to pass to the next problem. The participants were allowed to perform a maximum of 6 attempts for each problem and up to 15 moves per problem. If the problem was solved with more moves than the minimum number, participants were told the number of moves they had made and asked to try to solve the problem in fewer moves. A score of six was given to participants who passed the first and second trials, five if they passed the second and third trials, and so on to the fifth trial. If the subject did not solve the problem on the fifth trial a score of zero was assigned. Number of moves for each problem and initial thinking time (time from the start of the problem to the time when the participant released the mouse to do the first move) were recorded.

N-Back. The N-Back task measures tap updating, i.e. the ability to replace irrelevant information with relevant information in working memory (Morris & Jones, 1990). We used the N-back task programmed by Robinson and Fuller (2004) in E-prime (Schneider et al., 2002). Participants performed a letter version of the task consisting of three levels: 1-back, 2-back, and 3-back. All consonants were used and presented in the center of the screen as stimuli in all blocks. In the 1-back task, participants had to compare the current letter with the previous one and press the “yes” key when the two subsequently presented letters were the same or the “no” key if the two letters were different. In the 2-back and 3-back tasks, participants had to compare the currently presented letter to the one presented two and three trials before, respectively. Each block had the first three trials that were always non-target and the correct response was “no.” Each stimulus stayed on the screen for 500 ms and was followed by a blank screen for 3000 ms. Participants had to respond to the stimulus within 3500 ms. Accuracy for the target and non-target were recorded and included in the statistical analyses. Each level of the task was preceded by instructions, examples that included a sequence of six letters with the corresponding correct responses, and a practice block that consisted of 20 trials (30% “yes” trials). After the practice block, a feedback of percent of correct answers was presented to the participants. An additional practice block was administered if the participant did not reach 60% on the targets. There were two experimental blocks composed of 20 trials each (30% of "yes" trials), with a total of 40 trials per level. If the participant did not achieve the accuracy of 60% on an experimental block, the task ended, in order to avoid fatigue and frustration.

Go/no-go-task. The go/no-go task version from the Maudsley Attention and Response Suppression (MARS) task battery, which assesses inhibition, was used (Rubia, et al. 2001). Participants had to respond by pressing the space bar, to a *go* stimulus (airplane) while inhibiting their response to the *no-go* stimulus (bomb). The go stimulus appeared in the 70% of the trials and the no-go stimulus in 30%. The task was divided in two blocks of 90 trials; the first block was the practice block. The inter-stimulus interval (ISI) was 1600 ms and the stimulus duration was 200 ms. The stimulus was followed by a blank screen for 1400 ms. Participants had to inhibit the response to the no-go stimulus, but respond as fast as possible to the go stimulus. Hit trials (when the participants correctly pressed the space bar in response to the go stimuli) and false alarms (when participants pressed the space bar in response to the no-go stimuli) were recorded. We used the signal detection theory in order to have a measure of the participant's sensitivity to the task (A'). A' is a nonparametric measure of sensitivity ranging from .5 (chance performance) to 1 (perfect sensitivity), calculated according to Grier (1971) using the formula:

$A' = 0.5 + (H – FA)(1 + H - FA) / [4H \times (1 – FA)]$, where H = hits probability, FA = false alarms probability. All subjects showed a mean sensitivity score higher than the chance performance, $M = .92$, $SD = .08$, range = .64 – .99. We calculated the variable d', which is a measure of the perceptual sensitivity to different stimulus conditions independent of response biases (Schultz, Fan, Magidina, Marks, Hahn, & Halperin, 2007), using the formula:

$d' = z(H) – z(FA)$, where $z(H)$ and $z(FA)$ are the conversions of the hit and false alarm measures to *z*-scores.

Wisconsin Card Sorting Test. The Wisconsin Card Sorting Test (WCST) measures cognitive flexibility, which is the ability to shift between multiple operations and mental states (Anderson, 2002; Diamond, 2013). A computerized version of the WCST from Berg (1984) was programmed using Experiment Builder (SR Research Ottawa, Ontario, Canada). The task required participants to match a series of target cards presented individually in the middle of the screen with any one of the four reference cards shown in the upper part of the screen. Participants were instructed to sort the target cards into piles under the reference cards. The sorting followed one of three criteria—color (red, green, blue, or yellow), number (one, two, three, or four), or shape (circle, cross, star, or square). Each target card appeared until a response was given, at which point participants received visual feedback (i.e., correct or incorrect appeared below the target card). The criterion stayed the same until the participant correctly performed ten consecutive sorting actions, at which point the sorting criterion changed. Participants were not initially aware that the sorting criterion would change, and they were not explicitly told the exact number of the correctly sorted cards to be achieved before the criterion shifted. The task continued until the participants completed the 128 target cards. Number of the set completed (series of 10 consecutive correct responses triggering a rule switch and reflecting efficiency in rule discovery) and percent of the perseverative errors (when participants continued with the previously correct rule, despite negative feedback, and reflecting difficulty in flexibility) were collected.

Apparatus

Stimuli were presented on an 18.5-inch monitor (41 x 23 cm) connected to a computer interfaced with an EyeLink 1000 Plus eye tracker (SR Research, Ottawa, Ontario, Canada).

The Eyelink 1000 Plus is an infrared, video-based tracking system combined with hyperacuity image processing with a spatial resolution of 0.4 degrees, and a sampling rate of 1,000 Hz. While participants' viewing was binocular, only the movements of the right eye were recorded due to a discrepancy in fixation location between the eyes (Liversedge, Rayner, White, Findlay, & McSorley, 2006). Text was presented in black, Courier New font size 18 on a light grey background. Participants were seated 55 cm from the monitor.

Materials and design

Text creation. Three expository texts in Spanish were created. The texts were between 757 and 848 words long. Texts were composed of sentences that contained either central or peripheral information and allowed participants to answer the comprehension questions. The comprehension questions, referring to the central or peripheral information in the text, were presented at the end of the text with four possible responses. The texts were: *The Great Wall of China*, *Mount Vesuvius* and *Papua New Guinea* (the entire texts and central and peripheral questions are presented in Appendix 5). The Mount Vesuvius were adapted from Yeari and colleagues (2015); additional information on the Mount Vesuvius text and The Great Wall of China and Papua New Guinea texts were obtained from Wikipedia (2016). For each text, participants responded to questions (from 12 to 14 depending on the text) about central information and questions (from 12 to 13) about peripheral information. The response options represented: (i) the correct answer; (ii) an option that was different from the correct answer in one piece of information only, (iii) an option differing in two elements, and (iiii) an option differing in all the elements. No statistical differences in word and letter length were found between the three texts on the following variables: sentences in the texts (words: all $ps > .17$; letters: all $ps > .19$), questions and possible answers (words: all $ps > .42$; letters: all $ps > .32$). No statistical differences in word and letter length were found between central and peripheral information (all *ps* > .57) and questions (all *ps* > .43). To permit the accurate analysis of eye-tracking data, the text was double-spaced. Story content required minimal emotional understanding (Bodner et al., 2015).

Norming studies. We prescreened all texts, questions, and possible answers with adults who did not participate in the main experiment. First, three trained judges assessed the information centrality for each sentence contained in the texts. The first text was divided into 42, the second into 48 and the third into 37 units that contained a main predicate, its arguments, and the adjectives and/or adverbs of these arguments (see Appendix 5). As in Yeari et al. (2015), the judges evaluated the centrality level of each information unit on a scale of 1 (least central) to 5 (most central). The judges were instructed to evaluate the information centrality taking into consideration the following two criteria: (a) the extent to which an information unit was important for the overall understanding of the text; (b) the extent to which comprehension would be impaired if the information unit was missing (e.g., Albrecht & O'Brien, 1991; Miller & Keenan, 2009; van den Broek, 1988, Yeari et al., 2015). After the text evaluation, the judges discussed their scores for each information unit and reached consensus on disagreements. The centrality score of each information unit was determined as the average of the three judges' scores (Cronbach's α = .97). Units that had the highest and the lowest judges' scores were chosen as central and peripheral information, respectively. The rest of the units were not considered in the analysis of the target sentences, but served as filler sentences. The selected central information scores were the following for the three texts, respectively: The Wall of China: *M* = 4.3, *SD* = 0.3, Mount Vesuvius: *M* = 4.6, *SD* = 0.3, and Papua New Guinea: *M* = 4.4, *SD* = 0.1. The selected peripheral information scores were, respectively: *M* = 1.4, *SD* = 0.3, *M* = 1.4, SD = 0.3, and *M* = 1.5, *SD* = 0.2. The judges' scores showed no significant differences among texts.

The distance of each possible answer from the corresponding correct answer was assessed. We presented the three texts, the questions and the possible answers to twelve adults. The correct answer for each question was highlighted and the participants were instructed to place the possible options in a descending order, from the most similar to the correct response to the least similar. When more than two participants did not order the possible response options as expected, they were modified. Seven items were modified. Seven different adults re-evaluated these items, and no changes were needed to this latest version because all the participants agreed on the order of the answers.

Design and counterbalancing. The order of presentation of the goal condition was held constant between participants. First, we presented the entertainment condition, then the study and finally the skim condition. We decided to present the entertainment condition first, because we did not want participants to be aware of the presence of comprehension questions at the end of the text. Each text was assigned either to the entertainment, study, or skim conditions in a fixed order between groups: each text was read under a given condition the same number of times in each group. The order of the questions was held constant across participants and reflected the order in which the information was presented in the text. The order of the four answer options was randomized and held constant across participants. Prior to the presentation of each of the experimental texts, participants read one practice short text that included an example of each condition. The practice texts were excluded from the final analysis.

Procedure

Standardized tests were administered in the following order to all participants: intelligence, receptive oral language, and reading abilities. Participants completed the test assessment in three (control group) or four sessions (ASD group) of one hour each on different nonconsecutive days. The test used to confirm ASD diagnoses was administered only to the ASD participants on a different day and prior to any testing. The eye-tracking experimental task was performed in a single 40-minute session on a different day. Participants were tested individually, in a quiet room either at the university laboratory, or at the local ASD association. During eye tracking, chin and forehead rests were used to minimize head movements and ensure comfort. Reading goals were introduced by following instructions that preceded the reading of each text (Table 4.2).

Table 4.2

Instructions belonging to the three reading goal conditions: Entertainment, study and skim.

Reading goal condition	Instruction
Entertainment	In this task, I want to know if you think that the following text is interesting. So, read the following text to see if you think it is **entertaining**. I hope that the text interesting for you! Have fun!
Study	In this task, I want to assess your ability to study and remember a text. So, read the following text and **study** it. At the end of the text, you will answer to questions. We are going to directly compare your score with the ones of other participants in this study, so this is like a competition. Each answer it will be scored and your accuracy in responding to the questions of the text it will be registered and evaluated. It is very important that you try to do your best. You cannot know your score during the task.
Skim (adapted from Cain, 1999)	In this task, you are going to read 2 questions and then the text. What you have to do is 1) read the text as fast as possible 2) search for the answers to the questions that you read at the beginning. At the end of the task, you have to

answer the 2 questions.

Then, participants undertook a nine-point calibration procedure, following which they looked at a fixation point in the upper-left corner of the screen and the text appeared contingent on their gaze. Subjects were asked to fixate on a fixation point prior the presentation of each screen in order to check the calibration validity. If the fixation did not meet the criteria (maximum point error < 1.5 degrees, average error < 1.0 degrees) of accuracy, the participants were recalibrated. Participants were asked to read each text silently.

Entertainment. Participants were initially shown instructions to read a text to evaluate how entertaining it could be. They were then introduced to the practice short text by a screen showing: “Let’s start with a short practice text”. After participants pressed the spacebar on the keyboard, the example text was presented on a single screen. At the end of the example text, and on the next screen, they were asked to say if they liked the text (yes or no) and to respond orally what they liked most from the text. The experimental text was then introduced by a screen showing: “Now you will continue the task with a longer text”. When ready, participants pressed the spacebar to advance to the different sections of the text (8 screens for each text), after which they said if they liked the text or not and told the experimenter three things that they liked most in the text. Then, unexpected multiple-choice four-option comprehension questions were introduced by a screen displaying: “Now you are going to answer additional questions about the text”. To pass on to the next question, they pressed the spacebar.

Study. In this condition, participants were instructed to study the text and informed that they would have to respond to questions after reading it. The practice trial was introduced and a short text was displayed on the screen. After reading the practice text, participants were asked to rate their study from 1 (*I studied the text really badly*) to 5 (*I studied the text really well*). This evaluation was introduced in order to create a delay and distraction between the text reading and the comprehension questions comparable to the entertainment condition (Cain, 1999). Participants were then asked to answer a multiple-choice four-option comprehension question. The same procedure as the practice trial was applied for the experimental text.

Skim. The skim instruction informed participants that they would be shown two questions, and that they should read as fast as possible to find the answers. They were then presented with the practice trial and a question was shown. When participants felt ready, they pressed the spacebar and they started to read the practice text containing the previously presented question. After the presentation of the text, participants had to evaluate how fast they had read the text from 1 (*I read very slowly*) to 5 (*I read very fast*). Again, this evaluation was introduced in order to create the same delay and distraction between the text reading and the comprehension questions as the entertainment condition (Cain, 1999). Then participants were required to answer the previously presented questions by choosing one of four possible responses. The same procedure as the practice trial was applied for the experimental text, but in this case, there were two questions.

At the end of the eye-tracking experiment, participants were asked to respond to a questionnaire. First, participants had to say how confident they were in responding to questions by indicating how many questions they thought to have answered correctly in the entertainment and study conditions, by choosing between the following options: none of the questions, from 1 to 5 questions, from 5 to 10 questions, from 10 to 15 questions, from 15 to 20 questions, from 15 to 24 questions or all questions. For the skim condition, they had to choose between: none of the question, one, or both questions. The participants had to indicate to what extent they thought they had read differently the three texts on a Likert scale from 1 (*I read the three texts in the same way*) to 5 (*I read the three texts very differently*).

Eye-movement data. Five global measures were reported for the entire text. The same five global eye movements were analyzed for the questions (Rayner, 1998, 2009) (see Table 1.5 for the definitions of the eye movement measures).

Next, eight local eye-movement measures were explored for the sentences in the text (central and peripheral information; Appendix 5) (Get Reading Measures, SR Research, 2015; Rayner, 1998, 2009). For all local measures, values of zero were excluded. Participants who had zero reading times on all items in one condition were excluded from the analyses. Consequently, the number of participants kept for each analysis varied for some measures (i.e., re-reading time and first pass regression) (see Table 4.3 for the goal effects, Table 4.4 for the interactions between goals and groups and Table 4.5 for the interactions between goal, group and centrality).

Table 4.3

Means (and SD) of accuracy, global and local eye movement data during the reading response questions time, the entire text, the confidence rate and the reading target sentences in the entertainment, study and skim conditions for overall conditions scores.

	Question					
	Entertainment n = 44	Study n = 44	Skim n = 44			
	Mean ± SD	Mean ± SD	Mean ± SD	*F* (2, 41)	η^2	*p*
Percent correct	68.59 ± 14.94	74.02 ± 16.16	-	17.67	0.30	$p < .001$
Reading-and-response time	14043 ± 4753	13100 ± 4151	-	6.82	0.14	$p = .01$
Total number of fixations	53.91 ± 16.84	49.99 ± 14.82	-	7.36	0.15	$p = .01$
Average fixation duration	187.05 ± 29.57	185.79 ± 33.33	-	0.22	0.01	$p = .64$

Number of forward fixations	36.15 ± 20.53	31.59 ± 32.18	-	1.99	0.05	$p = .16$
Forward saccades length	6.09 (0.84)	6.14 (1.06)	-	0.30	0.01	$p = .59$
			Text			
	Mean ± SD	Mean ± SD	Mean ± SD	F (1, 42)	η^2	p
Reading time	37785 ± 16356 [b]	49491 ± 24263 [a, c]	27243 ± 15647	29.31	0.59	$p < .001$
Total number of fixations	34.93 ± 12.23	43.98 ± 19.06 [a]	82.52 ± 35.35 [b, c]	156.42	0.88	$p < .001$
Average fixation duration	202.36 ± 29.96 [b]	207.10 ± 31.31 [a, c]	193.39 ± 35.56	14.15	0.41	$p < .001$
Number of forward fixations	14.72 ± 6.89	13.57 ± 6.52	50.06 ± 22.04 [b, c]	66.49	0.76	$p < .001$
Forward saccades length	6.33 ± 1.35	6.27 ± 1.35	6.89 ± 1.32 [b, c]	16.54	0.45	$p < .001$
			Confidence rate in question responding			

Percent	63.18 ± 21.36	68.91 ± 21.12	-		Z = -1.47	*p* = .14
			Sentence			
	Mean ± SD	Mean ± SD	Mean ± SD	*F* (2, 41)	η^2	*p*
Gaze Duration	1848 ± 143 [b]	1826 ± 121 [c]	1290 ± 110	7.60	0.27	*p* = .002
Right Bounded Duration	3223 ± 272	3767 ± 247 [a, c]	2358 ± 256	23.94	0.54	*p* < .001
Regression Path Duration	4168 ± 399 [b]	5832 ± 479 [a, c]	2966 ± 316	26.76	0.57	*p* < .001
Re-reading Duration (n = 36; *F* (2, 33))	2878 ± 467	4563 ± 625 [a, c]	1814 ± 279	8.10	0.33	*p* = .001
Total Duration	4265 ± 269 [b]	5859 ± 439 [a, c]	2970 ± 274	32.54	0.61	*p* < .001
First Pass Regression (n = 40; *F* (2, 37))	0.48 ± 0.03	0.54 ± 0.03 [c]	0.44 ± 0.03	4.33	0.19	*p* = .02

Note. n = number of participants. Text reading time and average fixation are in milliseconds; saccade length is in degree of visual angle. Means are significantly different based on Bonferroni post hoc corrections. Gaze duration, go-past time, right bounded duration, re-reading duration, total duration and first pass regression are in milliseconds. [a] = Main effect between entertainment and study. Means are significantly different based on Bonferroni post hoc corrections. [b] = main effect between entertainment and skim. [c] = main effect between study and skim.

Table 4.4

Means (and SD) of accuracy, global and local eye movement data during the reading response questions time, the entire text, the confidence rate and the reading target sentences in the entertainment, study and skim conditions for ASD and control groups.

	Question								
	Entertainment		Study		Skim				
	ASD n = 22	Control n = 22	ASD n = 22	Control n = 22	ASD n = 22	Control n = 22			
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F (2, 41)	η^2	p_1
Percent correct	69.06 ± 15.15	68.12 ± 15.08 [a]	70.87 ± 16.39	77.16 ± 15.67	-	-	3.64	0.08	$p = .06$
Reading and response time	13464 ± 4472	14623 ± 5055	13488 ± 5124	12713 ± 2952	-	-	3.40	0.08	$p = .07$
Total number of fixations	48.85 ± 14.82	58.97 ± 17.53	47.48 ± 17.67	52.51 ± 11.15	-	-	0.72	0.02	$p = .40$

Average fixations duration	184.14 ± 30.94	189.96 ± 28.56	185.22 ± 43.63	186.36 ± 19.26	-	-	0.02	0.00	*p* = .90
Number of forward fixations	36.55 ± 18.69	35.74 ± 22.65	30.24 ± 27.50	32.95 ± 36.88	-	-	0.26	0.01	*p* = .61
Forward saccade length	6.04 ± 0.90	6.15 ± 0.78	6.20 ± 1.31	6.09 ± 0.77	-	-	1.40	0.03	*p* = .24

Text

	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*F* (1, 42)	η^2	*p*
Reading time	41718 ± 20563	33852 ± 9621	49939 ± 26982	49043 ± 21839	27192 ± 19426	27294 ± 11134	3.61	0.15	*p* = .04
Total number of fixations	36.62 ± 14.99	33.23 ± 8.71	42.03 ± 19.54	45.93 ± 18.82	77.19 ± 39.40	87.84 ± 30.78	3.86	0.16	*p* = .03
Average fixations duration	205.68 ± 36.44	199.05 ± 22.06	206.61 ± 39.79	207.59 ± 20.59	196.47 ± 42.88	190.31 ± 27.03	3.18	0.13	*p* = .05
Number of forward fixations	15.33 ± 6.76	14.10 ± 7.11	13.45 ± 6.85	13.69 ± 6.33	51.90 ± 22.07	48.22 ± 22.36	0.28	0.01	*p* = .76
Forward saccade length	6.53 ± 1.65	6.15 ± 0.97	6.57 ± 1.53	5.97 ± 1.09	7.06 ± 1.37	6.72 ± 1.27	0.86	0.04	*p* = .43

Target sentence

	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*F* (2, 41)	η^2	*p*
Gaze Duration	1714 ± 203	1982 ± 203	1258 ± 171	2393 ± 171	1050 ± 156	1530 ± 156	5.61	0.22	*p* = .01
Right Bounded Duration	3107 ± 384	3339 ± 384	3213 ± 349	4321 ± 349	2249 ± 363	2466 ± 363	1.71	0.05	*p* = .32
Re-reading Duration (n = 36; *F* (2, 33)	3350 ± 678	2406 ± 641	5093 ± 908	4034 ± 859	2115 ± 405	1513 ± 383	0.44	0.03	*p* = .65
Regression Path Duration	4283 ± 564	4053 ± 564	5553 ± 677	6111 ± 677	2759 ± 447	3172 ± 447	0.32	0.02	*p* = .73
Total Duration	4396 ± 419	4134 ± 419	5490 ± 621	6228 ± 621	2884 ± 387	3055 ± 387	0.85	0.04	*p* = .43
First Pass Regression (n = 40; *F* (2, 37)	0.46 ± 0.04	0.50 ± 0.04	0.58 ± 0.04	0.50 ± 0.04	0.46 ± 0.04	0.42 ± 0.04	1.52	0.08	*p* = .23
Confidence rate in question responding									

Percent	68.64 ± 21.54	57.73 ± 20.21 [a]	66.45 ± 19.83	71.36 ± 22.52	-	-

Note. n = number of participants. Text reading time and average fixation are in milliseconds; saccade length is in degree of visual angle. Means are significantly different based on Bonferroni post hoc corrections. [a] = Main effect between entertainment and study. [b] = main effect between entertainment and skim. [c] = main effect between study and skim.

Table 4.5

Means (and SD) of accuracy, global and local eye movement data during the reading response questions time, the entire text, the confidence rate and the reading target sentences in the entertainment, study and skim conditions for the interaction between goals, relevance and groups.

	Question														
	Entertainment				Study				Skim						
	ASD	ASD	Control	Control	ASD	ASD	Control	Control	ASD	ASD	Control	Control			
	Central n = 22	Peripheral n = 22	Central n = 22	Peripheral n = 22	Central n = 22	Peripheral n = 22	Central n = 22	Peripheral n = 22	Central n = 22	Peripheral n = 22	Central n = 22	Peripheral n = 22			
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F (1, 42)	η^2	p
Percent correct	67.86 ± 16.56	64.49 ± 18.16	65.75 ± 18.23	62.81 ± 18.46	73.11 ± 17.31	68.93 ± 19.12	62.81 ± 18.46	73.92 ± 17.86	-	-	-	-	0.15	.00	$p = .70$

Reading and response time	13504 ± 4840	13486 ± 4377	13431 ± 3886	15734 ± 6501	12874 ± 4922	14114 ± 5739	12524 ± 3054	12977 ± 3039	-	-	-	-	5.13	0.11	*p* = .03
Total number of fixations	48.28 ± 15.49	49.46 ± 15.06	54.33 ± 13.72	65.54 ± 22.44	44.45 ± 14.91	50.46 ± 21.14	49.66 ± 10.21	51.40 ± 11.80	-	-	-	-	5.54	0.12	*p* = .02
Average fixations duration	187.91 ± 36.91	184.37 ± 32.37	184.86 ± 19.58	190.79 ± 28.09	182.58 ± 44.56	187.99 ± 42.58	184.85 ± 19.72	187.92 ± 19.06	-	-	-	-	2.99	0.07	*p* = .09
Number of forward fixations	34.82 ± 27.50	38.05 ± 32.21	31.71 ± 29.97	40.05 ± 31.04	30.13 ± 32.81	27.03 ± 36.02	31.68 ± 32.41	32.70 ± 42.43	-	-	-	-	0.00	0.00	*p* = .96
Forward saccade length	6.07 ± 0.90	6.01 ± 0.93	6.22 ± 0.73	6.07 ± 0.85	6.16 ± 1.28	6.24 ± 1.37	6.07 ± 0.78	6.11 ± 0.76	-	-	-	-	0.10	0.00	p = .75

	Target sentence														
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	*F* (2, 42)	η^2	*p*
Gaze Duration	1719 ± 901	1708 ± 1236	1915 ± 1105	2049 ± 1127	1260 ± 851	1256 ± 1046	2525 ± 947	2261 ± 753	1115 ± 716	985 ± 663	1594 ± 842	1466 ± 843	0.27	0.01	$p = .76$
Right Bounded Duration	3203 ± 2834	3011 ± 1804	3499 ± 1476	3179 ± 1466	3289 ± 1514	3137 ± 1882	4485 ± 1417	4157 ± 959	2353 ± 2243	2144 ± 2157	2600 ± 1171	2333 ± 1001	0.76	0.04	$p = .48$
Regression Path Duration	3903 ± 3610	4664 ± 3778	4347 ± 1944	3760 ± 1668	4969 ± 4089	6137 ± 5060	5430 ± 1975	6792 ± 3974	2935 ± 2499	2583 ± 2302	3022 ± 1410	3323 ± 2566	4.72	0.19	$p = .01$
Re-reading Duration (n = 36; *F* (2, 33)	3042 ± 3866	3658 ± 4360	2941 ± 2394	1871 ± 1332	4388 ± 4086	5797 ± 6549	2944 ± 2153	5124 ± 5166	2537 ± 2779	1694 ± 1534	1638 ± 1415	1388 ± 1466	3.89	0.19	$p = .03$
Total Duration	4646 ± 3379	4146 ± 1993	4356 ± 1403	3912 ± 1307	5983 ± 3693	4997 ± 2583	6643 ± 3078	5814 ± 2726	2999 ± 2317	2770 ± 2140	3178 ± 1423	2932 ± 1225	0.19	0.01	$p = .83$

First Pass Regression (n = 40; *F* (2, 37)	0.39 ± 0.21	0.52 ± 0.23	0.50 ± 0.24	0.49 ± 0.19	0.58 ± 0.20	0.58 ± 0.20	0.48 ± 0.23	0.53 ± 0.21	0.44 ± 0.19	0.47 ± 0.20	0.40 ± 0.22	0.44 ± 0.23	2.52	0.09	p = .09

Note. n = number of participants. Text reading time and average fixation are in milliseconds; saccade length is in degree of visual angle. Means are significantly different based on Bonferroni post hoc corrections. [a] = Main effect between entertainment and study. [b] = main effect between entertainment and skim. [c] = main effect between study and skim.

Statistical analyses. The following measures were log-transformed: from the questions only the total number of fixations; from the texts, reading time and total number of fixations; from the target sentences, gaze duration, right bounded duration, regression path duration, and re-reading duration. The eye movements' data from the questions were analyzed using 3 X 2 X 2 (Goal X Group X Centrality) mixed ANOVA. The eye movements' data from the texts were analyzed using 3 X 2 (Goal X Group) mixed ANOVA. The eye movements' data from the target sentences were analyzed using 3 X 2 X 2 (Goal X Group X Centrality) mixed ANOVA. The effect sizes were interpreted in terms of Fritz and Morris's (2012) guidelines, with values of .10, .24, and .37 representing small, medium, and large effect sizes, respectively.

Nonparametric analyses were performed for all the confidence and reading performance self-assessment values. Main effects of goal and group were assessed using the Wilcoxon Signed-Rank test, or Mann-Whitney U test, respectively. The Goal X Group interaction was probed using Wilcoxon Signed-Rank test separately for each group.

Results

Eye-movement data recording and outlier exclusion. The velocity threshold was set to 30 deg/s and the acceleration threshold to 8,000 deg/s^2 to detect saccades of 0.5 degrees of visual angle or greater. Any sample that was not in a saccade was considered to be in a fixation. Fixations less than 80 ms and longer than 800 ms were excluded from the dataset. Data from each screen were visually inspected and those containing excessive blinks or track losses were excluded from the final analyses. Outliers for each eye-movement measure (> 2.5 *SDs* below or above the subject mean for each condition) were excluded from the analyses. This resulted in the exclusion of a total of 21.1 % of the data across all analyses and did not differ across texts, goal conditions and groups.

Questions

Percent correct. It was only possible to compare the accuracy and the eye movement measures in reading and answering questions between the entertainment and the study conditions. For the skim condition, we only explored the accuracy between groups. Since only two questions were available for the skim condition, we did not compare the skim accuracy with the entertainment and study accuracy due to the different number of questions between conditions. The mixed ANOVA shows a main effect of reading goal, entertainment vs. study) for accuracy, F (2, 41) = 17.67, $p < .001$, $\eta^2 = .30$. Higher scores were observed in the questions in the study condition compared to the entertainment condition (see Table 4.3).

A main effect of centrality was observed for accuracy, F (1, 42) = 4.93, $p = .03$, $\eta^2 = .11$. Central questions showed higher accuracy compared to the peripheral questions. No Goal X Group ($p = .06$) interaction was observed. However, due to the fact that the p value is close to a significant difference, we explored the post doc analysis that showed that the control group was more accurate in responding to the questions in the study condition compared to the entertainment condition ($p < .001$). However, the ASD group showed no differences among conditions ($p = .11$). No differences were observed between groups for the entertainment ($p = .68$) and study ($p = .22$) conditions (see Table 4.4). No Goal X Centrality ($p = .81$) and Centrality X Group interactions ($p = .70$) were observed for accuracy.

Reading-and-response time. A mixed ANOVA showed a main effect of reading goal (entertainment vs. study conditions) for the response and reading time, F (2, 41) = 6.82, $p = .01$, $\eta^2 = .14$, with longer response latencies in the entertainment compared to the study condition (Table 4.3). A main effect of centrality was observed for reading-and-response time, F (1, 42) = 13.40, $p = .001$). The peripheral questions had longer reading-and-response time compared to the central questions. No Goal X Group ($p = .07$) interaction was observed.

However, again due to the fact that the p value is close to a significant difference, we explored the post doc analysis that showed that the control group was slower in reading and responding to questions in the entertainment condition compared to questions in the study condition (p = .003). However, the ASD group showed no differences among conditions (p = .59). No differences were observed between groups for the entertainment (p = .40) and study (p = .86) conditions (see Table 4.4). No Goal X Centrality (p = .84) and Centrality X Group (p = .30) interactions were observed for response time. A Goal X Centrality X Group interaction was observed for reading and response latencies, F (1, 42) = 5.13, p = .03, η^2 = .11. Within the peripheral questions, only the control group responded faster to the questions in the study compared to the ones in the entertainment condition (p = .002). No differences were found between groups for the centrality and goals conditions (all ps > .15) or between goal conditions for centrality conditions and groups (all ps > .12) (see Table 4.5).

Total number of fixations. A mixed ANOVA indicated a main effect of reading goal (entertainment vs. study) for the total number of fixations, F (2, 41) = 7.36, p = .01, η^2 = .15. More fixations were observed in the entertainment condition compared to the study condition (see Table 4.3). A main effect of centrality was observed for the total number of fixations, F (1, 42) = 17.77, p < .001. The peripheral questions received more fixations compared to the central questions. No Goal X Group (p = .40), Goal X Centrality (p = .64) and Centrality X Group (p = .52) interactions were observed for total number of fixations. A Goal X Group X Centrality interaction was observed for total number of fixations, F (1, 42) = 5.54, p = .02, η^2 = .12. Within the central information, the ASD group showed more fixations in the questions in the entertainment condition compared to the questions in the study condition (p = .05). Within the peripheral information in the entertainment condition, the control group showed more fixations compared to the ASD group (p = .01) and the control group showed more fixations in the entertainment condition compared to the study condition (p = .01), but this was not the case for the ASD group. No other differences between goals for centrality and groups (all *p*s > .12) or between groups for centrality and goal conditions (all *p*s > .12) were observed (see Table 4.5).

Average fixations duration. No main effects of reading goal (p = .64) or centrality (p = .10) were observed for average fixations duration. No Goal X Group (p = .90), Goal X Centrality (p = .38), Centrality X Group (p = .27) and Goal X Group X Centrality (p = .09) interactions were observed for average fixations duration.

Number of forward fixations. No main effect of reading goal (p = .17) and centrality (p = .56) was observed for the number of forward fixations. No Goal X Group (p = .61), Goal X Centrality (p = .50), Centrality X Group (p = .57) and Goal X Group X Centrality (p = .96) interactions were observed for the number of forward fixations.

Forward saccades length. No main effect of reading goal (p = .59) and centrality (p = .50) were observed for forward saccades length. No Goal X Group interaction (p = .24) was observed for forward saccades length. A Goal X Centrality interaction was observed for forward saccades length, F (1, 42) = 6.32, p = .02, η^2 = .13. In the entertainment condition, the central questions had longer saccade length compared to the peripheral questions (p = .04). No differences between central and peripheral questions for the study condition (p = .18) or between entertainment and study conditions according to the information centrality (all *ps* > .20) were observed. No Centrality X Group (p = .30) and Goal X Group X Centrality (p = .75) interactions were observed for forward saccades length.

Texts

Reading time. A main effect of reading goal condition was observed for the reading time, F (1, 42) = 29.31, p < .001, η^2 = .59. The study condition showed longer reading time compared to both, the entertainment and skim conditions (all *ps* < .001) (see Table 4.3). No differences between groups were observed (p = .97). A Goal X Group interaction was observed for reading time, F (1,42) = 3.61, p = .04, η^2 = .15. Post hoc analyses showed that both groups read faster the text in the skim condition compared to both the text in the entertainment (all *ps* < .001) and study (ASD: p < .001; Controls p = .01) conditions. Only the control group also read the study text for longer than the entertainment text (p < .001) (see Table 4.4). All other comparisons, which involved the entertainment condition, were non-significant in both groups (all *p*s > .15). No differences were shown between groups across goal and centrality conditions (all *ps* > .11).

Total number of fixations. A main effect of reading goal condition was observed for the total number of fixations, F (1, 42) = 156.42, p < .001, η^2 = .88. More fixations were observed in the study condition compared to the entertainment condition. The skim condition received more fixations compared to both, the entertainment and the study conditions (see Table 4.3). A Goal X Group interaction was observed for total number of fixations, F (1, 42) = 3.86, p = .03, η^2 = .16. Post hoc analyses showed that in the control group, the text in the study condition received more fixations compared to the text in the entertainment condition (p = .001). This was not the case for the ASD group (p = .30). In addition, more fixations were observed for the text in the entertainment condition compared to the text in the skim condition in both ASD (p < .001) and control (p = .01) groups. More fixations were observed for the text in the study condition compared to the text in the skim condition for both ASD (p

< .001) and control (*p* < .001) groups (see Table 4.4 and Figure 4.1). No differences were observed between groups according to the reading goals (all *ps* > .20).

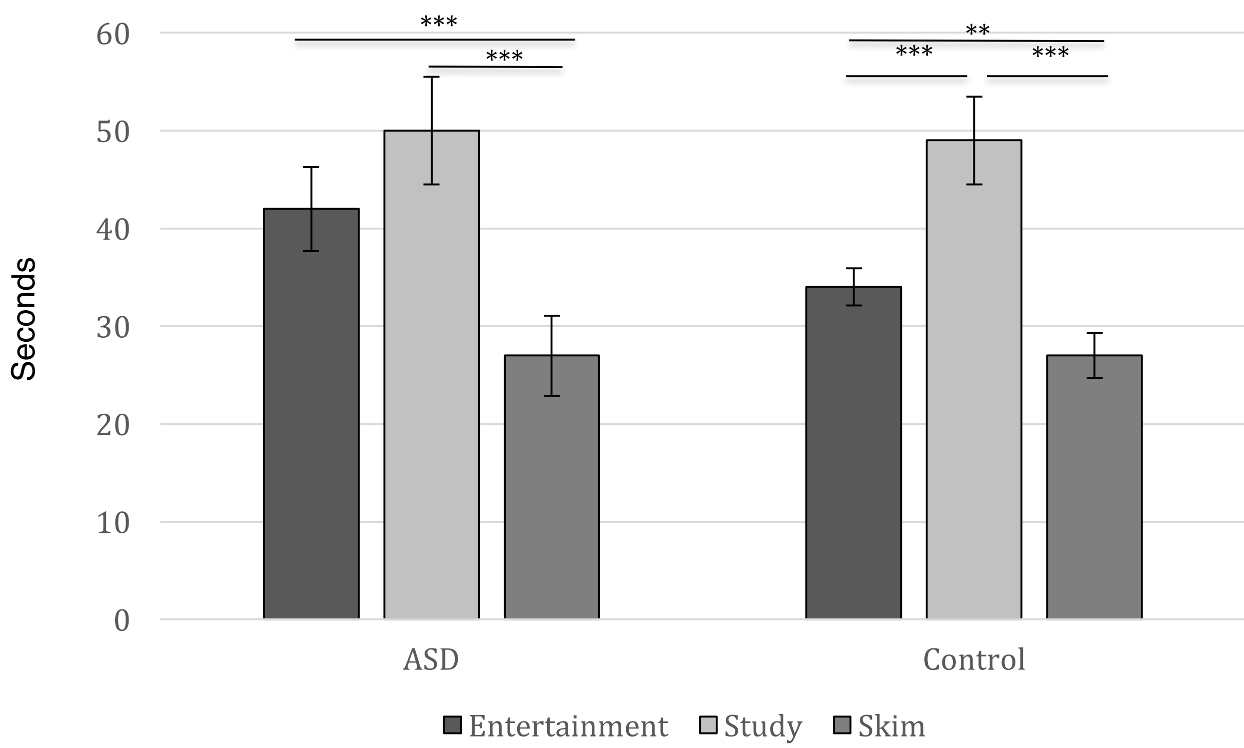


Figure 4.1. Difference between reading goals in reading time of the texts for the ASD and the control groups. Error bars indicate standard errors. *** $p < .001$. ** $p < .01$.

Average fixations duration. A main effect of reading goal condition was observed for average fixations duration, F (1, 42) = 14.15, $p < .001$, $\eta^2 = .41$. The study condition showed longer fixations compared to both the entertainment and skim conditions. The entertainment condition showed longer fixations compared to the skim (see Table 4.3). A Goal X Group interaction was observed for average fixation duration, F (1, 42) = 3.18, $p = .05$, $\eta^2 = .13$. Post hoc analyses showed that in the control group, the text in the study condition received longer fixations ($p = .02$) compared to the text in the entertainment condition. This was not the case for the ASD group ($p = 1$). Longer fixations were observed for the text in the study condition compared to the text in the skim condition for both ASD ($p = .05$) and control ($p < .001$) groups. No differences were observed for either group (ASD: $p = .13$, Controls $p = .16$) between the entertainment and the skim conditions (see Table 4.4 and Figure 4.1).

Number of forward fixations. A main effect of reading goal condition was observed for the number of forward fixations, F (1, 42) = 66.49, $p < .001$, $\eta^2 = .76$. The skim condition received more forward fixations compared to both the entertainment and the study conditions (see Table 4.3). No Goal X Group interaction ($p = .76$) was observed for the number of forward fixations.

Forward saccades length. A main effect of reading goal condition was observed for the forward saccades length, F (1, 42) = 16.54, $p < .001$, $\eta^2 = .45$. The skim condition received longer saccades compared to both, the entertainment and the study conditions (see Table 4.3). No Goal X Group interaction ($p = .43$) was observed for forward saccades length.

Target Sentences

Gaze duration. A main effect of reading goal was observed for the gaze duration, F (2, 41) = 7.60, $p = .002$, $\eta^2 = .27$. The sentences in the entertainment condition received longer gaze duration compared to the skim condition. The sentences in the study condition received longer gaze duration compared to the skim condition (see Table 4.3). No main effect of centrality was observed for gaze duration ($p = .17$). A Goal X Group interaction was found for gaze duration, F (2, 41) = 5.61, $p = .01$, $\eta^2 = .22$. The ASD group exhibited longer gaze duration in the entertainment condition compared to the skim condition ($p = .01$). The control group showed longer gaze duration in the study condition compared to the skim condition ($p = .002$), but the ASD group did not ($p = .06$). No differences were observed for the entertainment condition compared to the study in either the ASD ($p = .06$) or the control groups ($p = .07$). In the study and the skim conditions, the control group made longer gaze duration compared to the ASD group ($p < .001$, and $p = .02$, respectively) (see Table 4.4). No Goal X Centrality ($p = .24$), Centrality X Group ($p = .48$) and Goal X Group X Centrality ($p = .76$) interactions were observed for gaze duration.

Right Bounded Duration. A main effect of reading goal was observed for the right bounded duration, F (2, 41) = 23.94, $p < .001$, $\eta^2 = .54$. The sentences in the study condition received longer right bounded compared to the sentences in the entertainment condition. The sentences in the study condition received longer right bounded duration compared to the skim condition (see Table 4.3). No main effect of centrality was observed for right bounded duration ($p = .11$). No Goal X Group ($p = .32$), Goal X Centrality ($p = .30$), Centrality X Group ($p = .27$) and Goal X Group X Centrality ($p = .48$) interactions were observed for right bounded duration.

Regression Path Duration. A main effect of reading goal was observed for regression path duration, F (2, 41) = 26.76, $p < .001$, $\eta^2 = .57$. The sentences in the study condition received longer regression paths compared to the sentences in the entertainment condition. The sentences in the study condition had longer regression paths compared to the skim condition and the sentence in the entertainment condition had longer regression path compared to the sentences in the skim condition (see Table 4.3). No main effect of centrality was observed for the regression path duration ($p = .21$). No Goal X Group ($p = .73$), Goal X Centrality ($p = .09$), Centrality X Group ($p = .32$) interactions were observed for regression path duration. A Goal X Centrality X Group interaction was observed for regression path duration in the sentences, F (2, 41) = 4.72, $p = .01$, $\eta^2 = .19$. Within the central information, the ASD group showed longer regression path for the sentences in the study condition compared to the sentences in the skim condition ($p < .001$). Within the peripheral information, the ASD group showed shorter regression paths for the sentences in the skim condition compared to both the sentences in the entertainment condition (p = .001) and the sentences in the study condition (p < .001). Within the central information, the control group showed shorter regression path for the sentences in the skim condition compared to both the sentence in the entertainment condition (p = .05) and the sentences in the study condition (p < .001). Within the peripheral information, the control group showed longer regressions path for the sentences in the study condition compared to the sentence in the entertainment condition (p = .01), but no differences were shown in the ASD group (p = .26). Within the peripheral information, the control group showed also longer regression path for the sentences in the study condition compared to the sentences in the skim condition (p < .001) (see Table 4.4). Within the central information, no differences were found between the entertainment and the study condition for either the ASD (p = .15) or the control (p = .19) groups and between entertainment and skim condition only for the ASD group (p = .23). Within the peripheral information, no differences were observed between the entertainment and the skim condition in the control group (p = .41). No differences were shown between groups according to the goal and centrality conditions (all *ps* > .11).

Re-reading Duration. A main effect of reading goal was observed for re-reading duration, F (2, 41) = 8.10, p = .001, η^2 = .33. The sentences in the study condition received longer re-reading compared to the sentences in the entertainment condition. The sentences in the study condition received longer re-reading compared to the skim condition (see Table 4.3). No main effect of centrality was observed for re-reading duration (p = .80). No Goal X Group interaction was observed for re-reading duration (p = .65). A Goal X Centrality interaction was found for re-reading duration, F (2, 33) = 4.00, p = .03, η^2 = .20. Post hoc analyses showed that within the central information, the study condition had longer re-reading compared to the skim condition (p = .04). Within the peripheral information, the study condition showed longer re-reading duration compared to the entertainment (p = .003) and the skim condition (p > .001). In addition, longer re-reading duration was found in the entertainment condition compared to the skim condition (p = .02). No Centrality X Group interaction was observed for re-reading duration (p = .67). A Goal X Group X Centrality interaction was observed for re-reading duration, F (2, 41) = 3.39, p = .03, η^2 = .19. Within the central information, the ASD group showed longer re-reading in the sentences in the study condition compared to the sentences in the skim condition (p = .01). Within the peripheral information, the control group showed longer re-reading in the sentences in the study condition compared to both, the sentences in the entertainment condition (p = .02) and the sentences in the skim condition (p = .01) (see Table 4.5).

Total Duration. A main effect of reading goal was observed for the total duration, F (2, 41) = 32.54, p < .001, η^2 = .61. The sentences in the study condition received longer gaze compared to the sentences in the entertainment condition. The sentences in the entertainment and in the study conditions received longer gaze compared to the skim condition (see Table 4.3). A main effect of centrality was observed for total gaze duration, F (2, 41) = 19.67, p < .001, η^2 = .32. The central information received longer gaze duration compared to the peripheral information. No Goal X Group (p = .43), Goal X Centrality (p = .24), Centrality X Group (p = .84) and Goal X Centrality X Group (p = .83) interactions were observed for total duration.

First Pass Regression. A main effect of reading goal was observed for the first pass regression, F (2, 41) = 4.33, p = .02, η^2 = .19. The sentences in the study condition received longer first pass regressions compared to the skim condition (see Table 4.3). No main effect of centrality was observed for the first pass regression (p = .13). No Goal X Group (p = .23), Goal X Centrality (p = .84), Centrality X Group (p = .62), Goal X Centrality X Group (p = .09) interactions were observed for first pass regression.

Results' summary

Questions

Reading goal conditions (entertainment, study and skim) had a quite consistent impact through the results. A main effect of goal was observed in accuracy, reading-and-response time and total number of fixations for the questions.

A main effect of centrality (central vs. peripheral information) was observed mainly in the behavioral responses and reading behavior for questions (i.e., accuracy, reading-and-response time, and total number of fixations).

Goal X Group interactions were observed in the accuracy and reading-and-response time for questions. We observed that the control group tended to respond more accurately and to be faster in responding to questions in the study condition compared to questions in the entertainment condition, but neither result reached significance.

Goal X Centrality interactions were observed only for the forward saccade length of questions. In the entertainment condition, the central questions had longer saccade length compared to the peripheral questions.

Finally, Goal X Centrality X Group interactions were observed for the questions (i.e., reading-and-response time and total number of fixations). Mainly we observed subtle differences in reading behavior between the goal conditions. These differences differed between groups and centrality condition (possible explanation of these results are given in the Discussion session).

Text

A main effect of goal was observed for reading time, total number of fixations, average fixation duration, number of forward fixations and forward saccade length for the texts. Texts in the study condition were generally read longer compared to the texts in the entertainment and skim conditions and the texts in the entertainment condition were generally processed longer compared to the skimmed texts. In general, when participants studied the text, they also tended to answer more correctly compared to the questions in the entertainment condition.

No main effect of centrality was observed for the texts.

Goal X Group interactions were observed in the gaze behavior during reading texts (i.e., reading time, total number of fixations and average fixation duration). The control group read slower and did more and longer fixations in the texts within the texts in the study condition compared to the texts in the entertainment condition. These differences in the processing of the study and entertainment texts were not observed in the ASD group for any of the eye movement measures.

We did not find any Goal X Centrality interactions.

Target Sentences

A main effect of goal was observed for all eye movement measures for the target sentences. Target sentences in the study condition were generally read longer compared to the texts in the entertainment

For the target sentences we had a main effect of centrality for total duration. Participants were more accurate in responding to the central questions and had longer gaze duration in the target sentences containing central information, but read longer and did more fixations during the reading and responding of the peripheral questions.

Goal X Group interactions were observed in the target sentences (i.e., gaze duration). The control group read slower and did more and longer fixations in the target sentences within the texts in the study condition compared to the texts in the entertainment condition. These differences in the processing of the study and entertainment texts were not observed in the ASD group for any of the eye movement measures.

We did not find Goal X Centrality interactions.

Finally, Goal X Centrality X Group interactions were observed for the target sentences (i.e., regression path duration and re-reading duration). Mainly we observed subtle differences in reading behavior between the goal conditions. These differences differed between groups and centrality condition (possible explanation of these results are given in the Discussion session).

Confidence and reading performance self-assessment

Confidence rate in question responding. We compared the confidence rate (how many questions participants thought they had answered correctly) from the entertainment and the study conditions, since in the skim condition only two questions were available. No differences between conditions (p = 0.8) and groups (p = .83) were observed. The Wilcoxon Signed-Ranks Test run separately for each group indicated that the control group perceived to have scored significantly less in the entertainment condition compared to the study condition (p = .01). However, confidence ratings in the ASD group were not different between goals (p = .61).

Correlation analyses showed that, in the control group, accuracy and confidence rate were correlated in both, the entertainment p = .02, r = .50, and in the study condition, p = .001, r = .65. However, correlations were not significant for the ASD group (entertainment, p = .67; study, p = .79).

Reading performance Likert scale. We compared the confidence rate for reading performance in the study condition (*how well did you study?)* and the skim condition (*how fast did you read?),* because, in the entertainment condition, text was simply judged for pleasure. Analysis indicated no differences between the study and skim conditions (Study: 3.59 ± 0.78, Skim: 3.76 ± 0.82, p = .30) or groups (p = .15). No differences were observed between groups and within conditions (ASD, Study: 3.60 ± 0.89, Skim: 3.90 ± 0.83; Controls, Study: 3.59 ± 0.68, Skim: 3.61 ± 0.80, p = .23).

Enjoyability of the entertainment texts. No differences between groups (ASD: 16 yes, 5 no, 1 no answer; Controls: 21 yes, 1 no) were observed in the enjoyability of the entertainment texts (p = .07).

Executive function

Statistical analyses. Only the initial thinking time of the ToH was log-transformed and analyzed using a one–way repeated measure ANOVA. The other executive function measures were analyzed using nonparametric analyses. Main effects of conditions (different depending on the task) or group were assessed using Wilcoxon Signed Rank Test and Mann-Whitney U test, respectively.

Tower of Hanoi. A Wilcoxon Signed Rank Test revealed no significant difference (p = .31) in the 6 to 0 scores assigned to the performance of the one peg problems (M = 5.75, SD = .44) compared to the three pegs problems (M = 5.57, SD = 1.04). Significant differences in performance scores were observed between the one peg problems and the seven pegs problems (M = 2.91, SD = 2.35), z = -5.12, p < .001, with a large effect size, r = .77, and between the three pegs problems and the seven pegs problems, z = -5.10, p < .001, with a large effect size, *r* = .77; participants made more movements in the seven pegs problems compared to the one and three peg problems. A Mann-Whitney U Test revealed no significant differences between groups in any of the pegs problems (one peg problems: ASD, *n* = 22, *M* = 5.73, *SD* = .46; controls, *n* = 22, *M* = 5.77, *SD* = .43, *p* = .73; three pegs problems: ASD, *M* = 5.36, *SD* = 1.36; controls, *M* = 5.77, *SD* = .53, *p* = .27; seven pegs problems: ASD, *M* = 2.45, *SD* = 2.43; controls, *M* = 3.36, *SD* = 2.24, *p* = .23). A one–way repeated measures ANOVA showed a main effect of pegs problem for the initial thinking time, F (2, 40) = 11.62, $p < .001$, $\eta^2 = .37$, where one peg problem (*M* = 2691 ms, *SD* = 1002) had longer initial thinking times compared to three pegs problem (*M* = 2317 ms, *SD* = 1429, *p* = .01), and seven pegs problem (*M* = 3577 ms, *SD* = 2276) which had longer initial thinking times compared to the three pegs problem (*p* < .001). No difference was found between the three pegs problem and the seven pegs problem (*p* = .14). No main effect of group was observed for the pegs problem (one peg problem: ASD, *n* = 21, *M* = 2846 ms, *SD* = 1033 ms; controls, *n* = 22, *M* = 2544 ms, *SD* = 973, three pegs problem: ASD, *M* = 2401 ms, *SD* = 1440; controls, *M* = 2238 ms, *SD* = 1449, seven pegs problem: ASD, *M* = 3675 ms, *SD* = 2292; controls, *M* = 3484 ms, *SD* = 2311, *p* = .47) and no interaction between group and pegs problem (*p* = .93).

N-Back. A Wilcoxon Signed-Rank test showed a significant difference between the non-target and target accuracy (*n* = 37, *z* = -5.27, *p* < .001, with a large effect size, *r* = .87, non-target: *M* = 90.32%, *SD* = 13.38, target: *M* = 59.14%, *SD* = 14.55). Participants were more accurate in responding to the target compared to the non-target trials. A Mann-Whitney U Test revealed significant difference between groups in the non-target accuracy, *z* = -3.38, *p* < .001, with a large effect size, *r* = .55. The control group (*n* = 20, *M* = 95.91%, *SD* = 7.32) had better performance compared to the ASD group (*n* = 17, *M* = 87.74%, *SD* = 15.95). A significant difference between groups was observed also for the target accuracy, *z* = -2.61, *p* = .01, with a large effect size, *r* = .43. Control group (*n* = 20, *M* = 64.48%, *SD* = 10.74) had better performance compared to the ASD group (*n* = 17, *M* = 52.84%, *SD* = 16.18).

Go/no-go task. A Mann-Whitney U Test revealed no significant difference between groups in the hit trials (*p* = .41, ASD group, *n* = 22, *M* = 66.94%, *SD* = 4.02; controls, *n* = 22, *M* = 67.32%, *SD* = 5.98). A significant difference between groups was observed for false alarms, *z* = -2.70, *p* = .01, with a large effect size, *r* = .41, where the ASD group (*n* = 22, *M* = 28.03%, *SD* = 17.04) had more false alarms compared to the control group (*n* = 22, *M* = 15.66%, *SD* = 14.35).

Wisconsin Card Sorting Test. A Mann-Whitney U Test revealed a significant difference between groups in the number of set completed (*z* = -2.47, *p* = .01, with a large effect size, *r* = .38. The ASD group, *n* = 22, *M* = 6.52, *SD* = 2.82, completed less sets compared to the control group, *n* = 21, *M* = 8.55, *SD* = 2.11. No significant difference between groups was observed for the percentage of perseverative errors, *p* = .09, ASD group: *M* = 5.51, *SD* = 3.62, control group, *M* = 3.80, *SD* = 2.12.

Executive function combined scores. Executive function scores confirmed results from Wilson et al. (2014) that show lower performance in the Go/no-Go task compared to the typical population. Our participants with ASD found more difficulties in the N-Back task and WCST compared to typically developing individuals, differently from what found by Koshino et al. (2005) and Williams, Goldstein, Carpenter for the N-Back task and from Minshew (2005), and Landry and Al-Taie (2016) for the WCST, where similar performance in the tasks are described for ASD and control groups. No difference in ToH performance between groups as in Kiep and Spek (2017) were observed. However, we were not particularly interested in discussing the differences in performing the task, but we aimed to explore which of the executive function components could play a role in modulating readers behavior in response to the different goals.

We converted the executive function scores to *z* scores aggregated across tests in order to minimize the number of statistical comparisons of relationships between executive function tasks performance and reading times. We took the *z* scores of the whole sample for each test measure. In the ToH, we subtracted the *z* scores of the initial thinking time to the *z* scores of the number of moves for the problems 3 and 7, because of the opposite direction of the scores: higher score in initial thinking time means more time took to plan, but more moves mean worst performance. We then summed the two products producing the combined score. In the N-Back task, the combined score was created by summing all the accuracy *z* scores from all levels. For the Go/no-go task, the d' score was included in the regression analysis. Finally, in the WCST; the *z* score from the set completed was subtracted from the *z* score of the perseverative errors. Across all groups, the Cronbach's alpha for the executive function tests within each domain was .44 for the ToH, .89 for the WCST, .67 for the N-Back and .46 for the Go/no-go task. Although rather low, these internal consistency values are comparable with those generally found in studies using executive function tasks (Burgess, 1997).

Difference between study and entertainment text reading time. The difference between the reading times of the study text was subtracted to the reading times of the entertainment text. A standard regression was employed to determine if addition of information regarding executive function (ToH, WCST, N-Back, and Go/No-Go) improved prediction of reading time difference between study and entertainment conditions. Tables 4.6, 4.7, 4.8, 4.9 and

Figures 4.2, 4.3, display the correlations between the variables, the standardized regression coefficients (β), $R^{2,}$ after entry of all executive function scores. With all executive function scores in the equation, n = 36, R^2 = .13 with 95% confidence limits from .30 to .44, F (4, 31) = 1.24, p = .31 (Model 1). Because ToH was the only close to significant predictor (p = .06), we repeated the regression with only this variable, n= 43, R^2 = .15 with 95% confidence limits from .30 to .44, F (1, 41) = 7.77, p = .008 (Model 2). This pattern of results suggests that differences in reading times between study and entertainment are marginally predicted by ToH scores.

We replicated the analysis without two participants, one of each group, because their z scores in ToH were 2.5 SDs above the group mean. With only ToH scores in the model, the regression still suggests that differences in reading times between study and entertainment are predicted by ToH scores, n= 41, R^2 = .07 with 95% confidence limits from .30 to .44, F (1, 39) = 3.99, p = .05 (Model 2).

Difference between study and skim text reading time. The difference between the reading times of the study text was subtracted from the reading times of the skim text. A standard regression was employed to determine if addition of information regarding executive function (ToH, WCST, N-Back, and Go/No-Go) improved prediction of reading time difference between study and skim conditions. Tables 4.6, 4.7, 4.8, 4.9 and Figures 4.2, 4.3, display the correlations between the variables, the standardized regression coefficients (β), R^2, after entry of all executive function scores. With all executive function scores in the equation, n= 36, R^2 = .14 with 95% confidence limits from .30 to .44, F (4, 31) = 1.27, p = .30 (Model 1). Because ToH was the only significant predictor (p = .04), we repeated the regression with only this variable, n= 43, R^2 = .16 with 95% confidence limits from .30 to

.44, *F* (1, 41) = 8.13, *p* = .007 (Model 2). This pattern of results suggests that differences in reading times between study and skim are predicted by ToH scores.

We replicated the analysis without two participants, one of each group, because their *z* scores in ToH were 2.5 SDs above the group mean. In this regression model, the ToH scores did not influence the differences in reading times between study and skim, n= 41, R^2 = .05 with 95% confidence limits from .30 to .44, *F* (1, 39) = 2.27, *p* = .13 (Model 2).

Difference between entertainment and skim text reading time. The difference between the reading times of the entertainment text were subtracted to the reading times of the skim text. Standard regression was employed to determine if addition of information regarding executive function (ToH, WCST, N-Back, and Go/No-Go) improved prediction of reading time difference between entertainment and skim conditions. Tables 4.6, 4.7, 4.8, 4.9 and Figures 4.2, 4.3, display the correlations between the variables, the standardized regression coefficients (β), R^2, after entry of all executive function scores. With all executive function scores in the equation, n = 36, R^2 = .11 with 95% confidence limits from .30 to .44, *F* (4, 31) = .99, *p* = .42 (Model 1). In this regression model, ToH was not a significant predictor.

Table 4.6

Correlations among the executive function.

	1	2	3	4
Tower of Hanoi	-			
Wisconsin Card Sorting Test	-.22	-		
N-Back	-.38*	.09	-	
Go/No-Go	-.09	.22	.43**	-

Note. *p < .05 **p < .01

Table 4.7

Correlations among the differences between conditions text reading time.

	1	2	3
Difference between study and entertainment text reading time	-		
Difference between study and skim text reading time	.70***	-	
Difference between entertainment and skim text reading time	-.14	.59***	-

Note. *p < .05 **p < .01 ***p < .001

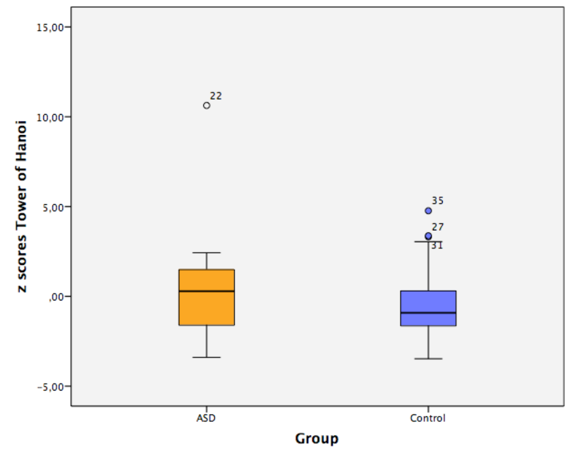
Table 4.8

Correlations among the differences between the reading times and executive function.

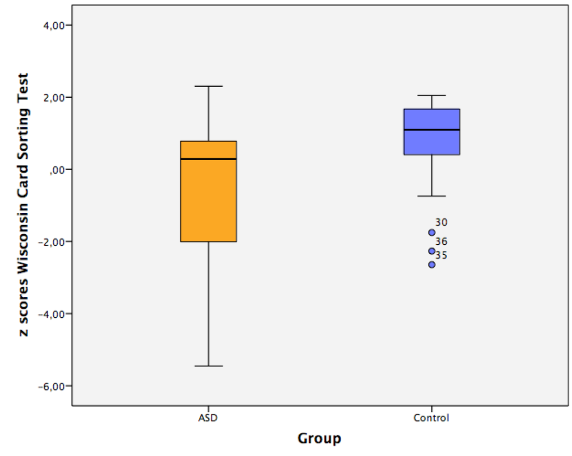
	Difference between study and entertainment text reading time	Difference between study and skim text reading time	Difference between entertainment and skim text reading time
Tower of Hanoi	-.39**	-.40**	-.12
Wisconsin Card Sorting Test	.16	-.01	-.23
N-Back	.18	-.00	-.20
Go/No-Go	.12	.05	-.06

Note. *p < .05 **p < .01

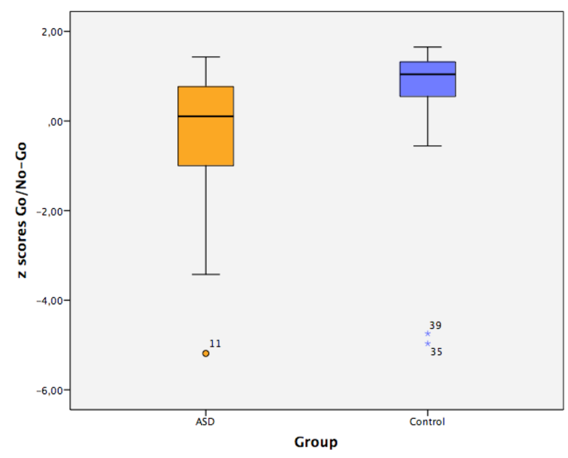
(a)



(b)



(c)



(d)

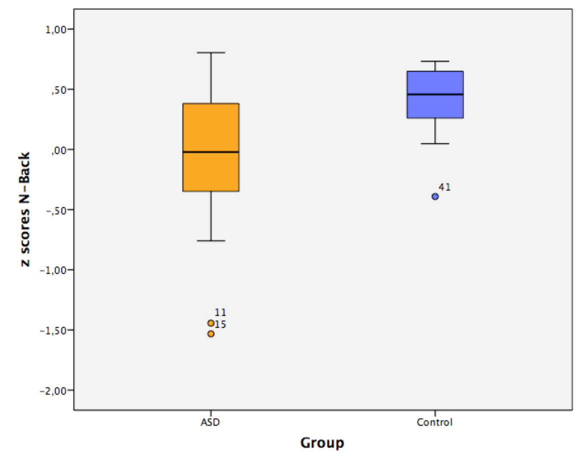
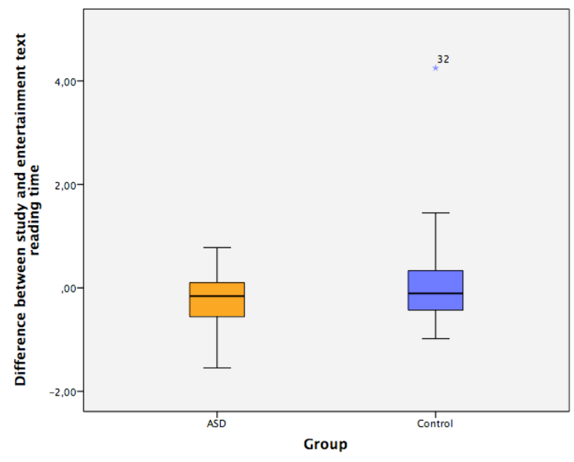
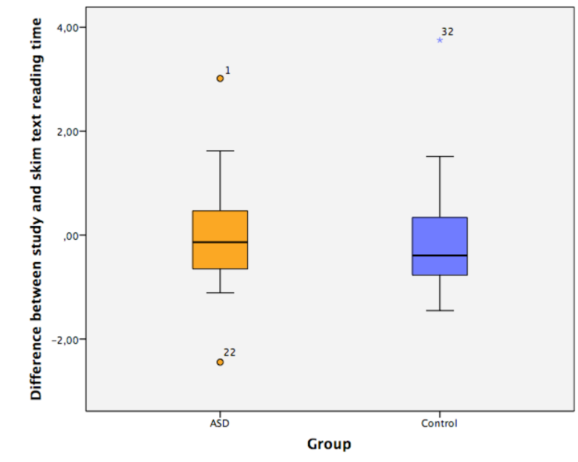


Figure 4.2. Boxplots showing the distribution of (a) Tower of Hanoi, (b) Wisconsin Card Sorting Test, (c) N-Back, and (d) Go/No-Go, for each group, of all participants (n = 43).

(a)



(b)



(c)

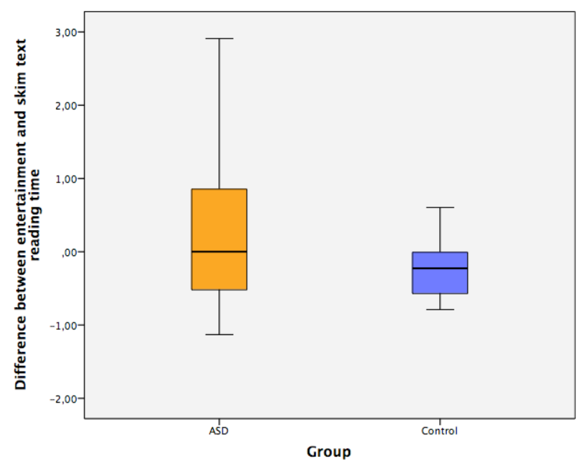


Figure 4.3. Boxplots showing the distributions of the differences between study and entertainment text reading time (a), the differences between study and skim text reading time (b), and the differences between entertainment and skim reading time (c), for each group.

Table 4.9

Standard and sequential regressions of executive function scores on difference between the reading times.

Variable	β	F	R^2
	Difference between study and entertainment text reading time		
Model 1			
Tower of Hanoi	-.35		
Wisconsin Card Sorting Test	.03		
N-Back	-.06		
Go/No-Go	.17	1.24	.13
Model 2			
Tower of Hanoi	-.39	7.77**	.15
	Difference between study and skim text reading time		
Model 1			
Tower of Hanoi	-.37		
Wisconsin Card Sorting Test	-.13		
N-Back	-.17		
Go/No-Go	.17	1.27	.14
Model 2			
Tower of Hanoi	-.40	8.13**	.16
	Difference between entertainment and skim text reading time		
Model 1			

Tower of Hanoi	-.15		
Wisconsin Card Sorting Test	-.27		
N-Back	-.20		
Go/No-Go	.06	.99	.11
Model 2			
Tower of Hanoi	-.12	.59	.01

Note. *p < .05 **p < .01.

Discussion

Questions

Accuracy

Accuracy was higher in the study condition compared to the entertainment condition. These results are in line with van den Broek et al. (2001), but not with Narvaez et al. (1999), who did not find any difference in reading time, recall, or accuracy in responding to comprehension questions as a function of reading purpose. This could be due to the different methodology (in Narvaez et al. study: thinking aloud vs. silent reading in our study) and time between text reading and recall (after one week vs. immediate).

In line with Britton et al. (1980), Brown and Smiley (1977) and Yeari et al. (2015), the accuracy for central questions was higher than for peripheral questions. These results can be interpreted in light of the selection attention hypothesis, which claims that subjects tend to allocate more attention on central information, which in turn results in better retention (Britton, et al.1979; Goetz et al., 1956; Meyer, 1975).

Our results also showed a marginally significant interaction for accuracy between reading goal and group (p = .06). The control group responded more accurately to the questions in the study condition than in the entertainment condition, which would indicate that the longer time they had spent reading the text lead to more accurate recall (Linderholm & Zhao, 2008). This was not the case for the ASD group: the lack of reading-goal modulation might have led to no differences in accuracy between goals. This result cannot be attributed to working memory impairments, as in the Linderholm & van den Broek (2002) and Linderholm and Zhao (2008) studies, since our two groups were carefully matched on working memory.

In the skim condition, we found no differences in accuracy between the control and the ASD groups, suggesting that knowledge of the information to look for by previously reading the question, could be beneficial for all participants. However, the small number of questions in the skim condition, and the contrast with Cain (1999) —she found that less skilled comprehenders were slightly poorer in finding the answers in a text— call for caution in the interpretation of this finding.

Eye movements

Participants were faster and showed fewer fixations while reading and responding to questions in the study than in the entertainment condition. They probably found the text representation under the study condition more accessible in their memory, and therefore the questions easier to respond to.

Participants read differently questions depending on their relevance to understanding the text. Questions about central information that were judged to be essential for the understanding of the text were associated with shorter reading-and-response time, fewer fixations, shorter forward fixations, and higher scores in accuracy compared to questions about peripheral information, consistent with Yeari et al. (2015). These results indicated that questions that are less relevant for understanding can be more difficult to process (longer reading time and poorer accuracy) because they contain more complex information (e.g., dates and proper names) or less accessible to memory information compared to central information.

We found an interesting interaction between reading goal, information centrality, and group: for peripheral information, the control group showed shorter reading-and-response time and fewer fixations in the questions in the study condition, compared to the questions in the entertainment condition. The ASD did not show this effect. This supports the hypothesis that the control group benefited from the extra time they spent reading the texts in the study condition, especially in peripheral information. The greater number of fixations in the entertainment condition indicates that the control group found it more difficult to process these questions. Since they did not pay much attention during the reading of the texts under the entertainment condition, more effort during question answering was needed.

For central information, the ASD group showed more fixations in the questions in the entertainment condition compared to the questions in the study condition, probably showing that they did not construct a complete situational model during the reading of the text for entertainment, but they did during study. It could be that the control group probably did not show these differences because during reading in any condition they were constructing an adequate situation model which would include most of the central information.

Texts

Texts in the study condition were read for longer and received longer fixations compared to the entertainment and skim conditions. These results agree with previous studies (e.g., Linderholm & van den Broek, 2002; Yeari et al., 2015), and show that readers process text more deeply when they study compared to any other conditions. More fixations, more forward fixations, and longer saccades length were observed for the texts in the skim condition, compared to the entertainment and the study conditions. This behavior could reflect a more superficial reading and an attempt of the participants to read rapidly back and forward in order to find in the text the answers to the two questions, as requested by the instruction.

Our study showed that both the ASD and the control groups largely read faster and performed shorter fixations in the skim condition compared to the study condition, meaning that the instruction modified the reading behavior of both groups. Fixations were longer in the studied texts than in the skimmed texts in both groups, implying deeper processing in the former.

The entertainment condition was also read faster than the study condition, but the main effect here was modulated by group. Interestingly, the difference in reading times and fixations (longer) between the entertainment and study conditions only occurred in the control group. It seems that the control group changed reading behavior according to the reading goal, such that they read the study text deeper compared to the ones that they had to read for entertainment. In contrast, the ASD group did not read differently across the two texts showing a less of adaptation to the reading goals.

Target sentences

The results observed in the global analysis of the entire texts, that showed a deeper processing for the studied texts, are confirmed by the behavior of the local eye movement measures in the target sentences. In the study condition compared to the entertainment condition, we observed longer right-bounded and total duration, and compared to the skim condition, longer gaze duration, right-bounded, re-reading and total duration. A more superficial reading behavior for the skim condition compared also to the entertainment condition, was confirmed by the local analysis, which showed that the texts read for skim had shorter gaze duration and total duration compared to the texts read for entertainment.

The main effect of information centrality, did not show slower reading time for central information compared to peripheral as in Cirilo and Foss (1980) and Britton et al. (1986), but we found longer gaze duration in the central sentences showing more visual attention compared to peripheral sentences (Hyönä & Niemi, 1990). As Birkmire (1985) suggested, central information requires less processing time to be stored in the long-term memory because it is more representative of the existing knowledge of the text structures than peripheral information.

Our results, concerning the reading goal and group interaction, also demonstrate that the control group had longer gaze duration compared to the ASD group in the sentences in the study condition. These results indicate deeper processing in the study condition for the control group compared to the ASD group. The control group also displayed longer gaze duration in the sentences in the skim condition compared to the ASD group, again indicative of deeper processing of information during reading. In addition, the control group had longer gaze duration in the study condition compared to the skim condition, implying they processed the studied text deeper than the skimmed. The ASD group performed longer gaze duration in the entertainment compared to the skim condition, but not in the study condition.

There was an interaction between reading goal and information centrality. For central information, sentences in the texts in the study condition received longer re-reading compared to the sentences in the skim condition. For peripheral information, sentences in the study condition had longer re-reading compared to both, the entertainment and the skim conditions. No differences were found for the reading behavior for the central sentences in the entertainment and study conditions, showing that central information is equally important in processing when a text is read for fun, since it is necessary to build a situation model in order to understand the text. However, the peripheral sentences in the study condition had longer re-reading compared to the sentences in the entertainment condition due to the attempt to processes peripheral information deeper with the aim of remembering it. Participants probably noticed the high content of dates, numbers, and names in the peripheral information —while central information generally included the elements that allowed the comprehension of the whole text—, and consequently adopted a reading behavior aimed at memorizing. In addition, in the entertainment condition, the peripheral information had longer re-reading than in the skim condition showing that more importance to details is deployed during reading for entertainment than for skim. It thus appears that the centrality effect is modulated by the reading proposes (Bowner, 1976; Bowner & Mandler, 1978).

Our results found no differences in reading central and peripheral information between groups possibly be due to the fact that our sample of participants with ASD was matched with the control group on reading fluency.

The interaction of reading goal and information centrality was modulated by group. For peripheral information, the control group had longer regression path duration and longer re-reading in the study condition than in the entertainment and skim conditions. This was not the case for the ASD group. These results showed that the control group re-reads longer the sentences containing more detailed information in the study condition, probably with the aim to remember them better. The control group also showed longer regression path duration for central information in the study and entertainment conditions compared to the skim condition, and within the peripheral information in the study condition compared to the skim condition. Interestingly, the control group did longer regression path in the study condition compared to the entertainment within the peripheral information, demonstrating to allocate more effort in processing information that is more difficult to record. On the contrary, the ASD individuals did not present this differentiation between study and entertainment conditions. The ASD group only showed longer regression path and longer re-reading for the study condition compared to the skim in both central and peripheral information and longer regression path for the entertainment compared to the skim only in the peripheral information. The only differences in the group with ASD was found between the study or entertainment vs. skim condition, showing again that perhaps only the skim instruction was strong enough to change the reading behavior in the ASD group.

Our study explored the confidence in responding to the questions, the perception of the reading performance, and the awareness of the change in reading strategies between reading goals. Our results showed that the control group was more confident in responding to questions after being instructed to study compared to when it read for entertainment. No differences in confidence rates were found for the ASD group. The control group seemed more aware of the fact that after studying accuracy should be better. The correlation analysis also showed that more accuracy in both entertainment and study conditions corresponded to more confidence in responding to questions. The fact that there was no difference between groups in the enjoyability of the entertainment texts suggests that the attitude toward reading was positive for both groups (we had generally more positive feedback compared to negative).

No differences between groups were observed for the confidence rates in reading performance (study condition: *how well did you study?* and skim condition: *how fast did you read?*) and in the awareness of the use of different strategies for different goals. Neither group felt they had read the texts differently depending on the reading conditions. This absence of difference between groups in the reading performance perception is not in line with the confidence rates in questions' accuracy, where the control group had more confidence in the study condition compared to the entertainment condition. The group with ASD did not show this discrepancy. This difference perceived reading performance vs. confidence rates may be due to the fact that the question about performance was more straightforward (*how many questions did you answer correctly?*) than the confidence rating item.

Executive function

We explored which components of executive function predicted individual differences in text reading time across conditions. Individual variation in reading time differences between the study and entertainment (only before the exclusion of the outliers) and the study and skim conditions was predicted only by planning skills as measure with the Tower of Hanoi. It is plausible that participants with a better planning ability are also able to adapt their reading behavior to different reading instructions. This pattern could be particularly true when participants read conditions that are very different from each other. When studying, participants read longer showing deeper processing compared to when they read for entertainment or they skim the text. Having the awareness of the need for changing reading behavior according to different reading tasks might be linked to planning skills. The influence of the planning on the reading time might reflect the manner in which readers approach the reading material and how they navigate and organize it.

It has been observed that reading monitoring (e.g., Oakhill & Yuill, 1996; Perfetti et al., 1996; Ruffman, 1996) and the way reading material is organized (e.g., Cornoldi, De Beni, & Pazzaglia, 1996) are predictive of reading comprehension. This pattern adds further evidence of the fundamental role that reading comprehension plays in reading comprehension.

Limitations and conclusion

Limitations of this study concerns the lack of measure of higher cognitive skills (e.g., ability to cope with the task demand), and habits around reading (e.g., social experiences around reading, motivational reasons to read, frequency and duration of home literacy practice), that could have been shown higher influence on texts' reading times depending on the reading goal conditions. This study, as the previous, assessed highly verbal and high-functioning individuals with ASD, limiting the generalization of the results to the general ASD population. However, again, by controlling for factors that have been observed to influence reading comprehension skills, and analyzing reading in a sample of individuals that differed from controls only in their diagnosis of autism, we were able to shape the outcomes of reading behavior, depending on the reading goals, and better isolate the influence of the executive function. Although the conditions for regression are met, a limitation concerning regression analyses is that there is little statistical power, since the number of participants is limited. Further research urges to replicate these results with a larger sample of participants in order to reach a more robust regression model.

In conclusion, this study showed that participants with ASD found it more difficult to adopt different reading strategies for different reading purposes. The control group processed the texts in the study condition more deeply, and this different reading behavior was less obvious for the ASD groups. The control group was also aware, unlike the ASD group, of the positive impact on reading accuracy of added effort during studying compared to reading from entertainment. General planning ability, as measured in a non-reading task, could be predictive of the ability to shift reading strategies following reading instructions, showing that this skill is particularly important for reading comprehension.

Chapter 5

General Discussion

The overall aim of this thesis was to improve our understanding of how individuals with and without ASD process online reading material during reading comprehension (Chapter 2) and the role played by metacognitive processes and executive functions in this process (Chapters 3 and 4). These aims were achieved by using a range of methods that included behavioral assessment and eye-tracking data.

1. Summary of results and implications

1.2. Inference generation in ASD

1.2.1. Aims Chapter 2

The first aim of Chapter 2 was to investigate the reading strategies of individuals with ASD and control peers matched on age, nonverbal intelligence scores, language, and reading skills during inference generation. This aim was achieved by measuring global paragraph reading behavior (1), as well as question-answering time while reading the texts and responding to the questions (2). In addition, we further explored the reading behavior on predefined target words. These target words, in the inferential conditions, were essential producing inferences, but in the literal conditions were only additional cues for answering the questions (3). The strategies while reading the predefined target words were further analyzed by counting the percentage of regressions coming from part of the text that followed the target words with the percentage of regressions coming from the questions (4). We also explored the reading behavior on three critical words in the text (5) —in the literal condition, the correct answer, in the inferential condition, the word that substituted the correct answer, and in both conditions, a distractor. It is important to highlight that we were particularly interested to see if any differences in accuracy and/or in reading strategies were observed after closely matching individuals with and without ASD on the main components that influence reading comprehension.

1.2.2. Hypothesis Chapter 2

We expected no differences between the two groups in accuracy (1) [1] or global eye-movement measures while reading the text and answering the questions (2) due to the online nature of the task and the highly verbal and high-functioning character of our clinical group. We expected slower processing times and a higher number of regressions to the target word needed for the inference for the individuals with ASD compared to the control peers (3). This would indicate a greater effort in the integration of the target word in the text's context. However, given the assumption of intact lexical processing, early processing eye-movement (informative of a word's representation orthography, phonology or meaning, Juhasz & Pollatsek, 2011) measures of the target word were expected to be similar between ASD and control groups. We carried out exploratory analysis on the regressions into the target word from either the question or the remaining part of the text in order to see whether participants needed to re-inspect the target word after having checked the question (4). We expected to find similar reading behavior for the correct answer, the distractor words, and the filler words between the two groups, since none of the words involved inferencing (5).

1.2.3. Results Chapter 2

Results showed, as we expected, that participants with ASD were as accurate as the control group in responding to both literal and inferential questions (1). We also found

[1] Numbers correspond to the investigated areas: In Chapter 2, number (1) corresponds to the accuracy, number (2) to the global eye-movement behavior during the presentation of the entire paragraph, question and three possible answers, number (3) to the local eye-movement behavior for the target word, number (4) to the exploratory analysis on the regression into the target word, and number (5) to the local-reading for the correct answer, the distractors words and the filler words. The number corresponding to each investigated area will be kept the same for the Aim, the Hypothesis, the Results, and the Implication sections.

similar reading patterns between the groups in the global reading of the entire paragraph (2). However, analyses on the target words showed that the two groups exhibited subtly different reading patterns (3). Our hypotheses were confirmed by the observation of longer gaze durations for the participants with ASD compared to the control group in the inferential condition, but not in the literal condition. Individuals with ASD had comparable first- and single-fixation durations to control participants. Both groups showed more regressions into the target word from within the remaining part of the text (after the target word) compared to the regressions made into the target word coming from the question (4). However, when only the regressions from the question were considered, the ASD group showed more regressions compared to the control group for both the inferential and the literal conditions. Finally, no differences between the two groups were observed for the correct answer in the text, the filler word and the distractor (5).

1.2.4. Implications Chapter 2

Chapter 2 provides supportive evidence for the idea that accuracy performance of the ASD group was comparable to the control level, probably due to the highly verbal and high-functioning sample of individuals with ASD and the presence of the text on the same screen as the question (and options) (1). The accuracy scores suggest that individuals with ASD are able, under specific conditions, to produce inferences at a level similar to that of control participants. Further support comes from the lack of differences between groups in the global reading behavior of the entire paragraph (2). No differences in the early processing of the target word (3), correct word in the text (5), filler word or distractor, were found, and this could be indicative of similar ability between the ASD group and the control group in representing the orthography, the phonology and the meaning of the words (Juhasz & Pollatsek, 2011). The ASD group appeared to have no difficulty in the early processing of the text, prior to integrating background knowledge and generating inferences to build the situation model (Van Dijk & Kintsch, 1983; Kintsch & Rawson, 2005). However, the longer gaze duration found for the target word may be due to the fact that when the participants with ASD encountered it, this word was less expected in the text's context (Rayner & Well, 1996). In addition, it is possible that participants with ASD need to more frequently re-inspect the target word to answer the question, whether the condition was inferential or literal (4). The ASD participants may find it more challenging to initially build the situation model, so they need subsequent regressions into the target word to re-inspect and re-process pieces of information suggested by the question (Just & Carpenter, 1978; Ehrlich, 1983; Shebilske & Fisher, 1983; Blanchard & Iran-Nejad, 1987; Vauras et al., 1992). This could be due, to either the fact that individuals with ASD have an underspecified situation model (Tirado & Saldaña, 2016) that lacks sufficient detail to respond to the question even when the response is actually presented in the text, or the re-reading reflects the attempts to re-engage working memory of prior text segments which are important to readers' reading goals (Kaakinen et al., 2003; Kaakinen & Hyönä, 2005, 2008). Finally, they may be adopting a more cautious reading strategy when responding to questions about a text (Au-Yeung et al., 2015; Howard et al., 2017). Even in a sample of individuals with ASD carefully matched on language and non-verbal skills with the control peers, we observed subtle differences in the way they read. With this study, we confirmed the suspected differences in the online processing of reading materials for individuals with ASD. Differences in reading behavior have been previously observed in overall increased regressions (Au-Yeung et al., 2015; Sansosti et al., 2013) and in longer overall reading times (Au-Yeung et al., 2015; Howard et al., 2017; Sansosti et al., 2013). With the following two studies, we aimed to explore metacognitive processes and executive function that may be plausible candidates in impacting reading comprehension in ASD. We wanted to explore metacognitive processes and executive function in individuals with ASD that showed intact language, decoding, and cognitive skills in order to exclude the possible impact of important variables that might influence reading comprehension.

1.3. Reading monitoring in ASD

1.3.1. Aims Chapter 3

The following two studies aimed to observe if metacognition and executive function may have an impact on reading comprehension in ASD. The second study explored those components through the manipulation of the context in which reading took place using different instructions. The paradigm to which we decided to apply this manipulation was error detection. The design we present in Chapter 3 allows for the investigation of reading monitoring by exploring if coherent instructions with the task could modulate the accuracy in detecting semantic and orthographic errors (1) [2], the global reading behavior of the entire sentences (2), and the local reading behavior of the semantic and orthographic errors (3), in individuals with ASD and control peers matched on age, nonverbal intelligence scores, language, and reading skills.

1.3.2. Hypothesis Chapter 3

We expected to find overall poorer performance in semantic error detection for the ASD group compared to the control group. We also expected to find an interaction between error and instruction: individuals with ASD would have a higher accuracy in semantic errors detection when instructed to focus on the semantic error detection compared to when instructed to focus on orthographic error detection (1). Secondly, we expected a different

[2] Numbers correspond to the investigated areas: In Chapter 3, number (1) corresponds to accuracy, number (2) to the global eye-movement behavior of the entire sentence, and number (3) to the local eye-movement behavior for the errors. The number corresponding to each investigated area will be kept the same for the Aim, the Hypothesis, the Results, and the Implication sections.

reading behavior depending on the error types (Rayner et al., 2004) for both groups and that the ASD group would show shorter gaze duration during reading semantic errors compared to the control group due to a poorer processing of the semantic error (2; 3).

1.3.3. Results Chapter 3

Accuracy scores failed to confirm our hypothesis. Individuals with ASD and controls did not significantly differ in accuracy in detecting errors depending on different instructions and error types. However, even if the results were not statistically significant, we observed a tendency for the participants with ASD to be as accurate as the control group in detecting both semantic and orthographic errors when the semantic instruction was presented. The ASD group with orthographic instruction showed poorer performance in the detection of semantic errors compared to the control group receiving these instructions (1). Results on the global sentence reading time showed that the sentences that contained semantic errors had longer reading times, and more frequent fixations, compared to the sentences that contained orthographic errors and the sentences without errors (2). Further analyses on the errors showed that the orthographic errors received longer and gaze duration, compared to the semantic errors (3). Semantic errors were re-read for longer, received more regressions-out and -into compared to orthographic errors. However, we did detect a difference in the way both groups returned to errors: The control group showed a greater difference in regressions-out between semantic and orthographic errors in comparison to the group with ASD.

1.3.4. Implications Chapter 3

We found no differences in accuracy scores between the groups in Chapter 3. There was a tendency for the individuals with ASD to benefit from an instruction that was focused on the detection of semantic error (1). In contrast, when the instruction was incongruent with the task (orthographic instructions and semantic errors), error detection tended to be poorer for the individuals with ASD compared to the control peers. However, due to the between-group design of this experiment, it is likely that this was due to more limited cognitive or language skills, than to a real benefit of the instruction.

The analysis of the eye movement behavior during reading of entire sentences (2) and errors indicated no differences between the ASD and control groups (3). This is consistent with the recent results by Howard et al. (2017) that found no differences on most eye-tracking measures between groups. The only subtle difference between groups was that our control group showed a greater difference in regressions-out between semantic and orthographic errors in comparison to the ASD group. This result may indicate that the ASD group exhibits less discrimination in the reading behavior between the types of errors and that was less influenced by the type of error. These eye movement findings are in line with the study by Koolen et al. (2012), where the ASD group did not modulate, unlike the control group, their attentional effort depending on the presence of low- or high-level inconsistencies. Overall, we could be looking at a weaker tendency in individuals with ASD to adapt their reading to the nature of the error. This ability to adapt to different demands of a reading task was further explored in the third experiment.

1.4. Reading goals and executive function in ASD

1.4.1. Aims Chapter 4

The study in Chapter 4 focused on the influence of different goals on the reading behavior in readers with ASD. We explored if reading behavior changed according to different reading goals by exploring three different sections of the reading task: multiple-choice questions (1)[3]; the entire text (2) and target sentences within the text providing central and peripheral information (3). For each component, we analyzed the main effect of reading goals (entertainment vs. study vs. read fast/skim), the main effect of information centrality (central vs. peripheral information; the centrality analysis was not available for the text analysis), and the interactions between reading goal and group, reading goal and centrality, centrality and group, and reading goal, centrality and group. Additionally, we explored the participants' confidence in responding to the questions and in their perception of their reading performance (how well they read during study and how fast during skim) (4). Finally, several executive function components (planning, inhibition, working memory and cognitive flexibility) were assessed to identify the predictor(s) of text's reading times in different reading goals (5).

1.4.2. Hypothesis Chapter 4

We expected to find differences in the accuracy (1) and reading strategies (2, 3, 4) depending on the reading goal across all participants. In particular, we hypothesized that participants would read more deeply (as indicated by slower reading times) the text in the study condition compared to the other two conditions (entertainment and read fast/skim), and that this would result in better performance in finding the correct answers. However, due to the high verbal and cognitive abilities of the individuals with ASD that we recruited, we did not expect to find differences in the accuracy rating. But, in line with the results of Chapter 2, we did expect to find differences between the two groups in the online processing of the reading material. We expected the control group to show different eye movements while

[3] Numbers correspond to the investigated areas: In Chapter 4, number (1) corresponds to the accuracy, number (2) to the eye-movement behavior while reading the questions, number (3) to the eye-movement behavior while reading the entire text (4) to the eye-movement behavior for the target sentences, number (5) to the confidence ratings, and (6) to the executive function. The number corresponding to each investigated area will be kept the same for the Aim, the Hypothesis, the Results, and the Implication sections.

reading of the question (2), entire text (3) and the target sentences (4), as well as differences in confidence ratings (5) in responding to the questions depending on the reading goals. Specifically, we expected the control group to show longer reading times, suggesting deeper processing, and higher confidence for the text in the study condition compared to both the entertainment and the skim conditions. In contrast, we expected less sensitivity to and discrimination of different reading goals for the ASD group in the eye movement behavior and confidence ratings, due to a poorer ability to change strategies according to reading goals. We expected that executive function would have an impact on reading given the fundamental role of these skills played in reading comprehension, as discussed in the Introduction section (6). Previous studies found that of all executive function components, planning skill is the strongest predictor for reading comprehension in young adults (Georgiou & Das, 2016). We hypothesized, based on previous studies (e.g., Yeari et al., 2015), that the change in reading times between different reading goals would be a good indicator of the application of different strategies necessitated by different goals.

1.4.3. Results Chapter 4

As expected, results of the accuracy scores in responding to the questions revealed better performance in the study condition compared to the entertainment condition for all participants. The results showed a trend toward significance in accuracy (p = .06) in the interaction between goal and group. The control group was more accurate in the questions in the study condition compared to the questions in the entertainment condition. This was not the case for the ASD group. Participants were faster and showed fewer fixations while reading the questions in the study condition compared to the questions in the entertainment condition (1). The texts in the study condition were read for longer and received longer fixations compared to the texts read in the entertainment and read fast/skim conditions (3).

Our study showed that both the ASD and the control groups were faster in reading and performed shorter fixations in the text in the read fast/skim condition compared to the study condition. However, only the control group had longer reading time and longer fixations in the study text compared to the text read for entertainment. Consistent with the results of the entire text, the control group had longer gaze duration compared to the ASD group in the sentences belonging to the study condition (4). The results on confidence in responding to the questions showed that the control group was more confident in responding to questions after being instructed to study compared to when they read for entertainment (5). As expected, no differences in confidence rates were found for the ASD group. We explored which aspects of executive function predicted the reading time of the texts (6). Differences in text reading times between some conditions were predicted by the Tower of Hanoi task.

1.4.4. Implications Chapter 4

Results from Chapter 4 showed that the control group read the entire text (3) and the target sentences slower (4) in the study condition, suggesting a deeper reading, and therefore had better performance in answering questions (in line with van den Broek et al., 2001, but not with Narvaez et al., 1999) (2) in the same condition compared to when they read for entertainment (Linderholm & Zhao, 2008). In contrast, the ASD group changed their reading behavior of texts and sentences much less (with the exception of sentence processing between the skim and entertainment conditions), and consequently, no change was found in their accuracy in responding to the questions. These results suggest that the group with ASD showed less adaptation to the different reading goals, similar to less skilled comprehenders in Cain (1999). However, the read fast/skim instruction was strong enough to bring about the most visible change in the reading strategy in both groups compared to other conditions. Both groups applied the strategy of reading fast, as suggested by the read fast/skim instruction. The pattern of less adaptation to different reading goals in ASD was confirmed by the results on confidence rates. The control group felt more confident in responding to the questions following the study text compared to the text read for entrainment, suggesting that they were conscious of their superior performance during study (5). Again, this was not observed in the individuals with ASD.

The difference in reading times between study and skim conditions were predicted by planning skill (6). It seems plausible that individuals with better planning can adapt best to different reading goals and generate strategies more effectively, compared to individuals with poorer planning performance. Concluding, results from Chapter 4 showed that individuals with ASD demonstrated less adaptation in reading behavior according to different reading goals. In addition, we observed that planning skill was the executive function that predicted differences between reading times under specific conditions.

1.5. General Implications

The study of reading comprehension in ASD has been compelling and extremely informative in the past years (e.g., Nation & Norbury, 2005; Ricketts et al., 2013). On one hand, it is informative for the understanding of typical processes involved in reading. For example, it has been possible through the study of autism to add further support to the dissociation between decoding and comprehension components in reading (e.g., Davidson & Weismer, 2014; Jacobs & Richdale, 2013, Jones et al., 2009; Nation et al., 2006; Ricketts, 2011). On the other hand, the study of reading comprehension in ASD increases the understanding of the reading in atypical populations with the final aim of improving our knowledge for the development of novel clinical assessments and interventions.

The focus of past studies was first to describe and quantify the reading comprehension profile in ASD (e.g., Ricketts, Jones, Happé, & Charman, 2013; Nation & Norbury, 2005;

Norbury & Nation, 2011; Snowling & Frith, 1986; Wahlberg & Magliano, 2004). We know that generally individuals with ASD find reading comprehension challenging and that this difficulty appeared to be approximately 0.7 standard deviations below that of typically developing groups (Brown et al., 2013), with a very large variability. After that, researchers focused on the possible variables that influence reading comprehension in ASD and the possible sources of this variability (e.g., Norbury & Nation, 2011, for oral language; Snowling & Frith,1986, for world knowledge). The variables that influence reading comprehension in ASD and that have been investigated so far are the ones that influence reading comprehension in typically developing populations (e.g., Cain & Oakhill, 2011, Nation, 2005, for vocabulary in poor comprehenders). As addressed in Chapter 1, the role of structural oral language skills (e.g., Nation et al., 2006), vocabulary (e.g., Cain & Oakhill, 2011, Nation, 2005), world knowledge (e.g., Snowling & Frith,1986), working memory (e.g., Assouline et al., 2012), contextual integration ability (e.g., Frith & Snowling, 1983), the ability to produce inferences (e.g., Joliffe & Baron-Cohen, 1999a, 1999b), comprehension strategies (e.g., Williamson,et al., 2012), and monitoring (e.g., Koolen et al., 2012, 2013a, 2013b) have been broadly recognized. Thanks to the past studies that carefully identified these variables, researchers can control for them and further explore their role using experimental designs. Also, clinicians are aware of the components that have to be assessed and possibly treated in order to achieve better results during intervention.

However, despite all this research conducted on reading comprehension in ASD, there are some important aspects of reading comprehension which are still in need of further study. Online reading behavior and the influence of higher cognitive skills such as metacognition and executive function are the two examples that have been addressed in this thesis. Many of the studies that used online measures, such as response or reading times, failed to find differences in accuracy in question answering between individuals with and without ASD when relevant variables were controlled for (e.g., Saldaña & Frith (2007, Sansosti et al., 2013). However, subtle differences between individuals with and without ASD could be captured by exploring their reading strategy, even in selected samples with comparable verbal and non-verbal skills with a control groups, using the eye-tracking technique (longer overall reading times, Au-Yeung, Kaakinen, Liversedge, & Benson, 2015; Howard et al., 2017; Sansosti, et al., 2013; overall increased regressions, Au-Yeung et al., 2015; Sansosti et al., 2013). Oral language and decoding (e.g., García & Cain, 2014) are fundamental for successful reading comprehension. However, after excluding the influence of the language and decoding skills in our samples with ASD by carefully matching them with control groups, we aimed to explore if differences were still evident in reading behavior and if other components such as metacognition and executive function could play a role in reading comprehension in autism.

The present thesis aimed to explore differences between individuals with and without ASD in reading comprehension using both behavioral and eye movement measurements. We selected samples of highly verbal and high functioning individuals with ASD. If differences in reading were still found, we further aimed to explore the possible underlying causal factors by investigating higher level processing in reading comprehension. With this in mind, we choose to explore in greater detail metacognitive processes and executive function.

First, the present thesis showed that high-functioning and high-verbal individuals with ASD can have the same level of comprehension of inferences compared to controls without ASD, but read differently a target word that was required to make the inference. Linguistic and cognitive skills are sufficient to perform successfully in simple inference-generation tasks. However, the underlying text processing might be different or involve different cognitive processes between groups. In the present thesis, we hypnotized that executive function and metacognition could be related to these differences. Variability between groups in the reading behavior around the target word could be due to an additional executive effort for the individuals with ASD in integrating the word in the situation model of the text. Alternatively, this atypical gaze pattern could be due to uncertainty in responding to the questions, or a more cautious or deliberate reading strategy. Individuals with ASD might implicitly recognize that producing inferences requires effort; they might spontaneously spend additional energy compared to controls, but ultimately be successful in the comprehension outcome. It could be the case that individuals with ASD with poorer cognitive and linguistic skills generally fail comprehension tasks because of a combination of deficits in different skills: executive, metacognitive, linguistic, and cognitive skills. However, our participants pass the comprehension task because their linguistic and cognitive skills are unimpaired, but they still show subtle differences in reading due to the different executive and metacognitive process of the text.

After finding evidence of differences in the reading behavior between individuals with and without ASD, despite intact language and other cognitive skills, we aimed to explore if those differences where due to a different way of monitoring the text or following instructions. As seen in the previous experiment, the experimental manipulation was more informative of variations in gaze behavior than in behavioral measures: the eye movements of individuals with ASD were less influenced by the error types compared to the one of the control group. This study suggested that there are differences in reading monitoring between groups, and specifically, that they could be finding it harder to adapt to the demands of different reading tasks.

We then aimed to further explore executive function and metacognitive abilities by manipulating reading context. We pursued this aim by analyzing the influence of different reading goals on the comprehension and processing of central and peripheral information. We found that the reading strategies of individuals with ASD were less influenced by different reading goals compared to the group without ASD. The control group appeared to process the text more deeply during a study condition, compared to an entertainment condition. However, individuals with ASD appeared were less responsive to the change of reading goals from entertainment to study. From our results, we can also infer that the ability to adapt the reading behavior to different aims is influenced by planning skill.

This thesis touches novel aspects in the field of reading in typical and atypical population. To our knowledge, text-level inference generation, reading monitoring, and adaptation to reading goals have not been studied previously using eye-tracking technology in ASD. The three studies in the present thesis confirm the differences in the processing of reading material between individuals with ASD and matched control peers (Au-Yeung, et al., 2015; Howard et al., 2017; Sansosti, et al., 2013). Despite a similar performance in accuracy in responding to inferential and textual based questions, the individuals with ASD showed subtle differences in reading behavior that documented an additional effort in processing inferences compared to the control group (Chapter 2). In addition, it was observed that participants with ASD are less likely to discriminate between error types (Chapter 3) and adapt reading behavior to given reading goals (Chapter 4).

Metacognitive strategies can be taught and learned by children including children with reading difficulties (Afflerbach et al. 2008; Palincsar, Brown, & Armbruster, 1984). Future studies should investigate if it might be beneficial to guide individuals with ASD into engagement in reading and help them to develop their own purposeful and meaningful strategies within a structured framework (Taylor et al., 1995). In addition, the present thesis highlights the importance of planning skills in reading in ASD. It is important to explore the influence of executive function on language as a problem-solving tool. Improvement in this area could lead to improvement in cognition and social experiences that, at the same time, can influence executive function control and language skills itself (Freund, 1990).

2. Limitations

This thesis is not without limitations. The specific limitations of each study are outlined in each chapter. Thus, only limitations that are common across chapters will be discussed here. The first problem concerns the standardized tests used to match the individuals with and without ASD on language, reading skills, and general and nonverbal intelligence. These tests may not have been sensitive to differences between the two groups in other important cognitive functions involved in reading. For example, such standardized tests are not entirely satisfactory because they are not able to register higher cognitive skills such as executive control, attention, motor control, depth of vocabulary knowledge (Ouellette, 2006; Tannenbaum, Torgesen & Wagner, 2006), and ability to cope with the task demand and higher-level linguistic components such as passage-level listening comprehension and story recall.

Second, it was not possible to measure social cognition and social experiences that could possibly influence language, cognitive skills, and consequently, reading comprehension, due to a lack of sophisticated measures of social cognition and experiences. We did not record information regarding social experiences around reading (e.g., to talk about or recommend books to friends, to give books as gifts, to have people around that encourage reading, to go to reading-related events) and motivational reasons to read (e.g., to read for pleasure, for learning, or because it is mandatory at schools). It would have been useful to see if frequency and duration of home literacy practice were positively associated with reading ability and attitude, as found in Lucas and Norbury (2017), or with faster reading behavior.

The third problem that we encountered was our inability to explore if the differences in reading strategies between individuals with and without ASD were present only in readers with autism, or if they were present also in other disorders or in individuals that have poorer cognitive or linguistic skills. A poor comprehender group without ASD might have been of interest. In the introductory chapter, were reviewed predictors of reading comprehension in ASD, and showed that they were the same found in the typical population and in other disorders. However, the variability in reading comprehension among the individuals with ASD is greater compared to typically developing individuals.

The fourth limitation concerns the matching between groups in several skills. It was challenging and lead to the exclusion of several participants from the analyze. This practice limits the generalization of results because the sample of individuals that was recruited may be not representative of the general ASD and typical populations. However, we considered it more important to control for factors that have been observed to influence reading comprehension skills, and to analyze reading in a sample of individuals that differed from controls only in their diagnosis of autism. This careful match gave us the opportunity to test the theoretical implication that subtle differences in reading can be found also in highly verbal individuals with ASD. By excluding language and other nonverbal cognitive skills from the possibility of shaping reading comprehension, we were able to further explore additional components such as executive function and metacognitive processes.

Fifth, reading during the eye-tracking sessions was not totally ecologically valid. In the experiment presented in Chapter 3, for example, we used the sentence-by-sentence presentation and the purpose of the task was to detect errors. The environment and the way the participants read during our task was not representative of the usual reading context. However, we exposed both groups to the same experimental setting and consequently, the differences that we observed between the groups with and without ASD should not be attributed to the experimental task.

Sixth, due to the difficulty of recruiting the clinical and nonclinical sample, we were only able to collect data from a relatively small number of participants (around 20 for each study and group) and with wide age and grade level ranges (from 10 to 18 years old). Due to the small sample size, some of the data were not normally distributed and we had to use nonparametric analyses, some of which may lack in power compared to parametric approaches (Siegel & Castellan, 1988). In addition, the participants' age span covers a wide developmental period and it is possible that age (or some dimension of reading competence) moderates the effects in a manner that we cannot control for.

Finally, it has been also documented that individuals with ASD might show problems in motor preparation (Rinehart, Bradshaw, Brereton, & Tonge, 2001) and motor response (for a review, Ming, Brimacombe, & Wagner, 2007). This could be of concern because the participants responded to the comprehension questions by pressing a key on the keyboard. However, we did not find considerable differences between individuals with and without ASD in the responding times. It is possible that our samples had well preserved motor skills.

3. Future Directions

Research could proceed in various directions based on the research contained in this thesis. From a methodological perspective, there are several points that could be improved. First, future studies should seek to replicate the present results using different reading materials (e.g., the study in Chapter 4 should be replicated with narrative texts instead of expository texts). It would also be interesting to see if the same results could be obtained using materials containing social and emotional information. Bodner et al. (2015) observed that individuals with ASD find it particularly challenging to make inferences with emotional content. It would be interesting to see if the eye movement behavior reflects these behavioral difficulties, as we found in the study in Chapter 2 using inferences without emotional content.

In addition, it would be informative to examine how the reading behavior and the processing of question answering changes in individuals with ASD when they are instructed to respond to open-ended questions compared to close-ended type questions as in Chapters 2 and 4. Ozuru, Briner, Kurby and McNamara (2013) observed that the open-ended and multiple-choice format questions measure different aspects of comprehension processes; open-ended questions correlated with the quality of self-explanations and the multiple-choice questions with the level of prior knowledge about the text. It seems that the open-ended questions are more sensitive than multiple-choice questions to the detection of the quality of active generation processing of relevant and accurate text's ideas during reading and are more independent from prior knowledge.

Finally, a direction for future research would be to explore the possible patterns of causality between the cognitive and linguistic skills, the traditional theories associated to ASD (i.e., central coherence, theory of mind and executive function), and comprehension ability. Causal processes might be investigated using training studies focused on single skill at the time such as theory-of-mind, language skills, vocabulary, metacognition or executive function. If improvement is observed in reading comprehension after the single skill intervention, it is possible that the specific skills have a causal role on reading comprehension in ASD. The other way in which it is possible to explore causality is by analyzing, in a longitudinal study, how various skills in which individuals with ASD are problematic (e.g., inference generation, metacognitive skills, executive function), predict later comprehension, and how well comprehension skill predicts performance on tasks that measure those skills at a later age (Oakhill & Yuill, 1996). This approach would also make it possible to explore if the differences in reading between individuals with and without ASD are due to a developmental delay or a persistent deficit.

The results from the present thesis are promising in terms of intervention. In Chapter 2, we observed that during inference generation, individuals with ASD showed difficulty in the integration of the target word needed to make the inference in the context of the text. We need to develop approaches based on our experimental results and test them in classrooms. For example, we could improve inference generation (especially in off line reading tasks) in individuals with ASD by helping them to detect the target word that is needed for the inference and support their understanding during the integration of that word in the text's context. Chapter 3 failed to confirm the hypothesis that direct and focused instructions might improve performance in reading monitoring in individuals with ASD. It would be interesting to see if providing students with simple and direct instructions leads to improvement in reading comprehension, using more ecological paradigm than error monitoring. Finally, Chapter 4 showed that individuals with ASD have less adaptation to different reading goals. It would be useful if educators could drive the students with ASD toward specific reading purposes by explaining to them which are the most convenient strategies to adopt while reading for each specific purpose. Some types of strategies that can be taught in order to implement comprehension are self-listening or listening to others reading aloud (Elliott-Faust & Pressley, 1986), graphic organizers (Harris & Hodges, 1995), listening actively (Dickson, 1981), mental imagery, mnemonic instruction (Peters & Levin, 1986), activation of prior knowledge (Anderson & Pearson, 1984), question answering, question generation, story structure, summarization (Brown & Day, 1983), vocabulary instruction and multiple-strategy instruction. Intervention on reading comprehension could also generalize on other skills and positively impact for example the socialization of children with ASD, as already observed in reading fluency (Kamps, Barbetta, Leonard, & Delquadri, 1994).

4. Conclusion

This thesis has several strengths and gave light to novel findings. First, a wide range of cognitive and linguistic assessments was deployed to carefully evaluate and match the participants with and without ASD. Even though the group with ASD was not representative of all the spectrum of individuals with ASD, we considered it important to control for the majority of the variables that influence reading comprehension. Our aim was to investigate the reading processes in individuals with ASD, excluding the influence of linguistic and/or cognitive deficits.

Second, we used eye-tracking to study online processing, which is especially informative in reading. In using this technology, we were able to address the global (the entire paragraph or sentence) and local (target word) processing for low (early processing such as lexical and phonological access) and high (later processing such as context integration) levels. This technique has been applied in readers with ASD in very few studies (e.g., Au-Yeung, Kaakinen, Liversedge, & Benson, 2017; Howard et al., 2016; Sansosti et al., 2013), and has been observed to be extremely informative of differences between individuals with and without ASD that could not be detected if only behavioral data —such as traditional comprehension accuracy, reading and responding times— were recorded. In our studies, no differences between the groups with and without ASD were observed in accuracy. However, thanks to eye-movement data, it was possible to observe subtle differences between groups that were very informative of the online reading processing.

Finally, one of the major novelties of this thesis was the first investigation of executive function as a potential modulator of reading comprehension. The effect of executive function on reading comprehension has been explored in typical populations and in poor readers, but very little has been done in clinical populations as ASD. In our third study, we explored the effect of executive function on reading times. Of all the executive functions we analyzed, planning seemed to modulate the adaptation to different reading goals. These findings highlight the importance of training planning skills in order to improve the ability to adapt the reading strategy to different reading goals.

In conclusion, the thesis used behavioral and eye-movement data to further probe the differences between individuals with and without ASD in reading comprehension processing. Previous findings suggest that metacognitive processes and executive function account for a substantial amount of variance in reading comprehension (e.g., Catts et al., 1999; McCardle et al., 2001; Sesma, Mahone, Levine, Eason, & Cutting, 2008; Swanson, 1999). However, very little was previously investigated in the field of ASD. The findings presented in this thesis suggest that, although language and other cognitive skills are necessary, they are not sufficient for successful reading comprehension in ASD, and that individuals with ASD could be processing reading material differently than individuals without ASD. It appears that these differences in reading comprehension performance could be linked to variability in metacognition and executive function.

5. Conclusión

Esta tesis tiene varios puntos fuertes y aporta dados novedosos. En primer lugar, se emplearon una amplia gama de evaluaciones cognitivas y lingüísticas para evaluar cuidadosamente y emparejar a los grupos de autismo y control. A pesar de que el grupo con TEA no era representativo de todo el espectro, consideramos que era importante controlar la mayoría de las variables que influyen en la comprensión lectora. Nuestro objetivo fue investigar los procesos de lectura en personas con TEA, excluyendo la influencia de los déficits lingüísticos y / o cognitivos.

En segundo lugar, utilizamos la técnica de movimientos oculares, que nos proporcionó un marco de procesamiento online que es especialmente informativo en lectura. Al utilizar esta tecnología, pudimos abordar el procesamiento global (todo el párrafo o frase) y local (palabra objetivo) en niveles bajos (procesamiento temprano, como acceso léxico y fonológico) y alto (procesamiento posterior, como integración de contexto). Esta técnica se ha aplicado en lectores con TEA en muy pocos estudios (por ejemplo, Au-Yeung, Kaakinen, Liversedge, y Benson, 2017; Howard et al., 2016; Sansosti et al., 2013), y se ha observado que es extremadamente informativo de las diferencias entre individuos con y sin TEA que no se abrían podido detectar si solo se fueran registrados los datos conductuales, tales como la tasa de aciertos y los tiempos de respuesta. En nuestros estudios, no se observaron diferencias entre los grupos con y sin TEA y en el comportamiento de lectura global (lectura y tiempos de respuesta). Sin embargo, gracias a los datos del movimiento ocular, fue posible observar diferencias sutiles entre los grupos que fueron muy informativos del procesamiento de lectura online.

Finalmente, una de las principales novedades de esta tesis fue la primera investigación de la función ejecutiva como modulador potencial de la comprensión lectora. El efecto de la función ejecutiva en la comprensión lectora ha sido explorado en poblaciones típicas y en lectores pobres, pero se ha hecho muy poco en poblaciones clínicas como TEA. En nuestro tercer estudio, exploramos el efecto de la función ejecutiva en los tiempos de lectura, y seleccionamos una muestra de individuos con TEA que tenían intactas habilidades lingüísticas, cognitivas y de lectura. De todas las funciones ejecutivas que analizamos, la planificación parecía modular más claramente la adaptación al cambio de acuerdo con los diferentes objetivos de lectura en algunas condiciones. Estos hallazgos resaltan la importancia del entrenamiento de las habilidades de planificación para mejorar la capacidad de adaptar la estrategia de lectura a diferentes objetivos de lectura.

En conclusión, la tesis utilizó datos sobre el comportamiento y los movimientos oculares para investigar más a fondo las diferencias entre individuos con y sin TEA en la comprensión lectora. Nuestro objetivo era explorar el procesamiento metacognitivo y la función ejecutiva en la comprensión de la lectura en relación con individuos con y sin TEA. Nuestros resultados mostraron que, a pesar de presentar el mismo nivel de comprensión inferencial, el grupo con TEA mostró diferencias en la lectura de una palabra objetivo que se requirió para producir la inferencia. Interpretamos esta diferencia en el comportamiento de lectura como una dificultad para integrar la palabra objetivo en el modelo de situación del texto o como inseguridad al responder a las preguntas. Además, nos propusimos explorar si esas diferencias se debían a una forma diferente de monitorear los errores en el texto después de recibir las instrucciones para hacerlo. Descubrimos que el comportamiento del movimiento ocular de las personas con autismo estaba menos influido por los tipos de error en comparación con el grupo control. Finalmente, decidimos explorar más a fondo cómo la manipulación del contexto de lectura afecta las estrategias de lectura en TEA, analizando la influencia de diferentes objetivos de lectura en la lectura de informaciones centrales y periféricas. Encontramos que la lectura de las personas con TEA estaba menos influenciada por el objetivo de lectura que las del grupo control. Los controles mostraron un procesamiento más profundo del texto estudiado en comparación con el texto leído para entretenimiento. Este patrón de diferencia entre objetivos no se encontró en las personas con TEA. Además, observamos que solo la planificación y bajo condiciones específicas (diferencia entre estudio y descremada), entre los diferentes componentes de funciones ejecutivas, influyó en los tiempos de lectura.

Los hallazgos anteriores sugieren que los procesos metacognitivos y la función ejecutiva influyen de forma importante en la comprensión de lectura (por ejemplo, Catts et al., 1999; McCardle et al., 2001; Sesma, Mahone, Levine, Eason, y Cutting, 2008; Swanson, 1999). Los resultados presentados en esta tesis sugieren que, si bien el lenguaje y otras habilidades cognitivas son necesarias, no son suficientes para una comprensión de lectura exitosa en TEA, y que las personas con TEA podrían estar procesando material de lectura de manera diferente que las personas sin TEA. Parece que estas diferencias en el rendimiento de comprensión lectora podrían estar relacionadas con la variabilidad en la metacognición y la función ejecutiva.

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Appendix 1: Information and consent

The informational sheet, provided to the participants (if more than 18 years old) or participants' parents or legal guardians, contains the aims of the studies and guarantees the confidentiality of the data. The participants (if more than 18 years old) or the participants' parents or legal guardians had to sign the written consent form prior to any testing.

Para los padres o tutores legales

Estudio sobre la comprensión de lectura desde los movimientos oculares

Estimado D./Dª.,

El motivo de la presente carta es invitarle a participar en un estudio que pretendemos llevar a cabo a lo largo de este curso sobre las habilidades de comprensión de la lectura de textos, mediante la detección de los movimientos oculares.

¿De qué trata el estudio?

La capacidad de seguir correctamente las instrucciones que preceden a un texto y la capacidad de encontrar una respuesta a una pregunta en un texto requiere integrar diversos tipos de recursos cognitivos. Estudios previos han mostrado que los lectores con autismo parecen ser capaces de producir inferencias durante la lectura pero encuentran dificultades a la hora de responder a preguntas sobre estas inferencias en las tareas tradicionales (responder a opciones múltiples o preguntas abiertas). El por qué de esto sigue siendo un enigma. Para responder a esta pregunta experimental, se desea investigar los mecanismos subyacentes a la estrategia de selección utilizada para la lectura. Por este motivo, y porque las técnicas de detección de los movimientos oculares ofrecen una excelente manera de investigar la lectura relevante para nuestro estudio, nos proponemos analizar la precisión, la velocidad de lectura y las fijaciones de los movimientos oculares.

¿Qué conlleva el estudio?

La implicación en el estudio supondría que usted participara en una actividad de ordenador sobre textos escrito. El tiempo necesario para llevar a cabo todo ello estará entre 45 - 50 minutos en una sola sesión, incluyendo varios descansos a lo largo de la tarea.

¿Será confidencial la información que se recoja?

Toda la información y los datos recogidos se custodiarán con las máximas garantías para su confidencialidad. Los datos sólo se emplearán en el marco del proyecto de investigación y en ningún caso se publicarán sus datos de forma que pueda ser identificado individualmente.

¿Tengo que participar?

Como es lógico, su participación es totalmente voluntaria. Si decide que desea hacerlo, le pedimos que firme la autorización que acompaña a esta carta y la entregue al experimentador o bien nos la envíe a la dirección de correo electrónico mmicai@us.es Puede también llamarnos por teléfono al 954554331, donde le atenderá Martina Micai.

¿Es importante participar?

Su participación en el presente estudio es de gran importancia por varias razones. Por un lado, gracias a ella pretendemos avanzar en un conocimiento más preciso sobre los mecanismos de formación de las inferencias en los niños con autismo. Así, nos permitirá definir de una forma más exacta por qué los lectores con autismo parecen ser capaces de producir inferencias durante la lectura pero no pueden responder a preguntas sobre estas inferencias en las tareas tradicionales opciones múltiples o preguntas abiertas.

Por otro lado, queremos estudiar el modo de procesamiento e integración de textos en personas sin dificultades y personas con dificultades y a aplicar los resultados obtenidos en la detección de una intervención directa en personas con autismo al igual que en personas con dificultades de comprensión de textos escritos.

Agradeciendo de antemano su colaboración, reciba un saludo,

David Saldaña Sage
Director del estudio

Departamento de Psicología Evolutiva y de la Educación. Universidad de Sevilla.
C/ Camilo José Cela s/n. 41018 Sevilla. Tel. 954 55 43 31 Martina Micai *mmicai@us.es*

Para los padres o tutores legales

CARTA DE CONSENTIMIENTO

Escriba sí o no, según proceda, en la casilla de la derecha.

1. Conozco los objetivos y actividades a realizar durante este estudio y los he comprendido plenamente. ☐

2. Entiendo que la participación de mi hijo/a es voluntaria y puede retirarse del estudio en cualquier momento sin tener que dar ninguna explicación y sin que sus derechos legales se vean afectados. ☐

3. Estoy de acuerdo con la participación de mi hijo/a en este estudio. ☐

4. (Opcional) Deseo que este equipo de investigación contacte con nosotros en ocasiones futuras para la realización de otros estudios (no implica participación en los mismos). ☐

Nombre y apellidos de mi hijo/a

Fecha de nacimiento

Centro en el que se encuentra escolarizado mi hijo/a

Curso

Diagnóstico exacto de mi hijo/a

Firma

Nombre de la persona que da el consentimiento

Dirección

Localidad

Teléfono fijo de contacto

Teléfono móvil de contacto

E-mail

Investigador que acepta el consentimiento

Responda Sí ☐ o No ☐ :
Autorizo a los responsables de la investigación para que proporcionen los datos de la evaluación al centro o a la asociación en la que se encuentra mi hijo/a (en caso de que éste los solicite) con el fin de mejorar la atención y apoyo que recibe en la misma.

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Appendix 2: Ethical approval

The Andalusian Regional Biomedical Research Ethics ethical approval is presented below.

JUNTA DE ANDALUCIA

CONSEJERÍA DE IGUALDAD, SALUD Y POLÍTICAS SOCIALES
Dirección General de Calidad, Investigación, Desarrollo e Innovación
Comité Coordinador de Ética de la Investigación Biomédica de Andalucía

DICTAMEN ÚNICO EN LA COMUNIDAD AUTÓNOMA DE ANDALUCÍA

D/Dª: Víctor Sánchez Margalet como secretario/a del CEI Hospital Universitario Virgen Macarena

CERTIFICA

Que este Comité ha evaluado la propuesta de (No hay promotor/a asociado/a) para realizar el estudio de investigación titulado:

TÍTULO DEL ESTUDIO:	Estudio sobre el lenguaje en niños y niñas con Trastorno del Espectro autista (TEA), síndrome de Asperger y Trastorno Específico del Lenguaje (TEL) ,(Lenguaje en TEA y TEL)
Protocolo, Versión:	Primera
HIP, Versión:	Primera
CI, Versión:	

Y que considera que:

Se cumplen los requisitos necesarios de idoneidad del protocolo en relación con los objetivos del estudio y se ajusta a los principios éticos aplicables a este tipo de estudios.

La capacidad del/de la investigador/a y los medios disponibles son apropiados para llevar a cabo el estudio.

Están justificados los riesgos y molestias previsibles para los participantes.

Que los aspectos económicos involucrados en el proyecto, no interfieren con respecto a los postulados éticos.

Y que este Comité considera, que dicho estudio puede ser realizado en los Centros de la Comunidad Autónoma de Andalucía que se relacionan, para lo cual corresponde a la Dirección del Centro correspondiente determinar si la capacidad y los medios disponibles son apropiados para llevar a cabo el estudio.

Lo que firmo en SEVILLA a 11/10/2014

D/Dª. Víctor Sánchez Margalet, como Secretario/a del CEI Hospital Universitario Virgen Macarena

Código Seguro De Verificación:	16e1c7e89869360c4bb8dd7427589100c102b370	Fecha	11/10/2014
Normativa	Este documento incorpora firma electrónica reconocida de acuerdo a la Ley 59/2003, de 19 de diciembre, de firma electrónica.		
Firmado Por	Víctor Sánchez Margalet		
Url De Verificación	https://www.juntadeandalucia.es/salud/portaldeetica/xhtml/ayuda/verificarFirmaDocumento.iface/code/16e1c7e89869360c4bb8dd7427589100c102b370	Página	1/2

Appendix 3: Experimental material Chapter 2

The two practice trials are presented in the inferential and literal version. The stories composed of five paragraphs in the inferential version follow below. In parenthesis and bolded are presented the correct answers contained in the text (and the corresponding option), only for the literal condition. Underlined are the target words that allowed the participant to answer to the question and in italics one of the option contained in the text. Wavy underlined are the words that substituted the correct answer only in the inferential paragraph. The dashed options correspond to the semantic distractors. In the present appendix, the options are ordered as follow: correct option, option contained in the text and semantic distractor. In the original study, the options were presented in a randomized order and held constant across participants. The original test in Spanish is presented for all the trial components.

Practice passages

Paragraph condition	Spanish paragraph	Question and options
Inferential	Lucía invité sus amigos en casa para cenar. Lucía siempre está muy distraída cuando cocina. Esta noche toda la comida parecía muy buena: ella había preparado pescado y verduras a la plancha riquísimas. Llegó el momento del postre y todos los amigos no podían esperar. Lucía trajo el postre del horno en una nube de humo.	¿Qué pasó al postre? **a. Se había quemado** b. Tenía un olor delicioso c. Era muy caliente
Literal	Pilar y Pablo estaban apretados en sus asientos listos para empezar su gran aventura. El vehículo era más grande que un coche y más largo que un tren. Cuando pulsaran el gran botón rojo en el panel de mando del cohete despegarían a gran velocidad. Se miraron el uno y el otro y a la de tres, los **astronautas** apretaron el botón.	¿Cuál es el trabajo de Pilar y Pablo? **a. Astronautas** b. Taxistas c. Maquinistas de tren

Story 1

Spanish Paragraph	Question and options
Era lunes por la mañana y hacia mucho sol. Don Francisco le dio la comida a su *loro* y luego se fue para ver si el pequeño (**gato**) Mico estaba bien. Dormía profundamente y parecía que estaba soñando. Las piernas de Mico se movían para adelante y para atrás como si estuviera imaginando a un ratón que perseguía velozmente, intentando atraparlo.	¿Que animal es Mico? a. **Un gato** b. Un perro c. *Un loro*
Una vez fuera de casa, don Francisco se encontró con que su coche no funcionaba y se enfadó. Llegaba tarde y, si se iba *caminando*, sabía que llegaría tarde al trabajo. No quería que sus estudiantes estuvieran solos en la clase. En lugar de eso, para ir al trabajo (con su nueva **bicicleta)**, don Francisco se fue pedaleando mientras pensaba en su día.	¿Cómo llegó don Francisco al trabajo? a. **En bicicleta** b. En motocicleta c. *Caminando*
Don Francisco llegó al trabajo y avanzó rápidamente hacia el interior del edificio. Vio a sus alumnos que hacían el tonto, jugando al *fútbol* con un libro mientras que entraba en la clase de cuarta (**plástica**). Cuando lo vieron, se sentaron enseguida y se callaron. Don Francisco entregó colores a los niños. Ellos eligieron sus pinturas favoritas y empezaron a colorear.	¿Que asignatura enseña don Francisco? a. **Plástica** b. Historia c. *Fútbol*
Don Francisco decidió relajarse haciendo algo que le gustaba: pintar. Tenía ganas de pintar un *arroyo*, pero no tenía el azul. Así que decidió otra cosa. Las partes del dibujo que requerían detalles le llevaban más tiempo que las otras. En los colores del fondo no tardaba mucho, mientras que el sujeto (**pájaro**) y sus plumas largas le ocuparon más tiempo.	¿Que pinta don Francisco? a. **Un pájaro** b. Un conejo c. *Un arroyo*
Más tarde, don Francisco empezó a sentirse cansado porque aquel día era el más caluroso del *verano*, así que se fue a su habitación. A esa hora hacía un calor abrasador. Don Francisco se puso a leer una historia de brujas, magos y creaturas mágicas que existían hace mucho tiempo (durante el **invierno**) en un bosque nevado y lejano. Su gato salió fuera.	¿Cuándo tenía lugar la historia del libro de don Francisco? a. **El invierno** b. La primavera c. *El verano*

Después de haber terminado de reservar el *hotel* en la ciudad para él y sus estudiantes, don Francisco intentó irse a la cama. Pero no podía dormir, porque estaba muy nervioso por la excursión de estudio (al **circo**) que él y su clase iban a hacer al día siguiente. Don Francisco estaba asustado por los payasos coloridos. Se puso música y descansó.	¿Dónde se irán mañana don Francisco y su clase de excursión? a. **Al circo** b. En una plaza c. *A un hotel*

Story 2

Spanish Paragraph	Question and options
Había una gran fiesta y Daniel no podía esperar. Todos sus amigos estaban llegando *lentamente*. Sus padres iban a pasar todo el día fuera y tenían que coger un tren. En cuanto se despidieron y salieron de la casa, Daniel los miró por la ventana. Vio a sus padres que iban cargados (**de prisa**) y corrían por la calle hacia la estación.	¿Como iban los padres de Daniel? a. **De prisa** b. En coche c. *Lentamente*
Daniel se había pasado la tarde decorando la casa como hacía para *Navidad*. Poco a poco los invitados empezaron a llegar. Su hermana se había vestido de princesa, pero Daniel le dijo que ese disfraz para la fiesta (para **Halloween**) no valía. Él le había dicho que todos tenían que ir disfrazados. Daniel iba de fantasma y quería ver los otros disfraces.	¿De qué es la fiesta que Daniel está celebrando? a. **Halloween** b. Un ensayo c. *Navidad*
Daniel iba esparciendo arañas falsas alrededor de toda la casa cuando el primer invitado disfrazado de *Spider-Man* tocó a la puerta. Daniel se quedó muy impresionado con el traje del segundo invitado. La brillantina de aquel disfraz del chico (de **esqueleto**) era lo que más le gustaba a Daniel. Esta brillantina tenía la forma de los huesos y estos parecían de verdad.	¿De qué era el disfraz del segundo invitado? a. **Esqueleto** b. Fantasma c. *Spider-Man*
Cuando llegaron los invitados a casa de Daniel, los llevó a una habitación de la planta baja. Se llevó abajo también los dulces de la *panadería*. Todos miraron a su alrededor y se mostraron impresionados con el esfuerzo que había hecho Daniel para preparar la fiesta. Esta habitación, que parecía algo diferente (una **discoteca**), hizo querer bailar alegremente a todos los invitados.	¿A qué se parecía la habitación? a. **A una discoteca** b. A un trastero c. *A una panadería*
Decidieron ir a hacer algo de truco o trato. Daniel y Marcelo pasaron por delante de la *piscina* y de muchas casas adornadas, algunas con tenebrosas calabazas. Se acercaron a un enorme edificio (**castillo**) al final de su calle. Cuando iban subiendo por el oscuro camino se dieron cuenta de que este edificio tenía cuatros torres altas. llamaron a la puerta.	¿Que era el edificio al que Daniel y Marcel tocaron? a. **Castillo** b. Puente c. *Piscina*

Daniel y Marcelo vestidos de *oruga*, esperaron en el porche, pero no hubo respuesta. Se miraron el uno al otro y comenzaron a alejarse, de vuelta por el camino. Cuando se habían dado la vuelta, se oyó crujir la puerta que se estaba abriendo. Se volvieron y vieron a una persona (**bruja**) que llevaba una escoba vieja y sucia mirándoles fijamente.	¿De qué era el disfraz de la persona en el edificio? a. **De bruja** b. De araña c. *De oruga*

Story 3

Spanish paragraph	Question and options
Era el cumpleaños de Juan. Sus padres lo llevaban fuera a pasar el día. Dónde iban a ir era una sorpresa. El camino era diferente del que hacía para ir al *instituto* cada día. Cuando llegaron al sitio (**zoológico**), Juan no podía esperar para salir del coche. Estaba emocionado, porque iba a ver a las cebras, que eran sus animales favoritos.	¿Dónde han llevado a Juan sus padres? a. **Al zoológico** b. Al acuario c. *Al instituto*
Juan y su familia se lo pasaron muy bien viendo todos los animales. A su madre le gustaron las *mariposas* y a su padre las jirafas. Mientras que caminaban hacia el servicio, Juan sintió salpicaduras de agua fría en sus brazos. Juan se volvió. Vio un animal (**elefante**) que le estaba echando agua con la trompa y le hizo mucha gracia.	¿Qué animal mojó a Juan? a. **Un elefante** b. Un cocodrilo c. *Una mariposa*
Los padres de Juan le habían preparado otra sorpresa. Juan esperaba que no fuera el *parque natural*. Cuando el coche llegó al sitio misterioso (**parque temático**), su cara se iluminó. Podía escuchar gritos de entusiasmo de los niños, que se divertían mucho. Juan no podía esperar para entrar. Todo lo que Juan veía era un enorme tiovivo amarillo desde la gran entrada.	¿Dónde están ahora? a. **En el parque temático** b. En el parque acuático c. *En el parque natural*
Cuando Juan y su familia llegaron a casa, se fue a abrir sus regalos. La familia se sentó alrededor del *postre* para merendar. Sus padres le habían regalado unas entradas para el fútbol. Sin embargo, su regalo favorito fue el de sus abuelos. Juan no podía esperar a utilizar el regalo (**teléfono**) para mandarles mensajes a sus amigos y contárselo todo.	¿Qué regalo le han hecho a Juan sus abuelos? a. **Un teléfono** b. Unas entradas c. *Un postre*
Después de un día tan emocionante, llegó la hora de cenar. El tío empezó a poner la mesa con *cuchillos* y tenedores. En ocasiones especiales, la familia solía ir al restaurante, pero tenían ganas de hacer algo diferente (una **barbacoa**) para todos. El padre de Juan quería hacerse cargo de cocinar. El padre se fue al jardín para prepararlo todo muy bien.	¿Qué utilizó el padre de Juan para cocinar la cena? a. **Una barbacoa** b. *Un cuchillo* c. Una microonda

Esa noche, Juan quería ver una película con amigos. José y Elena querían ver una *romántica*, pero Juan y María decidieron poner una muy diferente (de **terror**). Sin embargo, José y Elena no estaban disfrutando de la película en absoluto. Elena y José pasaron la mayor parte del tiempo mirando el móvil, mientras que María se escondía detrás de una gran almohada.

¿Qué tipo de película estaban viendo los niños?

a. **De terror**
b. De ciencia
c. *Romántica*

Story 4

Spanish Paragraph	Question and options
Irene estaba en un grupo musical. Hoy estaba nerviosa por la idea de viajar. La *moto* era el único medio de transporte que le gustaba. Pero en unos pocos días se iba de viaje lejos (en **avión**) con su grupo para tocar. Ella estaba alterada porque se acordaba de que una vez se asustó cuando aterrizó brusca y rápidamente en la pista.	¿En que transporte iba a viajar Inmaculada? a. **En avión** b. En barco c. *En moto*
Irene y su banda estaban en el hotel. Ella llevaba la mochila y ya estaba lista para irse al ensayo del grupo. Miró a través de la ventana esperando que fuera un día *caluroso*, viendo sorprendida que en realidad era diferente (**lluvioso**) y corrió a decírselo a las compañeras. Fue a buscar al armario su chubasquero y se fue con prisa.	¿Qué tiempo hacía? a. **Lluvioso** b. Húmedo c. *Caluroso*
A Irene le encantaba tocar. Cuando era niña también sabía tocar el *clarinete,* pero lo dejó de tocar. Su banda estaba compuesta por otras tres chicas llamadas Pía, Eva y Lola. Ellas podían tocar muchos instrumentos. En el ensayo, en cuanto el grupo empezó a actuar, Irene tocó su instrumento (**guitarra**) muy velozmente. Tocaba las cuerdas finas al son de música.	¿Qué instrumento estaba tocando Inmaculada? a. **La guitarra** b. La batería c. *El clarinete*
La semana siguiente, Irene y su banda tocaban en una escuela de Madrid. Habían tocado muchas veces antes con sus pianos y violines, pero ellas no volverían a tocar *música clásica* nunca más. Esa noche Irene estaba muy emocionada, porque iba a tocar con un instrumento nuevo. Todas las chicas tocaban música (**rock**) con sus guitarras y todo el mundo bailaba.	¿Qué tipo de música estaba tocando la banda de Inmaculada? a. **Música rock** b. Música rap c. *Música clásica*
Empezó a salir fuego, y una enorme nube de humo y *polvo* apareció de uno de los altavoces. Las chicas pararon de tocar y todos empezaron a asustarse. Los maestros guiaron a todos a la salida más cercana. Los estudiantes se taparon los oídos con las manos. Todos hacían eso porque algo (la **alarma**) producía mucho ruido en el interior del edificio.	¿Qué puede haber causado que los estudiantes se taparan los oídos? a. **La alarma** b. La música c. *El polvo*

Una vez que todos estuvieron fuera sanos y salvos, los *maestros* pasaron lista. Luego, todo lo que se podía hacer era esperar a que llegara alguna ayuda (llegaran los **bomberos**). Irene miró preocupada a través de la ventana para ver cómo de grande era el daño. Había un montón de humo negro proveniente del techo y las llamas eran cada vez más grandes.	¿Quién venía a ayudarles? a. **Los bomberos** b. La policía c. *Los maestros*

Story 5

Spanish paragraph	Question and options
Iba a ser un día muy caluroso y Yago no podían practicar *boxeo*, el deporte que le gustaba hacer en el gimnasio. Fátima y Yago entonces decidieron practicar otro deporte durante la mañana. Jugaron mucho tiempo (al **tenis**) y Fátima ganó por tercera vez. Yago decidió que eso era suficiente por ese día y tiró la raqueta al suelo, frustrado y enfadado.	¿Que deporte estaban practicando Fátima y Yago? **a. Tenis** b. Golf *c. Boxeo*
Después del partido, decidieron caminar por la calle de la ciudad. Había una tienda que vendía helados, entraron, se compraron dos y se sentaron fuera. Después decidieron entrar para terminar de comérselos. Hasta hace poco *hacía calor,* pero entraron porque Fátima notó que podía cambiar el tiempo (**llover** pronto). De repente, habían aparecido un montón de nubes en el cielo antes azul.	¿Qué pensaban que iba a pasar fuera de la tienda? **a. Iba a llover** b. Iban a aburrirse *c. Iba a hacer calor*
Luego, el sol salió de nuevo y decidieron ir a relajarse. Pasaron por la *calle* de antes y llegaron a otro lugar (la **playa**). Fátima se puso las gafas y comprobó que había olvidado el teléfono. Aunque ella nunca olvidaba meterlo en la bolsa. A pesar de esto, se relajó porque le gustaba muchísimo sentir la arena caliente debajo de los pies.	¿Dónde habían ido a descansar? **a. A la playa** b. A la sauna *c. A la calle*
La playa estaba llena de familias que nadaban en el mar y hacían castillos de arena. Fátima encontró un sitio bonito lleno de *macetas* con flores tropicales cerca del paseo marítimo y se acostó disfrutando del sol. Yago pensó que sería aburrido estar allí sin hacer nada todo el día y (y con una **palita**) se fue a excavar un redondo y profundo agujero.	¿Que estaba utilizando Yago? **a. Una palita** b. Un tenedor *c. Una maceta*
Una vez que el calor se hizo totalmente insoportable, la pareja decidió darse un baño en el mar, esperando que el agua estuviera *caliente* y limpia. Les parecía bonita, ya que era de color azul y brillaba al sol. Yago entró y comenzó a salpicar con un poco de agua (el agua **helada**) a Fátima. Ella chilló cuando el agua tocó su piel.	¿Como estaba el agua? **a. Helada** b. Tibia *c. Caliente*

Después de un día tan divertido en la playa, la pareja se dirigió a casa. Fátima hizo la cena y vieron una película. Mientras que Yago aún estaba *cenando*, Fátima empezó a sentirse mal. Decidió irse a la cama con una buena manzanilla (buen **libro**). Tanto le gustaba lo que estaba haciendo, que Fátima pasaba las paginas muy rápidamente y disfrutaba mucho.	¿Qué estaba haciendo Fátima en la cama? **a. Leyendo** b. Soñando *c. Cenando*

Appendix 4: Experimental material Chapter 3

The practice story is presented. The eight stories, including the semantic and orthographic errors and the corresponding corrections in parenthesis, follow below. Underlined are the errors that could be either semantic or orthographic depending on the version presented. First, is presented the error belonging to the first version and then the error belonging to the second version. In parenthesis is presented the error correction. In the original study, the stories were presented in a randomized order. The original test in Spanish is presented for all the trial components. The original test in Spanish is presented for all the trial components.

Practice story

Error condition	Spanish sentence
No error	Pilar estaba cansada después de pasar toda la mañana en la escuela. No quería hacer los deberes.
Semantic/Orthographic error	Se puso a hacer varias cosas sin sentido para no quedarse frente al barranco/cuaverno (cuaderno) en blanco:
Orthographic/Semantic error	Se fue a la cocina, abrió la nevera, se bebió un vaso de acua/pila (agua) y se comió un helado.
Orthographic/Semantic error	Luego regresó a su cuaderno, sacó punta al lápzi/tapón (lapis), hizo un garabato feo y soltó un suspiro.
No error	De vuelta a la cocina, se comió dos piezas de pan, un pedazo pequeño de queso y una galleta.
Semantic/Orthographic error	El libro aún seguía ahí. Al día siguiente, en el aula, el profesor le pondría probablemente una mala nube/ntoa (nota).

Semantic/ Orthographic error	Mientras tanto, el tiempo pasaba y fuera empezaba a oscurecer. Por suerte, la madre volvía del universo/trabayo (trabajo).
Orthographic/Semantic error	La madre vio a Pilar frente al cuaderno en blanco y le preguntó si había terginado/cocinado (terminado) su tarea.
No error	Se trataba de escribir una historia acerca de un lugar imaginario y fantástico, fuera de lo real.
Semantic/ Orthographic error	Mamá, haciéndole una suave caricia, le dijo a Pilar que escribir colgantes/hitsorias (historias) fantásticas e imaginadas es muy difícil,
No error	mucho más difícil que contar cosas que se saben y son reales, pero al final es más divertido.
Orthographic/Semantic error	Pilar y su mamá cerraron juntas los ojso/ríos (ojos) y comenzaron una historia inventada de la siguiente manera:
No error	había una vez una princesa que esperaba a su príncipe azul en el castillo, vio una rana...
Orthographic/Semantic error	Pilar y su madre escribieron/escalaron (escribieron) cosas raras y se divirtieron juntas, cerrando los ojos e imaginando cosas fantásticas.
Semantic/ Orthographic error	Al día siguiente, en la escuela, Pilar y sus compañeros leyeron las historias imaginarias que tropezaron/escirbieron (escribieron).
Semantic/ Orthographic error	Todos se divirtieron mucho al cerarr/gritar (cerrar) los lugares y volar en los lugares de la imaginación de sus amigos.
Semantic/ Orthographic error	Pilar no podía esperar para inventar muchas otras historias y escribió otros dulces/tetxos (textos) más y más complejos.
No error	Al final, Pilar no encontraba dificultades para escribir, y le gustaba contar las aventuras que imaginaba.

Story 1

No error	Bañador, albornoz, zapatillas, gorro, gafas de protección, champú y jabón: ¡la bolsa de la piscina está lista!
Semantic/Orthographic error	José sale de la casa y va en el sobre/coshe (coche) de la madre de su mejor amigo David.
Orthographic/Semantic error	Después de unos minutos, lleagn/beben (llegan) a la entrada del centro deportivo, donde los esperan sus compañeros de natación.
Orthographic/Semantic error	Una parada rápida en el vestuario para ponerse el bañador y luego… ¡todos a la piscina a natar/trepar (nadar)!
No error	Bajo la mirada del instructor hacen ejercicios en el agua para calentar los músculos de las piernas y brazos.
Semantic/Orthographic error	¡El agua está un poco fría! Pero todos los niños están demasiado entusiasmados como para pensar en el bolo/fíro (frío).
Semantic/ Orthographic error	Después de las primeras brazadas están listos para una botella/cafrera (carrera). Todos los niños están muy nerviosos.
Orthographic/Semantic error	José y David están muy emocionados y miran a sus pdares/fresas (padres) que están en las gradas altas.
No error	El instructor pide toda la atención de las personas en la piscina y anuncia el inicio de la carrera.
Semantic/ Orthographic error	Todos los niños y niñas, andando rápido se colocan en sus posiciones de comida/paritda (partida) para nadar.
No error	Los padres esperan ansiosos por ver a sus hijos nadar. Llevan esperando todo el año este momento.
Orthographic/Semantic error	El instructor hace sonar el silabto/hámster (silbato) y la piscina se llena de grandes olas a causa de las brazadas.
No error	Pasan rápidamente los minutos y todavía nadie podía imaginar el resultado final de la buena carrera de natación.
Orthographic/Semantic error	De repente, José se separa de todo el grupo y avanza hacia la línea de meva/zumo (meta).
Semantic/ Orthographic error	Todos los espectadores en las playas/grafas (gradas) lo animan, mientras que él deja atrás a sus compañeros de carrera.
Semantic/ Orthographic error	David inesperadamente lo alcanza y con unas cuantas rápidas brazadas lo adelanta. Se oyen muchos caballos/grtios (gritos) desde las gradas.
Semantic/ Orthographic error	El instructor señala el final de la carrera con un silbato y anuncia la croqueta/victaria (victoria) de David.

No error	Todo el mundo corre a abrazarlo y felicitarlo. El instructor se muestra satisfecho por la victoria inesperada.

Story 2

No error	Era un día soleado. Después de la escuela dos amigos, Carlos y Santiago, decidieron jugar al aire libre.
Semantic/Orthographic error	Carlos y Santiago, mientras se aventuraban en el bosque, se encontraron con un árbol con grandes y fuertes manos/ravas (ramas).
Orthographic/Semantic error	Al lado del tronco había una escalera emfinada/insípida (empinada). "Yo voy delante de ti ", le dijo Carlos a Santiago.
Orthographic/Semantic error	Poco a poco con mucho cuidado y un montón de curiosidad, comenzaron a subir los peldaños de la ecsalera/corriente (escalera)
No error	Santiago vio entre las ramas una plataforma de madera sobre la que había una casa bonita y pequeña,
Semantic/Orthographic error	con techo, dos pequeñas montañas/vetnanas (ventanas), una puerta y una lámpara! "¡Oh! " exclamaron los niños encantados.
Semantic/ Orthographic error	Más y más curiosos, llegaron a la gamba/poerta (puerta) de la casa. Se preguntaban si encontrarían un gnomo dentro.
Orthographic/Semantic error	"¿Vivirá un pequeño gnomo?", pensó Carlos. Santiago, el valiente, pidiendo permiso cruzó el umbral de la poerta/maceta (puerta).
No error	Los niños encontraron solo unos pocos juegos viejos, algún libro de historias de miedo y algunos restos de comida.
Semantic/ Orthographic error	Cuando regresaron a casa, cansados pero muy emocionados, Carlos y Santiago peinaron/conatron (contaron) a sus padres su aventura.
No error	Dijeron a sus padres la ubicación exacta de la pequeña casa, la estructura y lo que encontraron.
Orthographic/Semantic error	Los dos padres se mirraon/podaron (miraron) el uno al otro al mismo tiempo con expresión muy divertida y sorprendida.
No error	“Fue nuestra casa de juego en el árbol cuando éramos más pequeños. Se me había olvidado completamente”.
Orthographic/Semantic error	Al día siguiente, Carlos, Santiago y su padre jugaron juntos en su pequeña casa en el árlol/océano (árbol).
Semantic/ Orthographic error	También decidieron añadir una maceta a la casa y amueblarla con pequeños y bonitos deberes/muegles (muebles) construidos con sus padres.

Semantic/ Orthographic error	Hicieron una escalera más sólida y robubta/liquida (robusta), con la ayuda de uno de los dos padres, que era carpintero,
Semantic/ Orthographic error	y arreglaron el tejado, añadiendo una ventana nueva, con la ayuda del otro ratón/pdare (padre) que era experto albañil.
No error	Al final invitaron a otros amigos de su clase y también celebraron algunos cumpleaños en la casa.

Story 3

No error	Dos hermanos dormían en la misma habitación. Aun así, por las noches, se iban a dormir un poco asustados.
Semantic/Orthographic error	Todas las llaves/nohces (noches) oían un ruido extraño que parecía salir de la buhardilla, justo encima de su habitación.
Orthographic/Semantic error	Incluso después de ser capaces de conciliar el seuño/pueblo (sueño), se despertaban y luego se les hacía difícil dormir.
Orthographic/Semantic error	La buhardilla era un lugar donde no se les permitía ir. Sus padres les habían prohibido enbrar/volar (entrar).
No error	Los padres les habían explicado que era peligroso subir las escaleras hasta la buhardilla; que no había nada interesante.
Semantic/Orthographic error	Una noche, los dos hermanos decidieron ir a la buhardilla para averiguar qué producía el ruido soleado/mosesto (molesto).
Semantic/ Orthographic error	Ellos estaban muy emocionados y asustados porque la buhardilla era un guiso/siito () muy misterioso y también prohibido.
Orthographic/Semantic error	Entraron lentamente por la escalera de caracol. La habitación estaba muy oscura y la escalera era muy esrtecha/amargada (estrecha).
No error	Se cayeron por las escaleras, golpeándose fuerte el trasero. Esperaron un poco y luego subieron lentamente y cuidadosamente.
Semantic/ Orthographic error	Entraron en la buhardilla, donde casi no se veía nada. Solo un hilo de luz chupaba/entreba (entraba) en la habitación.
No error	Después de una respiración profunda, los dos hermanos resistieron al miedo y cruzaron el umbral de la buhardilla.
Orthographic/Semantic error	Querían saber quién o qué producía el ruido que tanto les molestaba durante toda la noshe/silla (noche).
No error	Cuando sus ojos se acostumbraron a la oscuridad, intentaron seguir la única luz que había en la habitación.
Orthographic/Semantic error	Mientras avanzaban, tropezaron con algunos juegos de los padres y abuelos que nadie había utiliazdo/respirado (utilizado) desde hace años.
Semantic/ Orthographic error	Si no hubieran estado motivados por el deseo de conocer la causa del ruido, habrían huido a toda noche/prsia (prisa).
Semantic/ Orthographic error	Había una hoja de la ventana abierta que cuando soplaba un poco de aite/palo (aire) giraba por las bisagras oxidadas.

Semantic/ Orthographic error	Los dos hermanos movieron la hoja de la camiseta/vemtana (ventana) para asegurarse de que el ruido venía de allí.
No error	El misterio fue revelado, el ruido que les daba miedo era simplemente una bisagra oxidada de una ventana.

Story 4

No error	Era una mañana cálida de verano y la mamá de Rocío la despertó bruscamente. La chica estaba confusa.
Semantic/Orthographic error	Se preguntó qué habría pasado que fuera tan importante para que la escayolara/desrertara (despertara), ya que la escuela había terminado.
Orthographic/Semantic error	La mamá le dijo a Rocío que se vistiera y la siguiera hasta el jradín/abrigo (jardín). Había una sorpresa esperándola.
Orthographic/Semantic error	Rocío estaba muy eufórica. Ella sebía/bebía (sabía) que ese día no era el de Los Reyes ni tampoco su cumpleaños.
No error	Acurrucado bajo un pequeño arbusto había un gatito lindo que lloraba mucho. Rocío corrió rápido hacia él.
Semantic/Orthographic error	A Rocío siempre le habían gustado los animales, aunque nunca había tenido ninguno. Tosía/ambaa (amaba) especialmente los gatos negros.
Semantic/ Orthographic error	Rocío pensaba que los gatos eran muy independientes y amables al mismo tiempo, cualidades que siempre ha recortado/admipado (admirado).
Orthographic/Semantic error	Era un gato negro y pequeño con un círculo blanco en el cotsado/primate (costado). Era realmente precioso.
No error	Rocío sabía que podría ser propiedad de alguien y que, quizás, vendrían a buscarlo en algún momento.
Semantic/ Orthographic error	También sabía que sus padres no lo podían tener, porque trabajan mucho y no podían hacerse reloj/cadgo (cargo) de él.
No error	Como Rocío quería quedarse el gato y quería un nuevo amigo le hizo una gran promesa a sus padres:
Orthographic/Semantic error	"Prometo que seré responsable y lo cuidaré, y si el duaño/folio (dueño) lo reclama se lo devolveré."
No error	Los padres decidieron dar a Rocío la oportunidad de demostrar si era capaz de cuidar a una mascota sola.
Orthographic/Semantic error	Los días pasaron y nadie vino a recogerlo. Tal vez la mmaá/lata (mamá) del gatito lo había abandonado.
Semantic/ Orthographic error	Rocío mostró cada día más amor en el cuidado de su gatito y se convirtieron en caídos/buneos (buenos) amigos.
Semantic/ Orthographic error	Todos los días antes y después de la escuela, Rocío le daba pienso para que creciera sano y fuorte/cocido (fuerte).

Semantic/ Orthographic error	Luego llegó el momento de bailar/degidir (decidir) el nombre y Rocío lo observó bien para ver algo peculiar.
No error	Su característica distintiva era la mancha blanca en el pelo negro. Así que Rocío decidió llamarlo "Bola de Nieve”.

Story 5

No error	El maestro llevó a su clase a un museo, fuera de la ciudad, en el que había cuadros famosos.
Semantic/Orthographic error	Entraron en una sala llena de melones/cuajros (cuadros) y el maestro se puso a explicar el significado de las pinturas.
Orthographic/Semantic error	Muchos niños comenzaron a jugar porque las balodsas/naranjas (baldosas) del suelo eran tan resbaladizas que se podía patinar.
Orthographic/Semantic error	Jugaron casi todos, excepto el maestro que siguió dando la espalda a los naños/monos (niños) y explicando un cuadro.
No error	Alberto no escuchaba al maestro, se imaginaba a sí mismo bajo la sombra de una palmera en la playa.
Semantic/Orthographic error	Alejandro, el mejor estudiante de toda la clase permanecía atento, cocinando/escuhcando (escuchando) al maestro y tomando notas.
Semantic/ Orthographic error	Alicia, a la que le encanta comer, se recortaba/mastenía (mantenía) firme frente a un cuadro que representaba un pastel.
Orthographic/Semantic error	Alicia pensó, pasándose la lengua por los labois/bancos (labios), que quería morder el rico pastel del cuadro.
No error	Ana jugaba con su nuevo móvil y se empeñó en ganar la partida de su juego favorito.
Semantic/ Orthographic error	Antonio era como un poeta: se puso a lavarse/escirbir (escribir) unos versos inspirados en un hermoso paisaje de un cuadro.
No error	Los niños se divertían y el maestro no se daba cuenta de lo que pasaba, pues estaba ocupado explicando.
Orthographic/Semantic error	El ruido que los niños hacían era fuerte. Al final llegó el vibilante/esparrago (vigilante) de seguridad del museo irritado.
No error	El maestro llevó a los niños a la puerta. Mientras Alicia todavía estaba frente al cuadro con el pastel.
Orthographic/Semantic error	El maestro se dio cuenta de que Alicia estaba hambrienta y sacó de su bolsillo un carmaelo/desierto (caramelo) para ella.
Semantic/ Orthographic error	Ya en clase, el maestro pidió a los estudiantes que escribieran un texto sobre el viaje al fuego/muteo (museo).
Semantic/ Orthographic error	Alejandro escribió muchas páginas sobre lo que el maestro había dicho y sacó una buena noga/cama (nota), como siempre.
Semantic/ Orthographic error	Antonio también tuvo buena nota porque escribió unos bonitos poemas inspirados en las pinturas que había bañado/vitso (visto).

No error	Los otros niños no recordaron nada, así que el maestro se dio cuenta de que no habían atendido.

Story 6

No error	María y Pepe viven en el campo, en una preciosa y pequeña casa amarilla con ventanas verdes.
Semantic/Orthographic error	Su papá trabaja todas las noches hasta muy tarde y tiene que coger el pollo/tven (tren) para volver a casa.
Orthographic/Semantic error	La madre no trabaja y puede quedarse en casa, así que puede ayudar sus hiyos/peces (hijos) a hacer sus tareas.
Orthographic/Semantic error	Cada noche los niños preguntan cuándo volvería su papá del trbaajo/plátano (trabajo). Les gustaría verlo antes de ir a dormir.
No error	Una noche, el padre llamó y dijo que esa noche volvería temprano para que todos pudieran cenar juntos.
Semantic/Orthographic error	Fue una gran alegría para María y Pepe y por eso decidieron ayudar a su mamá a trotar/coicnar (cocinar).
Semantic/ Orthographic error	Se divirtieron mucho fingiendo ser pequeños cocineros y llevaban sombreros y delantales para evitar plantarse/maciarse (mancharse) la ropa.
Orthographic/Semantic error	Pepe, el más joven, tenía la tarea de preparar las aceitunas y ponerlas todas en un plafo/coche (plato).
No error	María decidió rayar las zanahorias y cebollas, porque sabía que este plato le encantaba a su padre.
Semantic/ Orthographic error	La madre preparó un solomillo de ternera sabroso, con pelotas/paattas (patatas) al horno y calentó un poco de pan.
No error	La madre les dijo a los niños que pusieran la mesa, dándoles lo necesario: cubiertos, platos y vasos.
Orthographic/Semantic error	Además, la mamá les pidió que no ensuciaran la cocina y tuvieran cuidado de no ropmer/ahogar (romper) nada.
No error	"¡Papá!" gritaron los niños después de haber oído la puerta abrirse, e inmediatamente corrieron a él.
Orthographic/Semantic error	Su padre siempre vuelve cansado del trabajo. Esa nothe/multa (noche) no se sentía tan cansado, pero tenía mucha hambre.
Semantic/ Orthographic error	Los padres se sentaron en la mesa y los niños trajeron los platos en una ballena/banjeja (bandeja), como dos camareros.
Semantic/ Orthographic error	Comieron todo lo que los niños y la madre habían prepraado/dibujado (preparado) y quedaron todos satisfechos con su trabajo.

Semantic/ Orthographic error	Papá hizo elogios a los dos pequeños cocineros y prometió llevarlos al cine durante el fin de manzana/seamna (semana).
No error	Los hermanos tuvieron suerte, justo ese fin de semana iba a salir una película que les gustaba mucho.

Story 7

No error	Lorena es una niña que vive en una hermosa casa con sus padres, dos hermanos y dos gatos.
Semantic/Orthographic error	Desde que era muy pequeña, va a la escuela de ballet cateto/cláisco (clásico) dos veces a la semana.
Orthographic/Semantic error	Esta actividad le encanta, porque se le da bien y además puede ver a menudo a sus copmañeras/cocodrilos (compañeras).
Orthographic/Semantic error	Desde hace algún tiempo, Lorena decidió ir a un carso/barco (curso) de guitarra clásica con su hermana pequeña.
No error	Su hermana Laura es dos años menor que ella. Durante las lecciones, mientras Lorena toca, Laura canta.
Semantic/Orthographic error	Las dos hermanas están haciendo un gran progreso. A veces hacen ordenadores/confiertos (conciertos) en las fiestas del pueblo.
Semantic/ Orthographic error	Los padres se dan cuenta de que la música se está convirtiendo en una verdadera sandia/paisón (pasión) para ellas.
Orthographic/Semantic error	Una vez, se acercaba la Navidad y los padres pensaron en un reglao/barrio (regalo) que pudieran hacerles a las chicas.
No error	La mejor idea era regalarles una guitarra eléctrica y un micrófono profesional a Lorena y Laura.
Semantic/ Orthographic error	Eran regalos caros, así que los padres decidieron pedir a los abuelos y tíos que ayudaran con los toros/gadtos (gastos).
No error	Fueron a la tienda de música y compraron una hermosa guitarra eléctrica y un micrófono profesional.
Orthographic/Semantic error	La noche de Navidad, uno de sus tíos bajó las escaleras con un pequete/elefante (paquete) para las dos hermanas.
No error	Dentro del paquete había un cable de electricidad. Las dos chicas se preguntaban el porqué de ese extraño regalo.
Orthographic/Semantic error	Les dieron otro paquete. Dentro había una caja que se conetcaba/maquillaba (conectaba) con el cable que les acababan de regalar.
Semantic/ Orthographic error	De repente, en la radio sonó una sangría/cacnión (canción) que Lorena sabía tocar bien y que Laura podía cantar.
Semantic/ Orthographic error	Su hermano mayor y su madre bajafon/volaron (bajaron) las escaleras con dos paquetes, uno enorme y otro más pequeño.

Semantic/ Orthographic error	Las chicas habían reconocido la forma de los paquetes que sus padres les acababan de conducir/relalar (regalar).
No error	Unas lágrimas de emoción cayeron de los ojos de las niñas y corrieron a desenvolver los maravillosos regalos.

Story 8

No error	Cuando Carla estaba en la escuela secundaria, en un pequeño pueblo español, su asignatura favorita era el arte.
Semantic/Orthographic error	Sobre todo, le encantaba escuchar la lección del calabacín/prfoesor (profesor) acerca de la arquitectura de cualquier ciudad del mundo.
Orthographic/Semantic error	Los padres de Carla eran pobres y no habían podido viajar y vistiar/alquilar (visitar) nuevos lugares del mundo.
Orthographic/Semantic error	Un día la lección se centró en Venecia, una ciadad/bufanda (ciudad) que se encuentra en el norte de Italia.
No error	El profesor explicó que Venecia es una ciudad única, porque se compone de un total de ciento dieciocho islas.
Semantic/Orthographic error	Las islas están separadas por canales y están conectadas por plátanos/puintes (puentes), por donde los coches no pueden pasar.
Semantic/ Orthographic error	En Venecia hay sólo botes y góndolas. ¡Los coches no esquían/cicrulan (circulan)! Incluso las ambulancias y los taxis son barcos.
Orthographic/Semantic error	La característica de vivir en el agua lleva también a problemas como la inundación de la ciduad/jirafa (ciudad).
No error	La gente tiene que caminar con botas y el agua entra en las casas y estropea todos los muebles.
Semantic/ Orthographic error	A Carla le encantaron las características de esta ciudad y durante toda su adolescencia pelaba/soñoba (soñaba) con poder ir.
No error	El tiempo pasó y Carla empezó a trabajar y se enamoró de un chico que vivía en su país.
Orthographic/Semantic error	Carla recordó que el profepor/calcetín (profesor) dijo también que Venecia es la ciudad más romántica del mundo para las parejas.
No error	Llegó el día del cumpleaños de su novio y ella decidió regalarle un viaje a Venecia durante la primavera.
Orthographic/Semantic error	Cogieron un avión y viajaron dos hroas/gotas (horas). Luego, se trasladaron hasta el centro de la ciudad.
Semantic/ Orthographic error	Cuando llegaron al centro ambos fueron sorprendidos por la belleza y el tamaño de los palacios, pepitos/caanles (canales) y puentes.
Semantic/ Orthographic error	Fueron a torar/correr (tomar) una pizza y pasearon por las estrechas calles de la ciudad. Era un día soleado.

Semantic/ Orthographic error	Dieron también un paseo en góndola, mientras el que conducía el barco les explicaba la abuela/hivtoria (historia) de los edificios.
No error	Fue el viaje más hermoso para Carla. Se lo contó a sus padres mostrándoles todas las fotografías.

Appendix 5: Experimental material Chapter 4

The three texts divided in central and peripheral information units are presented. The central information units consist in the information units that received the highest judges' agreement. In bold are the period that was considered in the eye movement data analysis. Following each text, peripheral and central questions are presented. The first option is the correct option. The second option is the one that has one element different from the correct option and the third option has three elements different from the correct option. Finally, the last option has all elements that differ from the correct option. In the original study, the options were presented in a randomized order and held constant across participants. The original test in Spanish is presented for all the trial components.

Text 1: La Muralla China

Information unit condition	Spanish sentence	Question and options
Central	**Las murallas y la construcción de muros jugaron un papel importante en la cultura china.**	Las murallas y la construcción de muros 1. Jugaron un papel importante en la cultura china 2. Jugaron un papel importante en la cultura europea 3. Tuvieron un rol secundario para la cultura china 4. No fueron importantes para ninguna cultura
	Esta nación fue siempre consciente de la importancia de las murallas	
Peripheral	**desde el periodo del neolítico hasta la Revolución Comunista, donde las murallas eran parte de cualquier pueblo.**	¿En qué periodo las murallas formaron parte de cualquier pueblo? 1. Desde el neolítico hasta la Revolución Comunista 2. Desde el paleolítico hasta la Revolución Comunista 3. Desde el paleolítico hasta la Revolución Francesa 4. Desde antes del paleolítico hasta la Revolución Francesa
	Los muros se construían en todos los lugares, no solo en ciudades y pueblos, sino también en las casas y los templos.	
Peripheral	**Las casas no tenían ventanas exteriores, dando así la sensación de pasear por un enorme laberinto.**	Las ciudades chinas se parecían a un laberinto porque

		1. Las casas no tenían ventanas exteriores 2. Las casas no tenían puertas exteriores 3. Los comercios no tenían puertas interiores 4. Las calles no tenían salidas
	La palabra "ciudad" en chino (ch'eng) significa muro, y sobre estas ciudades, pueblos, casas y templos presiden los dioses de las murallas y los montes, cuya obligación era, y aún es, la de proteger y ser responsable del bienestar de los habitantes.	
Central Unit that was used in the skim condition	**La Gran Muralla mide diez mil li** (medida de longitud china).	¿Cuanto mide de longitud la Gran Muralla? 1. Diez mil li 2. Doce mil li 3. Once mil metros 4. Doce kilómetros
Central	**En China, diez mil li representan el "infinito."**	En China, la longitud de la Gran Muralla 1. Representa el infinito 2. Se parece al símbolo del infinito 3. Representa la Luna 4. Se parece a la forma de la Luna
Peripheral	**De media mide un metro más de alto que de ancho.**	De media la Gran Muralla mide 1. Un metro más de alto que de ancho 2. Dos metros más de alto que de ancho 3. Dos a tres metros menos de alto que de ancho 4. Dos metros menos de alto que de ancho

Central	El año 1987 **la Gran Muralla fue declarada Patrimonio de la Humanidad por la UNESCO.**	La Gran Muralla fue declarada 1. Patrimonio de la Humanidad por la UNESCO 2. Patrimonio de la Humanidad por el imperio chino 3. Monumento de China por la UNESCO 4. Monumento de China por la OMT
Peripheral	Eso significa que **la muralla es un sitio de excepcional importancia para la humanidad.**	La Gran Muralla es 1. Un sitio de excepcional importancia para la humanidad 2. Un sitio de excepcional importancia para China 3. Un sitio de escasa importancia para China 4. Una frontera de escasa importancia para China
Peripheral	**Un error bastante común es considerar a la Gran Muralla China como una estructura arquitectónica de una única pieza.**	Un error bastante común es considerar la Gran Muralla como 1. Una estructura arquitectónica de una única pieza 2. Una estructura arquitectónica de dos piezas 3. Una estructura provisional de dos piezas 4. Una edificación provisional de más de dos piezas
Central	En realidad, **la construcción del muro atravesó distintas dinastías consecutivas,**	La construcción de la Gran Muralla atravesó 1. Distintas dinastías consecutivas

		2. Distintas eras consecutivas 3. Una sola dinastía 4. Una sola república
	y cada una de las dinastías, de algún modo, contribuyó a las reformas y a la construcción del muro, cuyas bases se habían establecido muchos siglos antes.	
Central	Fue durante los **siglos tercero y cuarto antes de Cristo cuando cada estado construyó muros** **para proteger sus reinos del resto de los estados y de los nómadas** del norte.	En el siglo tercero y cuatro antes de Cristo se construyeron muros 1. Para protegerse del resto de los estados y de los nómadas 2. Para protegerse del resto de los estados y de los ejércitos 3. Para protegerse del resto de los reinos y de los ejércitos 4. Para dividir las fronteras de los reinos
Peripheral	Especialmente **tres de estos estados, antiguamente llamados el Ch'in, el Chao y el Yen, empezaron a construir muros** para protegerse.	Tres estados empezaron a construir muros. Antiguamente se llamaban 1. El Ch'in, el Chao y el Yen 2. El Ch'in, el Chao y el Hopei 3. Ch'in, el Shanzi y Hopei 4. Sur, central y occidental
Peripheral	**Dichos estados correspondían respectivamente a las modernas provincias de** **Shensi, Shanzi y Hopei.**	El Ch'in, el Chao y el Yen correspondían a las modernas provincias de 1. Shensi, Shanzi y Hopei 2. Shensi, Shanzi y Pekín 3. Shensi, Xiamen y Pekín 4. Xi'an, Xiamen y Pekín
Peripheral	**Estos tres estados establecieron las**	El Ch'in, el Chao y el Yen

	bases sobre las cuales Ch'in Shih Huang Di construiría su Gran Muralla.	establecieron las bases sobre las cuales 1. Ch'in Shih Huang Di construiría su Gran Muralla 2. Ch'in Shih Huang Di destruiría parte de la Gran Muralla 3. Shih Huang-ti destruiría parte de la Gran Muralla 4. Shih Huang-ti pondría las bases de su dinastía
Central	**El papel que la Gran Muralla jugó en el crecimiento de la economía china fue muy importante.**	Las murallas y la construcción de muros 1. Jugaron un papel importante en la cultura china 2. Jugaron un papel importante en la cultura europea 3. Tuvieron un rol secundario en la cultura china 4. No fueron importantes para ninguna cultura
	A lo largo de los siglos muchos asentamientos se establecieron junto a la nueva frontera.	
Peripheral	**Las tropas fueron instruidas para cultivar terrenos abandonados** y construir carreteras y canales.	Las tropas fueron instruidas para 1. Cultivar terrenos abandonados 2. Cultivar terrenos privados 3. Expropiar terrenos privados 4. Utilizar terrenos privados para la ganadería
Central	**La Gran Muralla contribuyó en gran medida a aumentar el comercio dentro del país, en el extranjero** y	La Gran Muralla contribuyó al aumento 1. Del comercio en China y en el extranjero

		2. Del comercio solamente dentro de China 3. Del turismo solamente en el extranjero 4. Del turismo solamente en zonas remotas
	también con las partes sur, central y occidental de Asia. Los intercambios con áreas muy lejanas, a las cuales eran imposibles de acceder anteriormente,	
Central	contribuyeron a formar la aún conocida como **Ruta de la Seda, mejorando la economía y el comercio.**	La Ruta de la Seda 1. Mejoró la economía y el comercio 2. Fue el inicio para la economía y el comercio 3. Empeoró la economía y el turismo 4. Empeoró la política y el turismo
	Constructores, artesanos, agricultores y campesinos dejaron un sendero de objetos, que incluyen tablas inscritas, artículos domésticos y trabajos escritos.	
Peripheral	**Los restos arqueológicos encontrados llegaron a ser evidencias para el estudio de las instalaciones defensivas de la Gran Muralla y la vida cotidiana** de estas personas que vivían y morían cerca del muro.	Los restos arqueológicos llegaron a ser evidencias para el estudio de 1. Las instalaciones defensivas y la vida cotidiana 2. Las actividades religiosas y la vida cotidiana 3. Las instalaciones comerciales y los conflictos militares 4. Las actividades turísticas y las relaciones comerciales

	Los materiales usados para la construcción de la Gran Muralla eran aquellos disponibles en los alrededores de la construcción, siendo la elección más accesible y asequible. Cerca de Pekín se utilizó piedra caliza, un tipo de piedra bastante resistente y, por lo tanto, ventajosa para impedir la ruptura de la estructura amurallada por parte de los enemigos. Sin embargo, a gran distancia de Pekín, se utilizó granito o ladrillo cocido. Básicamente, era una larga tapia de arcilla y arena, cubierta con varias paredes de ladrillo. Eso hizo a la Muralla muy resistente a los impactos de las armas de asedio.	
Central	**La Gran Muralla tiene tres puertas llamadas pasos del norte, del oeste y del este.**	Las tres puertas de la Gran Muralla se llaman 1. Pasos del norte, del oeste y del este 2. Pasos del norte, del oeste y del sur 3. Pasos del norte, del sur y oriental 4. Pasos del sur, occidental y oriental
	Las puertas estaban controladas por guardias que defendían las ciudades. Se construyeron fuertes a lo largo de la muralla, o directamente integrados en las paredes, con un sistema de señales de humo para impedir ataques de los enemigos. Las torres tenían una entrada con una escalera de difícil acceso.	
Central	Ahora, **la Gran Muralla está bien conservada al norte de Pekín siendo esto de gran interés turístico.**	Las partes bien conservadas de la Gran Muralla se encuentran al 1. Norte de Pekín

		siendo de gran interés turístico 2. Norte de Pekín siendo de escaso interés turístico 3. Sur de Pekín siendo de escaso interés turístico 4. Sur de Pekín siendo de escaso interés político
Peripheral Unit that was used in the skim condition	**Las partes desaparecidas del muro han servido para la reconstrucción de viviendas y carreteras.**	¿A que han servido las partes desaparecidas del muro? 1. La reconstrucción de viviendas y carreteras 2. La reconstrucción de viviendas e iglesias 3. La creación de viviendas y puertos 4. La reorganización de iglesias y puertos
Central	**En el futuro gran parte de la muralla situada en la zona más antigua de la misma desaparecerá debido a la fuerte erosión** a la que se ve sometida.	Gran parte de la muralla de la zona más antigua desaparecerá 1. En el futuro debido a la fuerte erosión 2. En el futuro debido a la fuerte lluvia 3. En el próximo año debido a la fuerte lluvia 4. En el próximo siglo debido a la fuerte lluvia
	Como ya ha pasado con las famosas torres vigías, las cuales han desaparecido ya completamente.	
Peripheral	**Alrededor de la zona más antigua de la muralla hay tormentas de arena que perjudican su conservación.**	Alrededor de la zona más antigua de la muralla hay 1. Tormentas de arena que perjudican su conservación 2. Tormentas de arena que perjudican su

		acceso 3. Lluvias torrenciales que perjudican su acceso 4. Lluvias torrenciales que imposibilitan su acceso
Peripheral	En esos lugares, **la altura de la pared se ha reducido entre dos y cinco metros.**	La altura de la pared de la Gran Muralla, se ha reducido 1. Entre dos y cinco metros 2. Entre cinco y seis metros 3. Entre cuatro y seis metros 4. Entre cuatro y seis li
Peripheral	**Muchas secciones occidentales de la muralla se construyeron a partir de barro, en lugar de ladrillo y piedra**, y por lo tanto son más susceptibles a la erosión.	Muchas secciones occidentales de la muralla se construyeron a partir 1. De barro, en lugar de ladrillo y piedra 2. De barro, en lugar de arena y piedra 3. De barro, en lugar de arena y granito 4. De piedra caliza, en lugar de arena y granito

Text 2: El Monte Vesubio

Information unit condition	Spanish sentence	Question and options
Central	**El Monte Vesubio es un volcán situado entre las antiguas ciudades romanas de Pompeya y Herculano en la región de** Campania,	El Monte Vesubio es un volcán situado entre 1. Pompeya y Herculano en la región de Campania 2. Nápoles y Herculano en la región de Campania 3. Nápoles y Bari en la región de Campania 4. Nápoles y Bari en la región de Calabria
	cerca de la moderna ciudad de Nápoles y situada alrededor de la bahía que recibe el mismo nombre en la provincia de Nápoles.	
Peripheral	**El nombre Pompeya derivaría del idioma osco pumpe (cinco)**, porque probablemente la ciudad se había formado a partir de cinco aldeas.	El nombre Pompeya derivaría 1. Del idioma osco *pumpe* (cinco) 2. Del idioma latino *pumpe* (cinco) 3. Del idioma latino *pumpe* (ocho) 4. Del idioma itálico *pella* (ciudad antigua)
Peripheral	**Herculano en su tiempo fue más pequeña que Pompeya,**	Herculano 1. Era más pequeña que Pompeya 2. Era más grande que Pompeya 3. Tenía el mismo tamaño que Pompeya 4. Tenía los mismos habitantes que Nápoles
	pero sus más mundanos comerciantes y mercaderes eran más ricos, cultos e intelectuales que la élite de la vecina Pompeya.	

	Herculano era una ciudad próspera, muy conocida como sitio de vacaciones para los más poderosos y estaba más cerca del volcán Vesubio que Pompeya.	
Central	**El monte Vesubio recibió mucha atención por sus erupciones frecuentes** y destructivas.	El Monte Vesubio 1. Recibió mucha atención por sus erupciones frecuentes 2. Recibió mucha atención por sus erupciones infrecuentes 3. Recibió poca atención por sus erupciones infrecuentes 4. Fue ignorado por su inactividad
Central Unit that was used for the skim condition	**La más famosa de las erupciones ocurrió en el año 79 después de Cristo.**	¿Cuándo ocurrió la más famosa de las erupciones? 1. En el año 79 después de Cristo 2. En el año 79 antes de Cristo 3. En el año 1944 4. Nunca ocurrió. Es una leyenda
	Hasta aquel momento el volcán había estado inactivo durante siglos.	
	Hubo una pequeña advertencia de que la erupción iba a llegar: un testimonio escrito desenterrado por los arqueólogos dice que una fuerte lluvia y un fuerte viento habían perturbado la calma durante la noche anterior.	
	Además, diecisiete años antes Pompeya fue destruida por un potente terremoto.	
Peripheral	**Algunos de los daños no habían sido aún reparados cuando el volcán entró en erupción.**	En el momento de la erupción, los daños del terremoto anterior 1. No habían sido aún reparados 2. Habían sido reparados 3. Habían sido ignorados 4. Iban a ser estudiados

	Sin embargo, no está claro si este suceso está relacionado con la erupción del volcán.	
	La mañana de la erupción, una columna de humo comenzó a ascender desde el volcán Vesubio.	
	La población pensó que se trataba de un escape más de humo.	
	El volcán esta vez derramó un enorme río de roca fundida abajo, sobre Herculano, enterrando la ciudad y llenando el puerto de lava coagulada.	
Central	Mientras tanto, **en el otro lado de la montaña, piedras y cenizas cayeron sobre Pompeya**.	En un lado de la montaña 1. Piedras y ceniza cayeron sobre Pompeya 2. Piedras y lava fundida cayeron sobre Pompeya 3. Piedras y lava fundida cayeron sobre Nápoles 4. Tierra y lava fundida cayeron sobre Nápoles
	Cayó ceniza ardiente que rápidamente incendió los techos de las casas.	
	Pompeya fue destruida casi en su totalidad por la lava.	
	La destrucción fue causada también por el fuego y los gases sulfúricos que saturaron el aire.	
Peripheral	**Estos gases se hundían hacia la tierra y la gente se ahogaba.**	Los gases 1. Se hundían hacia la tierra y la gente se ahogaba 2. Se hundían hacia la tierra y la gente se podía salvar 3. Salían del mar y la gente se ahogaba 4. Iban hacia el mar y la gente se podía salvar
	A lo largo de los años, las	

	excavaciones en Pompeya y Herculano han revelado mucho sobre el comportamiento del volcán.	
Central	Mediante el análisis de los datos, **los científicos han concluido que la erupción cambió gran parte de la geografía de la zona.**	Los científicos han concluido que la erupción 1. Cambió gran parte de la geografía de la zona 2. Dejó sin cambio gran parte de la geografía de la zona 3. Cambió gran parte del comercio marítimo 4. No cambió gran parte del comercio marítimo
Peripheral	Por ejemplo, **la geografía fue afectada por el cambio del curso del río Sarno y el aumento de la arena de la playa.**	La geografía después de la erupción se vio afectada por el cambio 1. Del curso del río Sarno y el aumento de la arena de la playa 2. Del curso del río Sarno y la disminución de la arena de la playa 3. Del curso del río Sarno y la disminución del agua del mar 4. Del curso del río Tíber y la disminución del agua del mar
	Los meteorólogos que estudian estos eventos también han llegado a la conclusión de que el Vesubio causó un enorme maremoto que afectó al clima del mundo.	
Central	Además de hacer estas investigaciones sobre los cambios geográficos y climáticos, **los arqueólogos han podido estudiar los esqueletos fosilizados de las víctimas,**	Los arqueólogos han podido estudiar 1. Los esqueletos fosilizados de las víctimas 2. Los esqueletos fosilizados de los animales 3. Los restos de comida fosilizada 4. Los restos de los edificios

	mediante el uso de agua destilada para quitar la ceniza volcánica.	
Peripheral	**Los huesos estaban en malas condiciones por lo que tuvieron que ser fortalecidos con pintura acrílica.**	Los arqueólogos fortalecieron los huesos 1. Pintándolos con pintura acrílica 2. Pintándolos con pintura al óleo 3. Pintándolos con una solución de aleación de metales 4. Inyectándolos de calcio debajo de la superficie
Peripheral	Tras este proceso, **los arqueólogos pudieron sacar conclusiones acerca de la dieta y los hábitos de los residentes.**	Los arqueólogos han podido sacar conclusiones 1. Sobre la dieta y los hábitos de los residentes 2. Sobre la dieta y la religión de los residentes 3. Sobre la vestimenta y la religión de los residentes 4. Sobre la vestimenta y la religión de los judíos
	Por último, desde las excavaciones de Pompeya y Herculano se han recogido muchos ejemplos del arte clásico, como joyas de bronce,	
Peripheral	**que es una aleación de cobre y estaño.**	El bronce es una 1. Aleación de cobre y estaño 2. Aleación de cobre y hierro 3. Desintegración de cobre y hierro 4. Desintegración de oro y hierro
Central	**La erupción del Monte Vesubio y sus trágicas consecuencias nos han proporcionado una gran cantidad de datos sobre el efecto que los volcanes** pueden causar en los alrededores.	La erupción del volcán y sus consecuencias nos han proporcionado 1. Una gran cantidad de datos sobre el efecto de

		los volcanes 2. Una gran cantidad de datos sobre el efecto del terremoto 3. Una gran cantidad de documentos sobre el efecto del terremoto 4. Una escasa cantidad de datos sobre el funcionamiento del maremoto
	El Vesubio tuvo su última erupción en el año 1944, durante la Segunda Guerra Mundial. Actualmente tres millones de personas viven cerca del volcán que está aún activo.	
Central	**Alrededor del volcán, el área se divide en zonas roja, amarilla y azul.**	El área alrededor del volcán se divide en 1. Zona roja, amarilla y azul 2. Zona roja, amarilla y verde 3. Zona roja, naranja y verde 4. Zona negra, naranja y verde
Central	**La zona inmediatamente alrededor del volcán, que es la zona roja, se encuentra en mayor peligro.**	La zona inmediatamente alrededor del volcán 1. Es la zona roja y se encuentra en mayor peligro 2. Es la zona roja y se encuentra en menor peligro 3. Es la zona negra y se encuentra en menor peligro 4. Es la zona negra y no se encuentra en peligro
Peripheral	**Esta zona está potencialmente en peligro por las posibles invasiones de flujos piroclásticos, o mezcla de gases y sólidos** a alta temperatura.	La zona roja está en peligro por las invasiones de 1. Flujos piroclásticos, o mezcla de gases y sólidos

		2. Flujos piroclásticos, o mezcla de gases y lava fundida 3. Flujos piroclásticos, o mezcla de cenizas y líquidos 4. Flujos de sedimentos, o mezcla de cenizas y líquidos
	Esta mezcla podría destruir con rapidez todo lo que se encuentra en su camino a gran velocidad.	
Central	**La zona roja entera se evacuaría a zonas seguras.**	La zona roja 1. Se evacuaría entera a zona segura 2. Se evacuaría entera a zonas próximas 3. Se evacuaría parcialmente a zonas más alejadas 4. No se evacuaría
	Los habitantes de los 18 municipios estarían fuera de peligro.	
	La zona amarilla presenta un riesgo menor que la zona roja	
Peripheral	y corresponde a toda la zona que se vería afectada por las consecuencias de **las partículas piroclásticas - ceniza y lapilli - que pueden, entre otras cosas, proporcionar una sobrecarga excesiva en los tejados de los edificios** hasta producir el colapso.	Las partículas piroclásticas pueden causar 1. Una sobrecarga excesiva de los tejados de los edificios 2. Una sobrecarga excesiva de los muros de los edificios 3. Una pequeña carga sobre los muros de las casas 4. Una sobrecarga mínima de las puertas de las casas
Peripheral	**La precipitación de partículas también puede causar problemas a los cultivos y al tráfico.**	La precipitación de partículas podría causar 1. Problemas a los cultivos y al tráfico 2. Problemas a los cultivos y al turismo

		3. Problemas a los edificios y a la ganadería 4. Mejoras a los cultivos
	La zona azul cae dentro de la zona amarilla, pero está sujeta a un riesgo de agentes adicionales.	
Peripheral Unit that was used in the skim condition	**La zona azul corresponde al valle de Nola** que, por sus características hidrogeológicas podría estar sujeta a inundaciones y desbordamientos, así como a consecuencias derivadas de las cenizas y lapillis.	¿A qué corresponde la zona azul? 1. Al valle de Nola 2. Al valle de Sola 3. Al valle de los molinos 4. Al Monte Blanco
Central	Hoy **los vulcanólogos pueden localizar y predecir erupciones,** salvar vidas y prevenir la destrucción de ciudades y culturas.	Los vulcanólogos 1. Pueden localizar y predecir erupciones 2. Pueden localizar, pero no pueden predecir erupciones 3. Pueden localizar, pero no pueden predecir terremotos 4. No pueden localizar ni predecir terremotos
	La erupción del volcán no es inminente, pero será precedida por desprendimientos de vapores y terremotos	
Central	ya identificados con bastante antelación desde **el Instituto Nacional de Geofísica y Vulcanología de Nápoles, que monitoriza el estado del volcán** las 24 horas.	La institución que monitoriza la actividad del volcán es 1. El Instituto Nacional de Geofísica y de Vulcanología de Nápoles 2. El Instituto Internacional de Geofísica y de Vulcanología de Nápoles 3. El Instituto Internacional de Geofísica y de Vulcanología italiano 4. El Instituto Internacional de Geografía y de

Vulcanología italiano

Text 3: Papúa Nueva Guinea

Information unit condition	Spanish sentence	Question and options
Central	**Papúa Nueva Guinea - el Estado Independiente de Papúa Nueva Guinea - es un país de Oceanía**	Papúa Nueva Guinea es 1. Un Estado Independiente de Oceanía 2. Un Estado Independiente de Asia 3. Un Estado Dependiente de Asia 4. Una Republica Dependiente de África
Peripheral	que **ocupa la mitad oriental de la isla de Nueva Guinea** y una numerosa cantidad de islas situadas alrededor de esta.	Papúa Nueva Guinea ocupa 1. La mitad oriental de la isla de Nueva Guinea 2. La mitad occidental de la isla de Nueva Guinea 3. La mitad occidental de la isla de Mauricio 4. La parte entera de la isla de Mauricio
	Su forma de gobierno es la monarquía parlamentaria	
Peripheral	**y su territorio está organizado en veintidós provincias divididas en distritos.**	El territorio de Papúa Nueva Guinea está organizado en 1. Veintidós provincias divididas en distritos 2. Cuarenta provincias divididas en distritos 3. Treinta provincias divididas en comunidades 4. Veintidós estados agrupados en comunidades

	La capital de Papúa Nueva Guinea y su ciudad más poblada es Puerto Moresby. Está situada al norte de Australia, al oeste de las Islas Salomón y al suroeste del océano Pacífico, en una región definida como Melanesia.	
Central	**Papúa Nueva Guinea es uno de los países con mayor diversidad cultural del mundo**	Papúa Nueva Guinea es uno de los países con 1. Mayor diversidad cultural del mundo 2. Menor diversidad cultural del mundo 3. Menor diversidad lingüística del mundo 4. Más uniformidad geográfica del mundo
Peripheral This unit was used in the skim condition	**y en donde se han contabilizado hasta 848 dialectos distintos**	¿Cuantos idiomas se contabilizaron en Papúa Nueva Guinea? 1. Hasta 848 dialectos distintos 2. Hasta 949 dialectos distintos 3. Hasta 949 dialectos africanos 4. Solo 300 lenguas asiáticas
Central	**Aún sigue siendo un país escasamente poblado, solo con 7 millones de habitantes.**	Papúa Nueva Guinea sigue siendo 1. Un país escasamente poblado con 7 millones de habitantes 2. Un país escasamente poblado con 15 millones de habitantes 3. Un país muy poblado con 30 millones de habitantes 4. Una región muy poblada con 30 millones de

		habitantes
Central	Además, **tiene una población ampliamente rural, ya que solo el 18% de la población está concentrada en núcleos urbanos.**	Papúa Nueva Guinea tiene una población 1. Rural, el 18% de la población vive en núcleos urbanos 2. Rural, el 52% de la población vive en núcleos urbanos 3. Rural, el 46% de la población vive en zonas campestres 4. Metropolitana, el 24% de la población vive en zonas campestres
Central	**Es uno de los países menos explorados, geográfica y culturalmente**, y muchas especies de plantas y animales están aún sin descubrir dentro del país.	Papúa Nueva Guinea es uno de los países 1. Menos explorados, geográfica y culturalmente 2. Menos explorados, geográfica pero no culturalmente 3. Más explorados, geográfica y socialmente 4. Más explotados, geográfica y económicamente
	El fuerte crecimiento de la minería en Papúa Nueva Guinea ha incrementado la economía hasta convertirse en el sexto país con el mayor incremento económico en 2011.	
Central	A pesar de ello **mucha gente se encuentra en la pobreza extrema, viviendo con menos de 1,25 $ diarios.**	En Papúa Nueva Guinea mucha gente vive 1. En la pobreza extrema con menos de 1,25 $ diarios 2. En la pobreza extrema con menos de 0,50 $ diarios 3. En la pobreza extrema con menos de 500 $ mensuales

		4. En la riqueza extrema con más de 2000 $ mensuales
	La mayor parte de la población vive aún de forma muy tradicional y su agricultura es de subsistencia.	
Central	**La presencia europea en Papúa Nueva Guinea trajo cambios culturales** para los habitantes de esta isla y de la isla vecina.	En Papúa Nueva Guinea, la presencia de 1. Europeos trajo cambios culturales en la isla y en las vecinas 2. Europeos trajo cambios culturales en la isla, pero no en las vecinas 3. Asiáticos trajo cambios culturales en la isla, pero no en las vecinas 4. Africanos trajo cambios económicos en la isla, pero no en las vecinas
	Cuando los primeros exploradores europeos llegaron a las islas, los habitantes tenían un sistema de agricultura productivo en el que aún se utilizaban herramientas de hueso, de madera y de piedra.	
Peripheral	**Comerciaron con los isleños a lo largo de la costa principalmente con productos cerámicos, adornos de conchas y productos alimentarios básicos.**	Los isleños comerciaban productos 1. Cerámicos, adornos de conchas y productos alimentarios básicos 2. Cerámicos, adornos de piedras y productos alimentarios básicos 3. De madera, adornos de piedras y productos alimentarios básicos 4. De madera, adornos de piedras y

		productos textiles
Peripheral	También se adentraron a otras zonas, pues **intercambiaron productos del bosque por bienes marinos.**	Los isleños 1. Intercambiaron productos del bosque por bienes marinos 2. Intercambiaron productos del bosque por bienes industriales 3. Vendieron productos del bosque por dinero 4. Vendieron productos artesanales por dinero
	Probablemente fueron los navegantes portugueses y españoles los que avistaron primero Nueva Guinea a principios del siglo XVI.	
Central	Entre 1526 y 1527, **don Jorge de Meneses llegó a la isla principal y la llamó Papúa, una palabra malaya que designa el carácter rizado del pelo de los melanesios.**	Don Jorge de Meneses llamó a la isla 1. Papúa, que representa el pelo rizado de los melanesios 2. Papúa, que representa el pelo liso de los melanesios 3. Guinea, que representa el pelo liso de los melanesios 4. Guinea, que representa el pelo rubio de los australianos
Central	En 1545, **el español Yñigo Ortiz de Retez añadió el término Nueva Guinea al nombre de la isla al observar un parecido entre los habitantes de la isla y los de la costa africana de Guinea.**	Yñigo Ortiz de Retez añadió el termino Nueva Guinea por el parecido 1. Entre los isleños y los de la costa africana de Guinea 2. Entre los isleños y los de la costa

		americana de Guinea 3. Entre los isleños y los del interior americano de Guinea 4. Entre los isleños y los del interior europeo de España
	No se sabía mucho de sus habitantes hasta que el antropólogo ruso Nicolai Miklukho-Maklai convivió varios años con las diferentes tribus y describió su modo de vida en un extenso informe.	
Peripheral	Posteriormente otro antropólogo polaco **Bronislaw Malinowski estudió a los habitantes de las islas Trobriand durante la Primera Guerra Mundial** y se quedó aislado.	El antropólogo Bronislaw Malinowski estudió a 1. Los habitantes de las islas Trobriand en la Primera Guerra Mundial 2. Los habitantes de las islas Trobriand en la Segunda Guerra Mundial 3. Los habitantes de las islas Maldivas en la Segunda Guerra Mundial 4. La fauna de las islas Maldivas en la Segunda Guerra Mundial
Central	**Los territorios de Papúa Nueva Guinea presentaron un fuerte colonialismo de otros muchos países europeos.**	Los territorios de Papúa Nueva Guinea presentaron 1. Un fuerte colonialismo de otros muchos países europeos 2. Un fuerte colonialismo de otros muchos países americanos 3. Un escaso colonialismo de otros países americanos 4. Una escasa influencia de otros países africanos

Peripheral	Por ejemplo, **la parte surorienta l fue colonizada en 1883 por la colonia británica de Queensland, en Australia.**	La parte suroriental fue colonizada en 1. 1883 por la colonia británica de Queensland, en Australia 2. 1883 por la colonia francesa de Queensland, en Australia 3. 1995 por la colonia holandesa de Queensland, en Australia 4. 1883 por la colonia española de Etiopia, en África
Peripheral	**Alemania colonizó la parte nororiental restante en el 1884 llamándola Kaiser-Wilhelmsland.**	La parte nororiental fue colonizada por 1. Alemania en 1884 llamándola Kaiser-Wilhelmsland 2. Alemania en 1995 llamándola Kaiser-Wilhelmsland 3. Francia en 1995 llamándola Kaiser-Wilhelmsland 4. España en 1993 llamándola Asia Nueva
Peripheral	Entre el 1884 y el 1899 **se proclamaron formalmente las colonias de la Nueva Guinea Británica y de la Nueva Guinea Alemana**.	Entre el 1884 y el 1899 se proclamaron formalmente las colonias de 1. La Nueva Guinea Británica y la Nueva Guinea Alemana 2. La Nueva Guinea Francesa y la Nueva Guinea Alemana 3. La Nueva Guinea Francesa y la Nueva Guinea Portuguesa 4. La Antigua Guinea Holandesa y la Antigua Guinea Española

Central	**La colonización trajo consigo consecuencias religiosas. Los europeos quisieron llevar el cristianismo a las islas.**	La colonización trajo consigo consecuencias 1. Religiosas, los europeos quisieron llevar el cristianismo 2. Religiosas, los americanos quisieron llevar el cristianismo 3. Religiosas, los asiáticos quisieron llevar el budismo 4. Culturales, los asiáticos quisieron llevar su gastronomía
	Para ello, fueron enviados misioneros ingleses que formaban parte de un grupo de profesores que llegaron en el año 1875.	
Central This unit was used for the skim condition	**Este fuerte colonialismo provocó numerosos conflictos, como el asesinato de cuatro de estos misioneros**, que además, fueron comidos por caníbales de la zona.	¿Cual es un ejemplo de los conflictos que provocó el colonialismo? 1. Los asesinatos de cuatro misioneros 2. Los asesinatos de ocho misioneros 3. Los asesinatos de nueve políticos 4. El encarcelamiento de seis embajadores
	Estos asesinatos cometidos por la gente de la tribu Tolai en la península de Gazelle, desencadenaron represalias de ira. El pastor ingles George Brown, que era el jefe de la misión vengó los asesinatos, participó en una expedición que resultó en la muerte de un gran número de gente de las tribus y la quema de varios pueblos. Los descendientes de los caníbales que asesinaron y se comieron a los cuatro misioneros en el año 1878 pidieron	

	disculpas por las acciones de sus antepasados.	
Peripheral	**Ellos hicieron una ceremonia de reconciliación, a la cual asistieron millones de personas**, en la provincia de la Nueva Bretaña del este, donde fueron asesinados.	Los descendientes de los caníbales hicieron una 1. Ceremonia de reconciliación, a la cual asistieron millones de personas 2. Ceremonia de reconciliación, a la cual asistieron pocas personas 3. Ceremonia religiosa, a la cual asistieron centenares de personas 4. Reunión política, a la cual asistieron centenares de personas
Peripheral	**Se encendieron velas en memoria de los cuatro asesinados.**	Los descendientes de los caníbales 1. Encendieron velas en memoria de los cuatros asesinados 2. Encendieron velas en memoria de todos los asesinados desde 1900 3. Encendieron antorchas en memoria de todos los asesinados desde 1900 4. Lanzaron fuegos artificiales en memoria de los encarcelados
Peripheral	**El alto comisionado en Papúa Nueva Guinea, Ratu Isoa Tikoca, aceptó las disculpas** en nombre de los descendientes.	En Papúa Nueva Guinea 1. El alto comisionado Ratu Isoa Tikoca aceptó las disculpas 2. El alto comisionado Ratu Isoa Tikoca no aceptó las disculpas 3. El alto embajador don Jorge de Meneses aceptó las

		disculpas 4. El alto embajador Yñigo Ortiz de Retez no aceptó las disculpas
Central	En la actualidad, las elecciones de 1972 dieron paso a la formación de un ministerio dirigido por **Michael Somare, quien prometió implantar un gobierno autónomo para más tarde, en el 1975, alcanzar la independencia.**	Michael Somare prometió implantar 1. Un gobierno autónomo para alcanzar la independencia 2. Un gobierno republicano para alcanzar la independencia 3. Una monarquía constitucional para alcanzar la independencia 4. Un estado totalitario para suprimir la independencia