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Bilingualism in autism:
A neurocognitive investigation of the influence of bilingualism on perspective-taking in autistic adults

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Abstract

Autism spectrum disorder (hereafter autism), is a lifelong neurodevelopmental condition with current prevalence estimates ranging around 1/100 worldwide. Autism is manifest in multiple forms, but always entails differences in communication and interaction behaviours. Consequent difficulties navigating the social world have been linked with altered social cognition, the complex set of cognitive mechanisms used to perceive, process, and respond to social interactions. The development of social cognition draws on social and linguistic inputs received during childhood. Indeed, it is hypothesised that the influence of language may play an additional role in autism, compensating for innate social cognitive difficulties. Thus, it is pertinent to investigate this relationship in an especially varied linguistic environment: bilingualism.

Bilingualism is a skill shared by half the world's population, and encompassing a wide range of language experiences shaped by multiple characteristics. There is considerable interest in the question of whether, and how, bilingualism shapes cognitive processes. Findings suggest that bilingualism does stimulate the development of social cognitive processes in neurotypical children. Does this stimulating effect of bilingualism on social cognition also exist in autism? This question has only been addressed in terms of general social functioning, and only in children or adolescents. Therefore, a dedicated investigation of specific social cognitive processes in adulthood is still lacking.

This thesis explores how bilingualism shapes the social cognitive profiles of autistic adults, also capturing their lived social experiences, and investigating the effects of bilingualism at a neural level. I adopted an innovative approach, setting aside the traditional categorical vision of bilingualism, to rely instead on a multidimensional definition taking into account several key features of the bilingual experience. Before investigating the relationship between bilingualism and social cognition in autistic adults, however, it was necessary to address a number of critical gaps.

The research currently available in the field of autism describes either early bilingual children, or adult polyglots, which is unlikely to represent the majority of bilingual experiences. Therefore, after an introductory chapter, the second chapter of the thesis provides an unprecedented description of the numerous bilingual experiences of autistic adults, gathering responses from a total of 208 bilingual and multilingual autistic adults via an online survey. This chapter also investigates the link between bilingualism and social life

quality in this sample, in comparison with 89 monolingual autistic adults. The results showed that multilingual respondents were more satisfied with their social life than were monolinguals, hinting that linguistic repertoire may shape social functioning in autism.

In the third chapter, I take a step back from autism, to first clarify the relationship between bilingualism and the social cognitive process at the centre of this research, perspective-taking, in typical development. Using a sample of 96 participants with a wide range of bilingual profiles, I found that not all forms of perspective-taking respond uniformly to the influence of bilingualism, and that not all bilingual experiences are equally influential. Specifically, cognitive and affective perspective-taking processes are susceptible to the influence of bilingualism, but not visual perspective-taking, and the main driver of this influence is the age of acquisition of the second language.

In the fourth chapter, I repeated this analysis with a sample of 39 autistic participants. Crucially, the results mirrored those in the neurotypical population: bilingualism showed in autism a developmental influence on cognitive and affective perspective-taking, but not visual perspective-taking, that endures into adulthood.

The fifth chapter is an exploratory investigation of the neural correlates of this developmental influence of bilingualism on perspective-taking. A sample of 15 neurotypical and 17 autistic participants were recruited into early and late bilingual groups. Early and late bilinguals showed in the anterior cingulate gyrus a tendency for distinct activity patterns during cognitive perspective-taking, and autism did not alter this effect, suggesting that the influence of early bilingualism on the neural basis of perspective-taking is similar between autistic and neurotypical populations.

My findings are the first to highlight the richness of the bilingual experience of autistic people, and to describe a long-lasting developmental stimulating influence of early bilingualism in autistic and neurotypical adults alike. The research presented in this thesis has implications in numerous academic disciplines, but most importantly will inform practices to support autistic people in their bilingualism journey.

Lay summary

Autism is a lifelong neurodevelopmental condition shared by approximately 1% of the world's population. Autism is characterised by atypical sensory sensitivity, repetitive behaviours, and differences in communication and interaction behaviours. Consequent difficulties navigating the social world have been linked with altered social cognition, the complex set of cognitive mechanisms used to perceive, process, understand, and respond to social interactions. In non-autistic populations, the development of these cognitive mechanisms relies on language, and it is stimulated by the rich language environment that is bilingualism. Can bilingualism also stimulate these social cognitive mechanisms in autism?

This is the question at the centre of this thesis. The research presented here explores the influence of bilingualism upon social abilities in autism, at three levels of social processes. After highlighting the unexpected richness and diversity of bilingual experiences existing in autistic adults, I first report how bilingualism is associated with a more satisfying self-rated social life for autistic adults. Secondly, I describe how bilingualism influences a key social cognitive process called perspective-taking, involved in our ability to represent in our own mind what other people think or feel. Crucially, I found that this stimulating influence of bilingualism started during childhood, with long-lasting effects that are still present in adulthood. Most importantly, I found that this positive effect of early bilingualism occurred in autistic and neurotypical adults alike. Building upon these findings, I assessed the activity of the brain while perspective-taking, and found that in one specific brain region, the activity varied between early and late bilinguals. Again, I found that this relationship between bilingualism and social processes was similar for both autistic and neurotypical adults.

Taken together, my findings are the first to highlight the richness of the bilingual experience of autistic people, and to describe how childhood bilingualism shapes social processes, with benefits enduring into adulthood, in autism just as in typical development.

Declarations

I declare that this thesis was composed by myself, and, except where stated otherwise, is entirely my own work. The research presented hereafter has not been submitted for any other degree or professional qualification.

This thesis includes one published article:

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Chapter 1: Introduction

This thesis explores how bilingualism shapes the social cognitive profiles of autistic adults. Social cognitive abilities, and especially the many forms of perspective-taking, are at the centre of this research. However, focusing exclusively on cognitive abilities would have only presented a fraction of the social characteristics of autistic bilinguals. Therefore, this research expands beyond the domain of cognition into both the lived social experiences of autistic people and the neural correlates of social processing. This thesis positions itself at the crossroad between autism, bilingualism, and social abilities, with a global and interdisciplinary approach, charting new territory for autism research. In the over-arching introduction below, I review the literature on autism, bilingualism, and social cognition, highlighting the overlap between these themes, and setting the scene for my research.

I. Autism

Autism spectrum disorder (ASD), hereafter autism, is a lifelong neurodevelopmental condition with a complex range of manifestations. Autism is characterised by atypical sensory sensitivity, repetitive behaviours, and difficulties in communication and interaction behaviours (American Psychiatric Association, 2013). Autism exists in a range of manifestations, at all levels of ability. Each person with autism can experience a specific combination of strengths and difficulties in the characteristics of autism, and this combination can change over time. The current estimated prevalence of autism in the United Kingdom is 1/100 (Baird et al., 2006), or 1/132 worldwide (Baxter et al., 2015).

A. Social life and social functioning in autism

Social interactions are often a source of great difficulty for autistic people, thus causing challenges in many aspects of their daily life (Feldhaus, 2015), for example in communication with relatives, in creating and maintaining friendships, but also at work, or in the community. Autistic adults indeed rate their social life quality as more problematic and less satisfactory than do neurotypical adults (Feldhaus, 2015; Schmidt et al., 2015), which is alarming as the ability to engage in social activities is for them a key aspect of general life satisfaction (Kim &

Bottema-Beutel, 2019; Mason et al., 2018). Therefore, being able to interact more fluently and comfortably could be one step towards more satisfying lives for autistic people.

B. Social cognition in autism

Our ability to navigate the social world involves social cognition, a complex set of multiple cognitive mechanisms used to perceive, process, understand, and respond to social interactions (Happé et al., 2017). The development of social cognition draws on the social and linguistic inputs received during childhood (Apperly et al., 2009; Garfield et al., 2001), and it is a crucial step for our functioning; it enables us to make sense of our social world, from the identification of social signals to the prediction of others' behaviours. Social cognition is used for social interactions by everybody, every day.

Previous research has highlighted that in autism, a key element underpinning social functioning is indeed social cognitive skills (Bishop-Fitzpatrick et al., 2017; Frith, 2001; Sasson et al., 2020). Social cognitive difficulties in autism occur in different types of processes, from basic mechanisms such as joint attention, imitation (Bottema-Beutel et al., 2019) or facial emotion recognition (Peñuelas-Calvo et al., 2019), to highly complex processes such as theory of mind (Chung et al., 2014; Pinkham et al., 2019; Velikonja et al., 2019). For example, drawing on a large sample (n = 108) of autistic people aged between 9 and 27.5, Bishop-Fitzpatrick et al. (2017) found that high social cognitive skills were associated with better social functioning, regardless of age, gender, or general intelligence. In a similarly robust study (n = 103) with autistic adults, Sasson et al. (2020) found that social cognition influenced social functioning beyond the role of other cognitive skills such as processing speed, working memory, or general intelligence. Thus, it is essential to better understand the social cognitive abilities of autistic people, as this could help them reach more satisfying social and general quality of life.

The specific influence of language on social cognitive development previously mentioned may play an additional role in autism, compensating for innate social cognitive difficulties (Farrar et al., 2017; Hamilton et al., 2016). As such, the interplay between language and social cognitive processes is particularly important for the later social functioning of autistic people. However, this relationship remains poorly understood, even in typical development. Slade & Ruffman (2005) found that in neurotypical children (n = 44) aged between 3 and 4 whose language and social cognitive abilities had been measured twice, six months apart, early language abilities predicted later social cognitive skills. A meta-analysis by Milligan et al. (2007), that included 104 studies and 8,891 neurotypical children under the age of 7, supported these findings, and reported that children's language abilities had a moderate to strong effect on their social cognitive abilities, regardless of their age. However, the findings currently available only highlight the critical relationship between language and social cognition during development. As such, it is possible that language is only crucial during the emergence of social cognition in childhood, but another possibility is that language and social cognition are fully intertwined, with language abilities shaping social cognition throughout life. Following the findings that environments rich in language inputs stimulate social cognition, it is pertinent to investigate this relationship in an especially varied linguistic environment: bilingualism.

C. Language in autism

Before examining the question of bilingualism in autism, it is necessary to first consider the language abilities of autistic people. The range of language profiles amongst people with autism is indeed remarkably wide. Between 15 and 25% of autistic children are minimally- or non-verbal (Norrelgen et al., 2015), but most people with autism do develop language (Brignell et al., 2018). Autistic people with language show typical or even enhanced language skills (Hyltenstam, 2016), with or without peculiar language or speech patterns (Gernsbacher et al., 2016). Importantly, the presence of language impairments is distinct from general non-verbal cognitive abilities, as recently described by Silleresi et al. (2020). In a sample of 51 autistic children aged 6 to 12, including 14 bilinguals, authors found that language impairments existed at both low and average non-verbal intelligence, just as typical language could occur at low, average, and high non-verbal intelligence. Remarkably, both bilingual and monolingual children were found in each of these five profiles.

Autism is frequently associated with difficulties with pragmatics (Tager-Flusberg et al., 2005; Walenski et al., 2006), the practical ability to interpret language beyond its literal meaning, which is particularly crucial in social situations. Common speech impairments seen in autism, especially in children, are echolalia (the repetition with similar intonation of what another person said), pronoun reversal (for example using "you" when meaning "I"), and stereotyped language (for example over-using routine expressions), which can all greatly hinder the clarity of what the person is trying to express (Tager-Flusberg et al., 2005; Walenski et al., 2006). Beyond these common speech difficulties, language impairments have also been reported in phonology (the sound patterns of a language), morphology (the structure of words as a combination of meaningful parts), and syntax (sentence structure), while lexical knowledge (vocabulary) is generally intact (Walenski et al., 2006).

II. Bilingualism

A. Defining bilingualism

Bilingualism, a skill shared by half the world's population, is intuitively defined as the knowledge of more than one language (Grosjean, 2010). However, the term effectively refers to a wide range of experiences, and includes people who:

- Know two or more languages,
- Know spoken and / or signed languages: bimodal bilinguals,
- Learned at least two languages from birth: simultaneous bilinguals,
- Learned the second language during childhood: early sequential bilinguals,
- Learned the second language after childhood: late sequential bilinguals,
- Have equivalent abilities in their languages: balanced bilinguals,
- Have stronger and weaker languages: unbalanced bilinguals.

In this diversity of bilingual profiles, the simultaneous balanced bilingual is the exception rather than the rule. Therefore, in the midst of this diversity of bilingual experiences, investigating the cognitive profiles of bilinguals and the cognitive influence of bilingualism is particularly challenging. There seems to be evidence for a "bilingual advantage" in some aspects of cognition, where bilinguals outperform their monolingual peers, but as introduced here, the distinction between bilinguals and monolinguals is not as neat as often thought. In this continuum of experiences, grouping bilinguals for the purpose of research can be an intricate task, and requires the consideration of several key variables that have been described as crucial in shaping the influence of bilingualism: the number of languages known, the age of acquisition of each language, the proficiency in these languages, and the amount of language switching in the daily life.

Age of acquisition of the second language has often been used by researchers as a selection criterion for bilingual participants, since bilingual exposure received during a sensitive period in childhood is expected to have a stronger impact than later in development (Johnson & Newport, 1989), though this hypothesis of a critical period for the bilingualism effect is still debated. For instance, when researching social cognitive processes, Rubio-Fernández & Glucksberg (2012) only included participants who had acquired their second language before age 9, while Javor (2017) set an age of acquisition limit at 6. Researching the influence of the age of acquisition of the second language on executive function with a task involving inhibition and attention switching, Kalia et al. (2014) did report a lower accuracy in late bilingual adults compared with early bilingual adults. Paap et al. (2014) found that while there was a bilingual advantage in managing task conflict for simultaneous bilinguals, this advantage was not found when comparing monolinguals to early sequential bilinguals. These studies suggest that age of acquisition may not always be reliable as a selection criterion. However, these results were obtained within the context of executive functioning, and the age of acquisition may be a more prevalent feature of the bilingual effect on other cognitive domains.

Language proficiency, either self-rated, parent-rated, or measured with standardised tests, is also a parameter often used to label bilinguals. Some researchers approached the matter of proficiency as a balance index, calculated as a ratio between each language's proficiency. Using such an index, Paap et al. (2014) found that, in a sample of 384 university students, increased proficiency balance was linked with increased Simon effect (the interference observed when the stimulus and the response have mismatched features), but did not predict the Flanker effect (the interference produced by irrelevant stimuli when responding to a target stimulus), or switching costs (linked to the cognitive effort of switching between tasks). These findings indicate that language proficiency, and particularly the proficiency balance across multiple languages, may be a key factor for the investigations of certain cognitive abilities.

The number of languages known can also potentiate the influence of bilingualism. Schroeder & Marian (2017) reported that knowing three languages appears to provide a larger advantage for cognitive reserve in older adults, while bearing the same benefits as bilingualism for inhibitory control in children and young adults. In infants and toddlers however, trilingualism did not yield the same benefits on memory generalisation as bilingualism. Thus, it seems that this variable, rarely investigated, is not to be set aside.

Finally, the way bilinguals use their languages is a key feature of the bilingual experience. Recent studies on executive skills highlighted that high levels of language switching is related to enhanced executive control (Green & Abutalebi, 2013; Verreyt et al., 2016). Verreyt et al. (2016) found that for equivalently balanced bilingual adults, those used to often switching between languages had higher executive skills than those rarely switching between languages. Hartanto & Yang (2016) also reported that bilingual adults used to language switching in a single context show smaller switch costs than bilingual adults used to speaking each language in different contexts, even though both groups display similar task switching performances. Thus, language switching experience may have a greater influence than proficiency. This finding is highly relevant to social processes, since language switching is triggered in the environment by social prompts. Drawing on these diverse findings from studies of the links between bilingualism and executive processes, I will incorporate measures of age of acquisition, proficiency, balance, number of languages known and language switching habits into this research.

Multiple other factors can shape the bilingual experience, such as the quality and quantity of the exposure to the languages (Green & Abutalebi, 2013; Verreyt et al., 2016), making measurement of the effects of bilingualism almost as complex as measurement of the effects of being autistic. For example, Bonfieni et al. (2019) found a role for language exposure, in that after controlling for age of acquisition and proficiency, higher exposure to the second language predicted smaller delay when bilinguals switch between using their first language alone and using it alongside their second language. This suggests that daily exposure to a second language changes bilingual adults' ability to switch between single- and dual-language contexts. These findings also bring into play larger sociolinguistic factors: for example, as discussed by Tabori et al. (2018), bilinguals with languages uncommon in their environment may be unable to use their languages frequently, and therefore may not show the same executive abilities as bilinguals with high exposure to both their languages.

However, when researching the influence of bilingualism on cognition, it is also necessary to account for the possibility that for certain cognitive skills a plateau of abilities is generally reached in adulthood, making any effect of bilingualism more delicate to identify in young adults. For instance, Bialystok et al. (2005) described that bilingual children, adults, and older adults displayed higher inhibitory control than their monolingual peers, but that this bilingual effect was not observed in young adults.

As such, defining a threshold above which one can be considered bilingual is a sensitive matter and varies between authors and fields. Providing a consistent definition of bilingualism valid across disciplines may never be possible (Bassetti & Cook, 2011). These discrepancies could explain the conflicting results found in bilingualism research (Luk & Bialystok, 2013b). Researchers who adopt a binary framework for bilingualism, comparing bilinguals and monolinguals, may select bilingual participants based on different criteria, often relying on age of acquisition or proficiency cut-offs. However, as the various features of the bilingual experience can differently impact cognition (see Chapter 1 section II.A above), relying on different definitions of bilingualism, and different inclusion criteria, can lead to contrasting findings (Kroll & Bialystok, 2013). For example, Emmorey et al. (2008) found that while accuracy on a set of tasks assessing the Flanker effect was similar between 15 monolingual, 15 unimodal bilingual (knowing two spoken languages), and 15 bimodal bilingual (knowing a spoken and a signed language) adults, unimodal bilinguals were faster than both other groups, and bimodal bilinguals did not differ from monolinguals. This finding illustrates how bilingual populations can differ from each other as much as they can differ from monolinguals.

B. Social cognition in bilingualism

There is considerable interest in the question of whether, and how, bilingualism shapes cognitive processes, including social cognition. Research on the cognitive effects of bilingualism has largely focused on executive functioning (see Donnelly et al. (2019) and van den Noort et al. (2019) for recent meta-analyses and systematic reviews), and studies on the interplay between bilingualism and social cognition are more scarce (Bak, 2016). What research there is, however, tends to indicate a positive effect of bilingualism on social cognitive skills.

In a meta-analysis of the bilingual effect on perspective-taking (a social cognitive process further described in Chapter 3 and Chapter 4) in children, Schroeder (2018) reviewed 16 studies, for a total of 655 monolinguals and 628 bilinguals. Results showed a small bilingual advantage, increasing to a medium-sized effect when only focusing on the 8 studies that controlled for the language proficiency of the children. These findings support the hypothesis that bilingualism improves certain social cognitive abilities in children.

However, studies in adulthood are undeniably scarcer. For example, Rubio-Fernández & Glucksberg (2012) reported a bilingual advantage in the looking patterns of monolingual (n = 23) and bilingual (n = 23) university students during a false-belief task, with bilinguals being less sensitive to their egocentric bias. A bilingual advantage was also found by Javor (2017) in a large sample of 240 young adults, in their ability to explicitly interpret short social stories and the thoughts of their protagonists. Together, these preliminary findings suggest that the positive influence of bilingualism on social cognitive skills found in childhood persists in adulthood, although these results must be replicated.

As mentioned above, the social cognitive outcomes of bilingualism are drastically under-researched compared to other cognitive domains, especially executive function skills. Interestingly, this interplay between bilingualism and social cognition has hardly been investigated in the context of autism, in spite of its distinctive social cognitive singularity.

III. Overlap between autism and bilingualism

A. An impossible combination?

The undeniable lack of research in the domain of the social cognitive influence of bilingualism in autism echoes the general dearth of research on bilingualism in autism. This is visible for example in the recently published Handbook of Neuroscience of Multilingualism (Schwieter, 2019), where "autism" is only mentioned twice. However, the overall portrait of the language abilities of autistic people does not exclude bilingualism, and if half the world's population is bilingual or lives in a bilingual environment, then so should be half the world's autistic population (De Oliveira, 2015). However, bilingualism is still often wrongly perceived as a heavy and expendable cognitive burden in autism (Hampton et al., 2017; Park, 2014). If a child is already having difficulties, or expected to have difficulties, with language, social communication, and other key abilities during development, parents and professionals may think "why add the challenge of a second language?"

B. Current landscape: children, parents, and practitioners

Most of the studies investigating the topic of bilingualism in autism focus on children, parents' perspectives, or practitioners' perspectives. This lack of experimental data leads practitioners to give uninformed advice to bilingual parents of autistic children. Parents have reported abandoning their native language to reinforce the majority language of the environment with the child so that they may access the services they need (Kay-Raining Bird et al., 2012, 2016). This forced use of the non-native language can induce difficulty or discomfort speaking to the child, sometimes leading to reduced communication with the child (Kay-Raining Bird et al., 2016), though this may not be the case when parents are already fluent in the majority language (Hudry et al., 2018). In turn, this can lead to poor quality and quantity of linguistic, meta-linguistic, and social inputs for the child, all of which are essential for the development of linguistic, communicative and social skills (De Oliveira, 2015). Furthermore, raising a child with autism monolingually in a bilingual household can have severe consequences in the child's identity formation and access to cultural heritage (Park, 2014). In contrast, some parents choose to maintain bilingualism exposure to help the child bond with their family and expand their social relationships (Jegatheesan, 2011), but they are then often unsupported by practitioners and services (Hampton et al., 2017; Kay-Raining Bird et al., 2012). Addressing this matter is critical, as it concerns the means of communication between the child and their family and community, and these interactions are decisive for the child's development. For this reason, the choice of language environment should be based on the children and families' functioning and needs (Yu, 2013). Recently, special education policies have started to recognise the need to incorporate the minority language of the children into their interventions, but practices are still lagging behind (de Valenzuela et al., 2016; Lim et al., 2019; Smith et al., 2018; Trelles & Castro, 2019).

Most studies involving bilingual autistic children focus on their language development, addressing the concern that bilingualism would hinder or delay their linguistic abilities. In a systematic review gathering eight studies, for a total of 182 children and 62 parents, Drysdale et al. (2015) found that while most parents had been advised against bilingualism by their practitioner, bilingualism did not have any impact on the language development of the children, when compared to their monolingual peers. Another review assessing the cognitive, linguistic and behavioural outcomes of autistic bilingual children across 9 studies (including 5 studies reviewed by Drysdale et al.) also highlighted some potential areas for a bilingual advantage on certain cognitive abilities, such as non-verbal intelligence and adaptive functioning (Wang et al., 2018). However, taken together these two reviews only include a total of 12 studies, covering cognition, behaviour, and language, illustrating the dearth of literature in the field of bilingualism in autism. Therefore, while these findings suggest that parents and practitioners' main reason to abstain from bilingualism is unfounded, the relationship between bilingualism and autism must be investigated further. This need for further research is strengthened by the finding that when directly asked about their bilingualism experience, autistic children attending schools with a high number of bilingual pupils had positive views about being bilingual (Howard et al., 2019).

C. Bilingualism and autism in adulthood

Following these findings in childhood, research in adulthood is remarkably lacking. In spite of the generally negative views from the perspective of parents and practitioners, reports by autistic adults are largely positive. Multilingual writers with autism have shared their experiences in multiple non-fiction books, presenting an enriching bilingual journey (Schovanec, 2016; Tammet, 2017).

To date, academic studies only involved single or multiple case studies of autistic polyglots or language savants (people highly proficient in many languages), assessing their overall cognitive (Tsimpli & Smith, 1998) or linguistic abilities (Bates, 1997; Hyltenstam, 2016; Smith & Tsimpli, 1991; Tsimpli & Smith, 1991, 1998; Vulchanova, Talcott, Vulchanov, & Stankova, 2012; Vulchanova, Talcott, Vulchanov, Stankova, et al., 2012). One most famously described autistic polyglot is Christopher, a language savant with exceptional language learning abilities, in spite of a below average non-verbal intelligence (Smith & Tsimpli, 1991; Tsimpli & Smith, 1991). Able to understand around 15 languages, Christopher still showed great difficulty in completing simple false-belief tasks (Tsimpli & Smith, 1998). However, considering the unique skillset and cognitive profile of Christopher and his uncommon language learning history, this sole finding should not be taken as sign that even knowing more than 10 languages cannot ease the social difficulties of autistic people. Indeed, the cognitive and linguistic experiences of Christopher may not reflect the reality of most autistic bilingual adults with average or above average non-verbal abilities, and without Christopher's unique language learning skills.

Therefore, these studies, though highly informative, do not provide an accurate picture of the interplay between bilingualism and autism in adulthood, as based on the findings in children with autism, it is unlikely that all autistic bilingual adults are language savants. Therefore, there seems to be more to the experience of autistic bilingual adults than the findings currently available in the literature.

D. Social cognition at the crossroads between autism and bilingualism

As discussed above, autism is characterised by difficulties in social functioning, linked with an impaired development of social cognitive processes, a developmental step closely linked with language abilities. Crucially, research has shown that in typical development, bilingualism can stimulate the development of social cognition. Therefore, could bilingualism have the same beneficial effect in autism, thus tempering the social cognitive difficulties experienced by many autistic people, or on the contrary, would bilingualism indeed be a burden?

We have seen that the language abilities of autistic people are not consistently altered by bilingualism, but what about their communicative and social skills? Few research studies have focused on the interplay between social cognition and bilingualism in the specific context of autism, and all of them have focused on children and adolescents. In children and adolescents with autism living (n = 39) or not (n=59) in a bilingual environment, Iarocci et al. (2017) found that bilingualism was not associated with a delay in parent-reported functional communication and that fewer bilingually-exposed children than monolingual children had communicative skills falling within the clinical range, suggesting a neutral or positive influence of bilingualism. Ratto et al. (2020) also reported a bilingual influence on the parent-reported social communication skills of a small sample of autistic children under the age of 6 (with 24 bilingual and 31 monolingual children). Reviewing clinical observations, Valicenti-McDermott et al. (2019) also concluded that bilingualism was not associated with added social functioning difficulties, comparing a large sample of 297 monolingual and 165 bilingual autistic children aged between 1 and 6. Finally, in a systematic review gathering 10 studies on the social and communication skills of autistic bilingual children, Uljarević et al. (2016) found a positive influence of bilingualism, thought these findings mostly relied on parental reports. Therefore, a direct assessment of social cognitive abilities in autistic bilinguals is still lacking.

IV. Overview of the present research

To date, experimental studies and reviews have only addressed social functioning or communication, but not directly social cognitive skills, and only focused on children or adolescents. While these findings are informative in showing that bilingualism does not hinder the social functioning of autistic children, it is necessary to go further, and address the underlying social cognitive processes. Understanding how bilingualism can shape cognitive skills will allow us to better support the language and social development of autistic people. In this regard, research must also detach itself from only addressing this phenomenon in childhood. This phase is obviously key in the development of social cognitive skills, but as discussed above, this development is disrupted in autism, which could mean that any bilingual effect might not be visible at the same age between autistic and neurotypical children. Investigating this matter in adulthood will address this issue, as at this stage social cognitive skills are set in typical development, and social cognitive difficulties are still present in autism. Focusing on adulthood is relevant also because most of one's life is spent in this phase; it is therefore necessary to ensure that any positive influence of bilingualism on social cognition, if it exists, is present at this stage.

Before directly addressing this matter in an experimental context, first and foremost, in Chapter 2 a critical gap in the field will be addressed: providing a clear picture of the bilingual profiles of autistic adults. Indeed, as mentioned above, the research currently available described either early bilingual children, or adult polyglots, which is unlikely to represent the majority of bilingual experiences, especially when considering the testimonials of autistic bilingual authors such as Daniel Tammet. In this chapter we will also address social functioning from the angle of lived experiences and examine social life habits. As described above, studies have focused on autistic children's general social abilities, but to date no study has addressed the influence of bilingualism on the overall social life of autistic people.

In Chapter 3, we will take a step back from autism, and first describe the relationship between bilingualism and the social cognitive process in focus here, perspective-taking, in typical development. Indeed, while this interplay has been researched in typical development more than in autism, it is still extremely poorly understood, especially in adulthood. The chapter will start with a detailed review of existing research on, and theoretical models of, perspective-taking. Thereafter, Chapter 3 will clarify this relationship in neurotypical adults, and allow me to validate my research strategy.

In Chapter 4 we will finally tackle the core question of this research and investigate the relationship between bilingualism and perspective-taking in autism, using an innovative approach that relies on a multidimensional definition of both bilingualism and perspective-taking.

In Chapter 5 we will build upon the findings of Chapter 3 and Chapter 4 to conduct an exploratory investigation of the neural correlates underlying the relationship between bilingualism and perspective-taking in autistic and neurotypical adults.

Finally, in Chapter 6, the overall findings of the study will be discussed, to reach a conclusion and identify implications for families, practitioners, and researchers.

Chapter 2: Bilingualism in autism: Language learning profiles and social experiences

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Abstract

Bilingualism changes how people relate to others, and lead their lives. This is particularly relevant in autism, where social interaction presents challenges. Understanding the overlap between the social variations of bilingualism and autism could unveil new ways to support autistic people. This research aims to understand the language learning and social experiences of mono-, bi-, and multilingual autistic people. A total of 297 autistic adults (mean age = 32.4 years) completed an online questionnaire including general demographic, language history, and social life quality self-rating (SLQ) items. The sample included 89 monolingual English speakers, 98 bilinguals, and 110 multilinguals, with a wide range of language profiles. Regression models were used to analyse how bilingualism variables predicted SLQ ratings. In the full sample, age negatively predicted SLQ scores while the number of languages known positively predicted SLQ scores. In the multilingual subset, age negatively predicted SLQ scores, while third language proficiency positively predicted SLQ scores. This is the first study describing the language history and social experiences of a substantial sample of bilingual and multilingual autistic adults. It provides valuable insight into how autistic people can learn and use a new language, and how their bilingualism experiences shape their social life.

Manuscript

I. Introduction

The social processes differences characteristic of autism can impact the quality of daily life and social life of autistic people, regardless of the cultural environment. Studies conducted in Europe and Asia showed that when rating their quality of life across multiple domains, autistic adults give the social life domain the lowest score (Kamp-Becker et al., 2010; Lin, 2014; Lin & Huang, 2017) – unlike neurotypical adults, who rate all domains as equally satisfying (Lin, 2014). Consistently, autistic adults rate their social life quality significantly lower than do neurotypical adults (Jennes-Coussens, Magill-Evans, & Koning, 2006; Kamio, Inada, & Koyama, 2013; Kamp-Becker et al., 2010; Lin, 2014; Lin & Huang, 2017; Schmidt et al., 2015; van Heijst & Geurts, 2015; Vincent et al., 2019). Since social life activities are a positive predictor of general quality of life for autistic adults (Mason et al., 2018; Schmidt et al., 2015) it is essential to understand the factors contributing to a more satisfying social life for autistic people. Bilingualism and multilingualism are among the relatively unexplored factors.

Bilingualism is a skill shared by half the world's population (Grosjean, 2010) with an inherent social and interactive dimension (Bialystok, 2007). There is a wide range of bilingual profiles described in the neurotypical population, and the term can be applied to all people who know two or more signed or spoken languages, learned simultaneously or sequentially, with varying proficiency levels. Defining a threshold above which one can be considered as bilingual is a sensitive matter, requiring agreement on both the relevant metric (e.g. proficiency in second language, age of acquisition of second language) and threshold. Definitions vary between authors and fields, which may explain some of the conflicting results found in bilingualism research (Luk & Bialystok, 2013). Different bilingualism parameters seem to influence different neurocognitive processes, and relevant contributing elements of bilingualism include the number of languages known (Schroeder & Marian, 2017), age of acquisition of each language (Johnson & Newport, 1989), proficiency in each language (Perani, 1998), or language-switching habits (Verreyt et al., 2016).

The linguistic and cognitive effects of bilingualism in autism are still poorly understood, compared to what is known in the neurotypical population. With rising autism prevalence and increases in the global bilingual population (de Oliveira, 2015) it is timely to chart the effect of bilingualism on the social life of autistic people. Anecdotal self-reports of bilingualism and multilingualism among autistic adults suggest that learning and using multiple languages may have a positive role in creating and sustaining good quality of life (Tammet, 2017). However, there is a lack of systematic research on bilingualism in autistic adults. Data from autistic children, while also limited, indicates that simultaneous bilinguals perform as well as age-matched monolinguals on linguistic measures and show no delay in language (Drysdale et al., 2015; Hambly & Fombonne, 2012; Kay-Raining Bird et al., 2016; Reetzke et al., 2015). Bilingualism may not only be harmless for cognitive processes in autism, but has even been suggested to have a positive influence, especially regarding social and communication skills (Iarocci et al., 2017; Uljarević et al., 2016). Despite the positive account presented by these – albeit preliminary – findings, parents still report a lack of support from practitioners and services when it comes to raising autistic children speaking more than one language (Kay-Raining Bird, Lamond, & Holden, 2012; Hampton, Rabagliati, Sorace, & Fletcher-Watson, 2017). This may be because bilingualism is still often perceived as entailing a heavy cognitive load (Park, 2014).

Indeed, autism is associated with a wide range of language abilities. While some autistic people are minimally- or non-verbal, others have typical (Brignell et al., 2018) or enhanced (Hyltenstam, 2016) language skills, with or without peculiar speech patterns (Gernsbacher et al., 2016). The presence of these linguistic capacities in many autistic people suggests that learning and achieving fluency in more than one language is also possible for autistic people, as it is for their non-autistic peers. Nonetheless, to date research on bilingualism in autism reports in majority only two profiles of autistic bilinguals. Most studies focus on autistic children raised in bilingual environments (Hampton et al., 2017) and describe the language (Drysdale et al., 2015; Hambly & Fombonne, 2012, 2014; Ohashi et al., 2012; Petersen et al., 2012; Reetzke et al., 2015; Valicenti-McDermott et al., 2013; V. Zhou et al., 2019) or cognitive (Iarocci et al., 2017) development of the autistic child. At the other extreme of the bilingual experience, a handful of case studies focus on autistic polyglots and describe their linguistic (Bates, 1997; Hyltenstam, 2016; Smith & Tsimpli, 1991; Tsimpli & Smith, 1991; Vulchanova, Talcott, Vulchanov, & Stankova, 2012; Vulchanova, Talcott, Vulchanov, Stankova, et al., 2012) or cognitive (Hyltenstam, 2018; Tsimpli & Smith, 1998) abilities. As such, the current literature on autistic bilinguals does not reflect the diversity of language history profiles extensively described in the non-autistic population (Grosjean, 2010).

The current study explores language profile diversity in the autistic bilingual population, and assesses the potential influence of bilingualism on the self-reported social habits and quality of life of autistic adults. The first aim is to richly characterise a substantial sample of autistic bilingual adults, describing their language learning history, current use and proficiency. We predict that the language history profiles existing in the bilingual autistic population will be more diverse than those currently described in the literature, with various levels of learning experiences and uses. The second aim is to examine the relationship between aspects of bilingualism (e.g. age of acquisition, proficiency) and self-perceived social life quality.

II. Methods

Participants

The final sample includes 297 participants (Table 2.1, and see Survey Data Management for data exclusion criteria), clinically diagnosed with autism (n = 237) or self-identified as autistic (n = 60). The mean age was 32.4 years (range: 16 – 80), with a mean age at diagnosis of 26.4 years (range: 2 – 78). The gender distribution is 58.2% female, 22.6% male, and 19.2% not listed or not disclosed. The study was conducted in the UK, and the recruitment strategy targeted residents of the UK, resulting in 48.8% of respondents being UK residents. The recruitment flyer was clearly advertising this study as focusing on bilingualism, but was also encouraging the participation of monolingual and multilingual autistic adults. It was circulated around universities and autism networks in the UK (see below in Procedure). However, the recruitment flyer was also circulated online through social media, which led to the participation of non-UK residents as well (51.2 % of the respondents). Notably, 27% of the respondents were residents of the United States of America, 4% residents of Canada, and 4% residents of Germany. All other countries represented no more than 2% of the sample (see Table 2.1 for further details about the countries of origin and residence of the respondents). The survey was circulated in English, and so required reading and writing proficiency in that language, and participants had to be 16 years or over to participate. Participants were not compensated for their participation in the study.

Table 2.1 - Respondents' Demographic Characteristics

Demographics	
Age in years, M (SD, range)	32.4 (12.0, 16 - 80)
Gender, N (%)	
Female	173 (58.2)
Male	67 (22.6)
Other gender identity	50 (16.8)
Not disclosed	7 (2.4)
Diagnosis, N (%)	
Diagnosed	237 (79.8)
Self-identified	60 (20.2)
Age of diagnosis, M (SD, range)	26.4 (14.5, 2 - 78)
Highest Education, N (%)	
Less than an undergraduate degree	138 (46.5)
Undergraduate degree or higher	159 (53.5)
Country of birth, N (%)	
UK	122 (41.1)
Non-UK, English-speaking [a]	108 (36.4)
Europe, non-English speaking [b]	45 (15.2)
Non-Europe, non-English speaking [c]	21 (7.1)
Country of residence, N (%)	
UK	145 (48.8)
Non-UK, English-speaking [d]	105 (35.4)
Europe, non-English speaking [e]	37 (12.5)
Non-Europe, non-English speaking [f]	10 (3.4)
Non-UK-born UK-residents, N (%)	22 (7.4)
Age of arrival in the UK, M (SD, range)	17.8 (10.5, 0.7 – 36)

Note: Sociodemographic characteristics of the respondents (n = 297).
a = Australia (6), Canada (14), Ireland (4), USA (84). b = Belgium (4), Czech Republic (1), Estonia (1), France (6), Germany (14), Italy (2), The Netherlands (4), Norway (3), Poland (1), Spain (4), Sweden (5). c = Algeria (1), Argentina (1), Bahrain (1), Brazil (1), Curacao (1), Hong Kong (1), Indonesia (1), Israel (1), Mexico (2), Paraguay (1), Puerto Rico (1), Singapore (3), Taiwan (1), Trinidad & Tobago (1), Turkey (2). d = Australia (5), Canada (13), Ireland (6), USA (81). e = Belgium (2), Estonia (2), France (6), Germany (12), Italy (1), The Netherlands (4), Norway (2), Spain (3), Sweden (4), Switzerland (1). f = Curacao (1), Israel (1), Mexico (1), New Zealand (1), Paraguay (1), Singapore (2), Thailand (1), Trinidad & Tobago (1), Turkey (1).

Design

This study was a cross-sectional survey design using self-report measures to explore correlations between bilingualism and social life quality.

Measures

The Autism & Bilingualism Census (ABC, Digard & Fletcher-Watson (2019)) is an online survey, created in SurveyMonkey and it is available to view at https://osf.io/xsqy7/. The ABC was created for this research, and designed to capture data from monolingual, bilingual and multilingual autistic adults. It consists of 4 sections:

- Section A: General demographic information;
- Section B: General life satisfaction and social life quality;
- Section C: Language history;
- Section D: Open-ended questions;

Section A collected demographic information about the respondents such as age, countries of birth and residence, highest education level, and autism diagnosis.

Section B focused on social experiences including social life habits (such as the making and maintaining of friendships, or online and in-person engagement in social activities), and quality of life. It was composed of 4 blocks of statements addressing General life satisfaction (5 statements), Current mood (11 statements), Social life quality (12 statements), Personality (6 statements). This section was inspired by pre-existing validated quality of life and quality of social life questionnaires: the WHOQOL (The Whoqol Group, 1995) – versions of which have been previously used with autistic populations (Jennes-Coussens et al., 2006; Kamio et al., 2013; Kamp-Becker et al., 2010; Lin, 2014; Lin & Huang, 2017; Mason et al., 2018; Vincent et al., 2019), the WHODAS 2.0 (Üstün et al., 2010), the Goldberg Depression Scale (Goldberg et al., 1988), the European Social Survey (ESS Round 8: European Social Survey Round 8 Data, 2016), and the Satisfaction with Life Scale (Diener et al., 1985). Items were composed, drawing on these scales (see supplementary materials Table s1), but tailoring the wording and content to the population being recruited. Participants rated their agreement with each statement on a 7-point Likert scale (from "strongly disagree" to "strongly agree"). Participants' ratings were converted to a 7-point scale for subsequent analysis (range: 1 – 7). All blocks but the current mood block only contained positive statements ("I can easily make new friends"), and for these blocks the conversion scores matched the original Likert scale. The current mood block only contained negative statements ("I feel anxious"), and these were reverse-scored, so that a high score indicates high satisfaction in all measured domains.

Section C focused on the respondents' language history and use. This section drew on pre-existing validated language history and language use questionnaires: the Bilingualism and Emotions Questionnaire (Dewaele & Pavlenko, 2001), the Language History Questionnaire (Li et al., 2006), the Language Experience and Proficiency Questionnaire (LEAP-Q, Marian, Blumenfeld, & Kaushanskaya (2007)) and the Bilingual Language Experience Calculator (BiLEC, Unsworth (2013)). For each language known, respondents were asked how old they were when they first encountered the language and in what context they encountered it. Participants self-rated their current proficiency on a 9-point Likert scale (from "Not at all" = 0 to "Excellent" = 8) in 4 standard language skills: oral expression, oral comprehension, written expression, written comprehension. Respondents also indicated on a 7-point Likert scale (from "Never" = 1 to "Always" = 7) the frequency with which they used each language with their friends, family, and other people in their environments, both currently and while learning the language, and the current frequency of use of each language for a selection of mental and communication tasks (e.g. "Do maths", "Swear") and daily activities ("Watching TV"). Participants could provide information for up to 7 languages, each language being covered in a separate page of the survey. If they knew more than 7 languages, they were offered the possibility to list any other languages they knew, without providing further details.

Section D involved open-ended questions asking about the respondents' language learning experience, their perception of the importance of language learning, and how these were influenced by autism. Open-ended comment boxes were also available for each language for the participants to provide, if needed, more details about their past and current use of the language. The qualitative data from these items are not covered in this report.

Procedure

The study was approved by the PPLS Research Ethics Committee of the University of Edinburgh. The consent form was built into the online survey and participants provided consent by completing the first page of the survey, which was a pre-requisite for progression to further questions. Respondents were recruited between February and March 2017, with a recruitment flyer circulated via autism charities and networks across the UK, disability services of UK universities, and social media. Participants completed the questionnaire online by themselves, on their own devices, in their own time.

Survey data management

A total of 491 responses were recorded by SurveyMonkey. No catch item or repeated item was used, but the requirement to type the name of each language known, and the multiple open-ended questions allowed us to ensure no bot-like response was present in the final sample. In addition, responses were excluded if they:

- Did not provide full information for at least their first language (179 responses), as this could indicate the respondent had not actually completed the questionnaire and had dropped out after completing the consent form, but before providing all the necessary information to be included in the analysis. This high dropout rate was in all likelihood due to the length of the questionnaire;
- Listed information about several languages on one page (2 responses), as it was unclear which language was associated with the proficiency and use reported;
- Failed to provide adequate information about diagnosis or self-identification of autism (7 responses);
- Did not list English as any of their languages, or indicated a general English proficiency strictly less than 3 ("Slightly less than adequate") (5 responses), as this suggests that the respondent might not fully understand the questions of the survey;
- Were duplicate responses from the same participant (1 response): in this case the second and more complete response was retained for analysis

Several variables were created based on the participants' responses.

Language proficiency: For each language, proficiency was calculated as the average of 4 self-rated standard language skills (oral expression, oral comprehension, written expression, written comprehension).

Number of languages reported (N language R): Each respondent provided data on a number of languages ranging from 1 to 7. This was further converted into a categorical variable (N language R-group) for analysis: monolingual (one language reported), bilingual (two languages reported) and multilingual (three languages or more reported).

Number of languages known with medium to high proficiency (N language P): For each participant, this was the number of languages reported with a proficiency equal to or over 3

("Slightly less than adequate"). This threshold was defined as indicating that the respondents had a more than basic grasp of the language. This discrete variable ranged from 1 to 7. This was further converted into a categorical variable (N language P-group) for analysis: monolingual (proficient in one language), bilingual (proficient in two languages) and multilingual (proficient in three or more languages).

Age of acquisition: Participants were asked "how old were you when you first encountered L2" and the answer to this question was defined as age of acquisition.

Language order: Participants reported their languages in varying orders (e.g. by increasing age of acquisition, or by decreasing proficiency). Languages were reordered by age of acquisition, with the 2nd language being the first language learned after the native language. Thirteen participants did not report a specific age of acquisition in years for some of their languages. In this case, answers were re-coded as missing data, but in most cases reordering of the languages by age of acquisition was still possible (e.g. where the respondent replied "infancy" for age of acquisition).

Balance: Relative proficiency between the first (L1) and second (L2) languages was calculated as the absolute difference between the first and second language proficiency. A score of 0 indicated a balanced proficiency, a score of 7 indicated a complete dominance in one of the languages. The same balance was calculated between the first and third (L3) languages.

Acquisition context: For each language, respondents indicated frequency of use with different interlocutors and in different contexts. The home environment included 5 item scores (parent 1, parent 2, siblings, other people in the household, other members of the family), the school environment included 1 item (school), and the community environment included 2 item scores (friends, community). Not all respondents assigned a score to all items (e.g. respondents without siblings did not report a score for this item). The maximum score reported in an environment was the score assigned to that environment. The main context of acquisition was identified as the environment with the highest score. When the main (highest-scoring) context had a score strictly under 3 ("Occasionally"), the main context was re-coded as "independent", highlighting the fact that the respondent mostly learned the language independently, and didn't use it in the home, the school, or the community.

Current context: The main context of current use was identified in the same manner as the main context of acquisition. For this variable, the home environment included 7 item scores (parent 1, parent 2, siblings, partner, children, other members of the family, flatmates), the school/work environment included 1 item (school/work), and the community environment included 2 item scores (friends, community). For the respondents' first language (L1) only, the community environment featured only one item (community) due to an error when building the online survey. When the main context had a score strictly under 3 ("Occasionally"), the main context was re-coded as "independent", as above.

Social life quality (SLQ) scores: For each block of statements in section B, internal consistency was measured using Cronbach's Alpha. Each block showed high internal consistency (general life satisfaction: α = 0.88, current mood: α = 0.86, social life: α = 0.83, personality: α = 0.7). For each participant, the scores in each block were therefore averaged to provide a single sub-scale score for that block. The SLQ score is derived from the social life subscale, and is the outcome variable used in the analysis described below.

The anonymised dataset and analysis script will be made available at https://osf.io/vd53u/ (Digard, Sorace, Stanfield, & Fletcher-Watson, 2019).

Analysis methods

Sociodemographic characteristics and social life quality predictors were determined by descriptive analyses. Then, linear regression models computed using R (version 3.5.3) and R studio (version 1.2.1335) were used to determine how language profiles predict social life quality. The available predictors varied with language group: for example, monolingual people do not have data on age of acquisition of additional languages, and do not have data on balance between L2 and L1. Therefore, the analysis deployed three different linear regression models, applied to specific samples of respondents. For each model, all the applicable predictors were first entered, and a stepwise regression with both forward and backward selection was then used to obtain the optimal model. The three optimal models were validated using 10-fold cross-validation.

Model 1 was applied to all 297 respondents to investigate how bilingualism and multilingualism predicted the self-rated social life quality of autistic adults, relative to monolingual peers. Relevant predictors available for these respondents were entered: respondent age; N language R; N language R-group; N language P; N language P-group.

Model 2 was applied to the bi- and multilingual respondents (n = 196, participants who reported 2 languages or more), to investigate how specific features of the bilingual experience predicted the self-rated social life quality of autistic bilingual adults. Relevant predictors available for these respondents were entered: respondent age; N language R; N language R-group; N language P; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

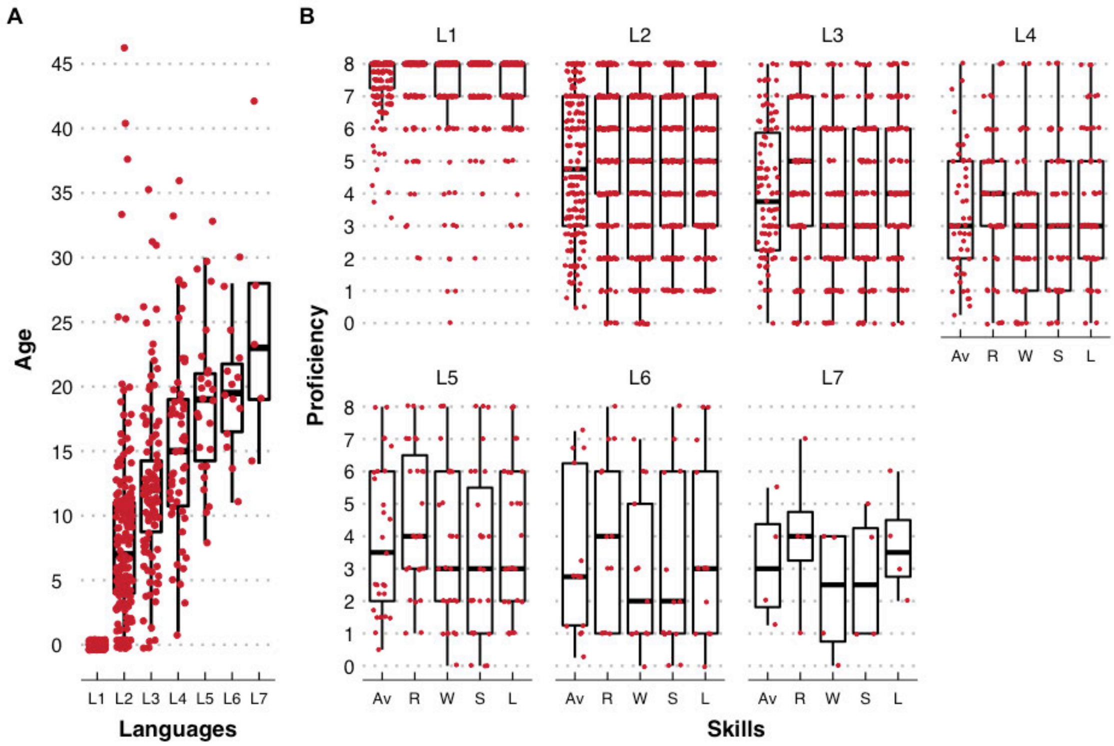
Model 3 was applied to the multilingual respondents (n = 108, participants who reported 3 languages or more), to investigate how specific features of the multilingual experience predicted the self-rated social life quality of autistic multilingual adults. All the predictors available for these respondents were entered: respondent age; N language R; N language P; L2 age of acquisition; L2 proficiency; L2/L1 balance; L3 age of acquisition; L3 proficiency; L3/L1 balance.

III. Results

Language profiles

The language characteristics of the sample are reported in Figure 2.1 and Table 2.2. The acquisition context and the current context for the respondents who reported more than one language are presented in the supplementary materials (Table s2).

Figure 2.1 - Age of acquisition and proficiency of the languages reported



Note. A. Age of acquisition: boxplot and scatterplot of the distribution of the reported ages of acquisition for the languages (L) 1 to 7, ranked by age of acquisition for each respondent.

B. Language proficiency: boxplot and scatterplot of the self-rated average (Av) and detailed (reading = R, writing = W, speaking = S, listening = L) proficiency for the languages 1 to 7, ranked by age of acquisition for each respondent (Digard et al., 2019).

Table 2.2 - Respondents' Language Characteristics (n = 297)

A. Number of languages			B. Age of acquisition and proficiency			
	R, n (%)	P, n (%)		Languages (N)	Age in years, M (SD, range)	Proficiency, M (SD, range)
1 lang.	89 (30.0)	121 (40.7)	Monolinguals	L1 (89)	0 (0, 0 - 0)	7.3 (1.1, 3 - 8)
2 lang.	98 (33.0)	104 (35.0)	Bilinguals and Multilinguals	L1 (208)	0 (0, 0 - 0)	7.6 (0.8, 3.3- 8)
3 lang.	56 (18.9)	43 (14.5)		L2 (208)	8.0 (6.9, 0 - 46)	4.9 (2.2, 0.5 - 8)
4 lang.	26 (8.8)	20 (6.7)		L3 (110)	12.3 (6.5, 0 - 35)	4.1 (2.0, 0 - 8)
5 lang.	14 (4.7)	6 (2.0)		L4 (54)	15.6 (7.5, 1 - 36)	3.5 (1.9, 0.3 - 8)
6 lang.	9 (3.0)	1 (0.3)		L5 (28)	18.9 (6.3, 8 - 33)	3.9 (2.3, 0.5 - 8)
7+ lang.	5 (1.7)	2 (0.7)		L6 (14)	19.9 (5.2, 11 - 30)	3.2 (2.5, 0.3 - 7.3)
				L7 (5)	25.2 (10.7, 14 - 42)	3.1 (1.7, 1.3 - 5.5)

C. Age of acquisition – Age groups distribution, n (%)						
Language (N) [a]	Birth (age = 0)	Early childhood (age = 1 – 5)	Late childhood (age = 6 – 10)	Adolescence (age = 11 – 17)	Early adulthood (age = 18 – 30)	Adulthood (age > 30)
L1 (297)	297 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
L2 (196)	23 (11.7)	61 (31.1)	54 (27.6)	46 (23.5)	8 (4.1)	4 (2.0)
L3 (108)	4 (3.7)	10 (9.3)	25 (23.2)	52 (48.2)	14 (13.0)	3 (2.8)
L4 (52)	0 (0.0)	4 (7.7)	9 (17.3)	18 (34.6)	19 (36.5)	2 (3.9)
L5 (26)	0 (0.0)	0 (0.0)	2 (7.7)	8 (30.8)	15 (57.7)	1 (3.9)
L6 (14)	0 (0.0)	0 (0.0)	0 (0.0)	4 (28.6)	10 (71.4)	0 (0.0)
L7 (5)	0 (0.0)	0 (0.0)	0 (0.0)	1 (20.0)	1 (20.0)	3 (60.0)

Note. Some percentages do not sum up to 100% due to cumulative rounding effects.
A. Number of languages: Number and proportion of respondents who reported (R) or were proficient (P) in 1, 2, 3, 4, 5, 6, or 7 or more languages (lang.).
B. Age of acquisition and proficiency: Age of acquisition (Age) and proficiency reported by the respondents in languages (L) 1 to 7.
C. Age of acquisition – Age groups distribution: Number and proportion of respondents who acquired their languages (L) 1 to 7 at birth, during early childhood, late childhood, adolescence, early adulthood and late adulthood.
[a] Reported sample sizes (N) reflect the number of respondents who provided useable age of acquisition data (in years).

In our sample of 297 autistic adults, 98 reported knowing 2 languages, 56 reported 3 languages, and 54 reported 4 or more languages (Table 2.2a). Proficiency in the 2nd language ranged from 0.5 to 8, with a mean of 4.9 (SD = 2.2), and proficiency in the 3rd language ranged from 0 to 8, with a mean of 4.1 (SD = 2.0) (Table 2.2b). When considering only the languages known at a “slightly less than adequate” level of proficiency or higher, 104 respondents knew 2 languages, 43 knew 3 languages, and 29 knew 4 languages or more.

Ages of acquisition for the 2nd language ranged from 0 to 46 years (mean = 8.0 years, SD = 6.9) (Table 2.2c). Twenty-three respondents (11.7% of the respondents who reported an age of acquisition for L2) reporting learning L2 from birth, and 61 (31.1%) between age 1 and 5, which indicates that 42.9% of the respondents who reported an age of acquisition for L2 fit the profile of simultaneous or early bilingualism generally reported in the field of bilingualism in autism research. Nonetheless, 46 (23.5%) reported acquiring their L2 during adolescence (between age 11 and 17), and 12 (6.1%) after age 18. Ages of acquisition for the 3rd language ranged from 0 to 35 years, with a mean of 12.3 years (SD = 6.5). While, based on the ages of acquisition of L3 reported, adolescence is the largest age group for the learning of L3 (48.2%), 14 respondents (13.0%) reported learning L3 before age 5, and 17 (15.7%) reported learning L3 after age 18.

Social life quality

The SLQ results are displayed in Table 2.3. After stepwise regression, model 1 included the following predictors: respondent age; N language P-group. Model 1 was applied to the full sample of respondents (n = 297) to investigate the relationship between the predictors (respondent age, N language P-group), and SLQ scores. The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. The post-hoc power was high, at 92.7%, and the model was a significant predictor of SLQ scores ($F_{2,294}$ = 8.016, p = 0.0004). There was a significant relationship between age and SLQ score (β = -0.01, p = 0.003), and between N language P-group and SLQ score (β = 0.19, p = 0.0067), together accounting for 4.53% of SLQ score variance, with a small effect size (f^2 = 0.047). There was a decrease of 0.014 points in the SLQ score per extra year of participant age, indicating lower social life quality for older respondents. There was an average increase of 0.19 points in the SLQ score from monolingual to bilingual groups, and from bilingual to multilingual groups, indicating higher social life quality with increasing number of proficiently-known languages, at a group level.

Table 2.3 - Prediction of SLQ Scores Using Multiple Linear Regression

	Model 1					**Model 2**					**Model 3**				
SLQ, M (SD, range)	3.59 (0.98, 1.17 – 6.33)					3.65 (1.00, 1.17 – 6.33)					3.75 (1.00, 1.41 – 5.92)				
Coef.	*β*	*SE*	*CI (95%)*	*Stat.*	*p*	*β*	*SE*	*CI (95%)*	*Stat.*	*p*	*β*	*SE*	*CI (95%)*	*Stat.*	*p*
Intercept	3.68	0.21	3.27 – 4.08	17.93	**<0.001**	3.04	0.38	2.30 – 3.78	8.03	**<0.001**	4.02	0.35	3.33 – 4.71	11.41	**<0.001**
Age	-0.01	0.00	-0.02 – -0.00	-2.95	**0.003**	-0.01	0.01	-0.02 – 0.00	-1.44	0.151	-0.02	0.01	-0.04 – -0.00	-2.33	**0.022**
N language P-group	0.19	0.07	0.05 – 0.33	2.73	**0.007**	0.33	0.12	0.10 – 0.56	2.76	**0.006**					
L2/L1 pro. balance						0.06	0.04	-0.02 – 0.14	1.53	0.128					
L3 av. pro.											0.10	0.05	0.01 – 0.19	2.07	**0.041**
Obs.	297					196					103				
R^2 / adj. R^2	0.052 / 0.045					0.047 / 0.032					0.085 / 0.066				
F-statistic	8.016					3.158					4.618				
p	**0.0004**					**0.026**					**0.012**				

Note. Coef. = coefficients. β = estimates of regression β coefficients. SE = standard errors. CI = confidence intervals. Stats. = t-statistics. *p* = *p*-value. pro = proficiency. av. = average. Obs. = observations. adj. = adjusted.

After stepwise regression, model 2 included the following predictors: respondent age; N language P-group; and L2/L1 balance. Model 2 was applied to the sample of respondents who reported 2 languages or more (n = 196) to investigate the relationship between specific bilingualism parameters (N language P-group, L2/L1 proficiency balance) and age, and the SLQ scores, in the autistic bi- and multilingual population. The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. The post-hoc power was low, at 54.9%, and the model was a significant predictor of SLQ scores ($F_{3,192} = 3.158$, $p = 0.026$). There was a significant relationship between N language P-group and SLQ score ($\beta = 0.33$, $p = 0.0063$), as seen in model 1 with the full sample of respondents: there was an increase of 0.329 points in SLQ score from the bilingual to the multilingual groups, indicating higher social life quality with increasing number of proficiently-known languages, at a group level. In this case, there was no significant relationship between age and SLQ score ($\beta = -0.01$, $p = 0.15$), and between the L2/L1 proficiency balance and the SLQ score ($\beta = 0.06$, $p = 0.13$), even though both these predictors were selected during the stepwise regression as improving the accuracy of the model. This model accounted for 3.21% of the SLQ score variance, with a small effect size ($f^2 = 0.033$).

After stepwise regression, model 3 included the following predictors: age of respondent; L3 proficiency. Model 3 was applied to the sample of respondents who reported 3 languages or more (n = 103, as 5 participants had missing values in one or several of the predictors selected) to investigate the relationship between specific bilingualism parameters (L3 proficiency) and age, and SLQ scores, in the autistic multilingual population. The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. The post-hoc power was low, at 66.2%, and the model was a significant predictor of SLQ scores ($F_{2,100} = 4.618$, $p = 0.012$). There was a significant relationship between age and SLQ score ($\beta = -0.02$, $p = 0.022$), and between L3 proficiency and SLQ score ($\beta = 0.10$, $p = 0.041$), together accounting for 6.63% of SLQ score variance, with a small effect size ($f^2 = 0.071$). For L3 proficiency, there was an increase of 0.098 point in SLQ score per extra proficiency point, indicating that higher proficiency in a third language is associated with higher social life quality. There was a decrease of 0.021 points in the SLQ score per extra year of participant age, indicating lower social life quality for older respondents.

IV. Discussion

This study reveals a great diversity in the language history profiles of autistic bilingual people, and demonstrates that bilingualism has a modest but significant positive association with the self-rated social life quality of autistic people.

Our descriptive data confirm our prediction that the language history profiles of the bilingual autistic population are more diverse than those currently described in the literature. Most studies on autistic bilinguals focus on one of the two extremes of the bilingualism experience: simultaneous or early bilingual autistic children raised in a bilingual family (Drysdale et al., 2015; Hampton et al., 2017), or on autistic self-taught polyglots (Hyltenstam, 2016, 2018), and seems to imply that the bilingualism diversity of the autistic population does not reflect the bilingualism diversity described in the non-autistic population. Our results add to the current picture of autistic bilingualism, showing a rich diversity of language profiles. Even the sample size is striking, given that these data were collected over just two months in an English-language survey, and circulated mainly in a country with a very dominant monolingual profile. This suggests a high level of interest in this research area from the autistic population. Responses reveal a broad range of numbers of languages known, with variable proficiencies in those languages. Similar to their non-autistic peers, autistic people can know several languages without necessarily becoming highly proficient polyglots. While some participants were raised in bilingual or multilingual households, we also revealed that successful acquisition of a second language can also occur later in life, and even in adulthood. Likewise, childhood trilingualism is also possible in autism, as well as the late acquisition of a third language during adolescence or adulthood, which could be linked to the study of foreign languages at school. To the best of our knowledge these language experiences have not yet been presented in autism research. Taken together, while this study, especially targeting bilingual and multilingual autistic adults, does not claim that this sample is representative of the whole autistic population in term of proportion of language profiles (for example in term of number of languages known), our results show that a wide diversity of language profiles does exist.

Overall our research suggests that there are areas of language research in autism that require greater investigation. For example, there is a need for better comprehension of the cognitive impact of early multilingualism – not only bilingualism – in autism, as well as more research into the potentially specific support needs of families with autistic children growing up in a multilingual setting. With language acquisition also occurring after childhood, it is interesting to consider the cognitive skills required for late language acquisition in autism, as well as best practices to support language learning for autistic people outside of the family environment.

In models investigating monolingual, bilingual and multilingual respondents, respondents with proficiency in two or more languages rated their social life as more satisfactory than their monolingual peers, though this effect is modest. Reinforcing this link, we also found that social quality of life was higher for the multi-lingual group compared with bilingual people. In addition, balanced proficiency between languages also contributed to the fit of our model of social quality of life. Taken together, these results indicate a possible dose-dependent relation between language proficiency and quality of life, such that increasing language knowledge is associated with increasing social life quality. However, there are apparent limits to this effect. There was no evidence that knowing 4, 5 or more languages is associated with even higher satisfaction with social life – though reducing power in this necessarily-smaller group would also influence that result. In addition, older respondents were less satisfied with the quality of their social life. This aligns with previous findings on social and psychological quality of life in autism (Mason et al., 2018), though a recent meta-analysis reported no association between age and general quality of life in autism, indicating that other factors may be more influential predictors (Kim & Bottema-Beutel, 2019). This argument is also relevant when taking into account the small proportion of the social life quality ratings explained by the models (3.2% to 6.6%). While our results show that bilingualism does have a small but significant influence on the social life quality of autistic adults, other factors, such as coexisting conditions or current family support (Kamio et al., 2013; Lin & Huang, 2017; Vincent et al., 2019) may have a greater impact.

What is the mechanism of these effects of bilingualism? One possibility is that acquiring proficiency in multiple languages requires cognitive and social resources that also confer quality of life benefits in the social domain. However, we found no predictive value of age of acquisition in our models, partly puncturing this notion. If cognitive skills were the underlying cause of both language proficiency and better social life quality, we might expect these effects to be especially pronounced in people who had mastered a second language late in life, rather than those who were raised in bilingual households. Put another way, if there is a positive influence of bilingualism on social life during childhood, acquiring a second or third language later in life seems to carry the same benefits in terms of social life habits. This suggests that an alternative mechanism, such as the social interactive benefits accrued from knowing multiple languages, opening up new communication and communities, is also worth probing in future research.

Limitations

The results of this study are necessarily restricted by the limitations of the cross-sectional, self-report methods used, making it impossible to draw causal inferences, and the circulation of the survey in English. For example, recent male-to-female ratio estimates in autism approach 3:1 (Loomes et al., 2017), and thus are at odds with the gender distribution in our sample, hindering its representativity. However, this overrepresentation of females reflects a regularly reported bias in online studies (Sax et al., 2003; Smith, 2008), including online studies with autistic respondents (Deserno et al., 2017). In addition, for proficiency ratings, it is possible that respondents had a variable and heterogenous understanding of what is an average or a good language proficiency. Although studies have shown that self-rated proficiency is generally accurate compared to standardised language testing (Brantmeier et al., 2012; Edele et al., 2015), this has not been verified in autism. Furthermore, our recruitment strategy focused on the United Kingdom (UK), though some respondents living in other countries were included. The UK is de facto a monolingual country with high immigration, meaning that our data may reflect the experience of a specific population defined not just by language knowledge and autism but also by high rates of immigration. The country of residence was not included in the analysis because of the distribution of the data. Indeed, 48.8% of the respondents were UK residents, and most other countries contributed 1 to 6 data points (2% or less of the respondents). The only exceptions were the United States of America, with 27% of the responses, and Canada and Germany, each with 4% of the responses (see Table 2.1 for a detailed account of the countries of origin and residence of the participants). Future research could explore the cultural differences in social life quality in relation to language knowledge, particularly contrasting monolingual and bilingual environments. Indeed, while the diversity of our sample is a strength, more focused examinations of the specific impact of bilingualism in specific demographic or linguistic sub-samples would be of interest. Lastly, as discussed above, several potential confounds linked to social life quality have not been accounted for in the present model, such as gender, level of education, relationship status, maternal support, aggressive behaviours, comorbid psychiatric conditions, and mental health conditions (Kamio et al., 2013; Lin & Huang, 2017; Mason et al., 2018).

Conclusion

This study reveals for the first time the range and complexity of language learning profiles amongst autistic people. We observe an impressive diversity of experiences of language learning across the lifespan, and variability in both proficiency and context of use. Autistic bilinguals and multilinguals are not all linguistic savants, nor all raised in multilingual households. Many have learnt one or more second languages at school or independently, and use them with moderate proficiency, as non-autistic people do. In addition, through statistically robust analyses, we find evidence that proficiency in two or more languages is associated with better self-rated social quality of life for autistic people. The consequences of these results for family decision-making, language education, and lifelong learning should be explored in future studies.

Declaration of Conflict of Interests

Authors declare that there is no conflict of interest.

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Chapter 3: Relationship between bilingualism and perspective-taking in neurotypical adults

I. Introduction

Chapter 2 highlighted that bilingualism shapes and improves the perceived social life quality of autistic adult. As well as having an impact on autistic people's experiences of social interactions, bilingualism may also have a role at the level of their social cognition, as it does in their neurotypical peers (see Chapter 1). One key social cognitive process identified as being sensitive to the influence of bilingualism in neurotypical population is perspective-taking. However, this relationship is still poorly understood in typical development, and before examining it in autistic adults, it is crucial to first define it in their neurotypical peers.

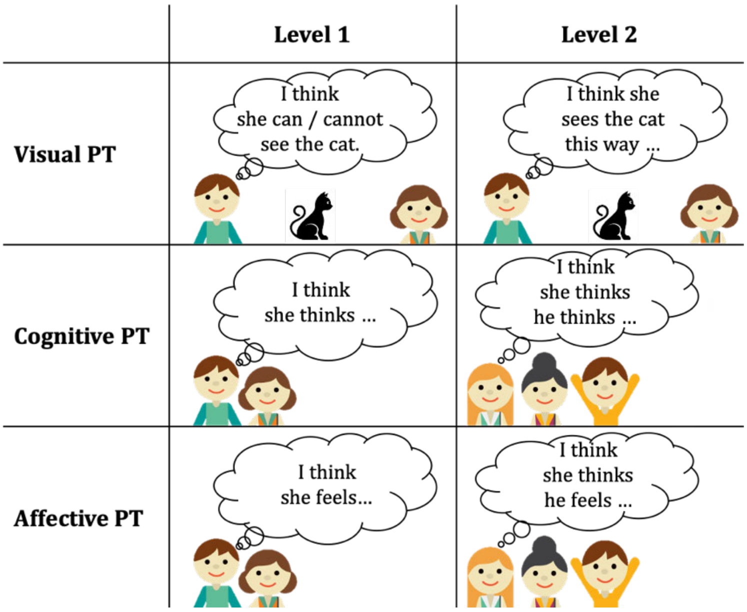
A. Defining social cognition and perspective-taking

1. *Adopted framework: Modalities, complexity, and explicitness*

As introduced in Chapter 1 section I.B, social cognition refers to a set of cognitive skills used to interact with people, and gathers multiple processes which contribute to perceiving social information, understanding this social information, and planning behavioural responses accordingly (Arioli et al., 2018). The second step, social understanding, relies on perspective-taking, a skill allowing people to mentally take the perspective of someone else, inferring and reasoning about their mental states (Birch et al., 2017). Perspective-taking occurs in several modalities (Figure 3.1): visual, cognitive or affective, with the latter two overlapping with the theoretical constructs of "mentalizing" or "theory of mind" (ToM) (Turner & Felisberti, 2017).

Visual perspective-taking is the ability to see the world from someone else's point of view, creating in our mind a representation of their visual environment, of what they can see and how they see it. For visual perspective-taking, two levels of complexity exist (Pearson et al., 2013): level 1 allows people to determine *whether* someone else can or cannot see an item. Level 2 enables people to describe *how* someone else sees an item (e.g. from what angle, what details are visible to them). A similar distinction exists in cognitive perspective-taking as well, when referring to someone's thoughts or state of mind (Turner & Felisberti, 2017). Level 1, or first-order, cognitive perspective-taking refers to the attribution of thoughts to someone else, while level 2, or second-order, cognitive perspective-taking is used when someone imagines what thoughts someone else is attributing to a third person. Affective perspective-taking follows a similar structure but describes the attribution of *feelings* to someone instead of thoughts.

Figure 3.1 - Examples of visual, cognitive, and affective perspective-taking.



Note. Examples of the different modalities (visual, cognitive, affective) and levels of difficulty (1 and 2) existing in perspective-taking (PT) processes.

Different frameworks have been proposed to explain the complex mechanisms behind perspective-taking (Happé et al., 2017). Only one of these frameworks can be applied to both the visual and the cognitive modalities of perspective-taking. This posits the existence of two components in the perspective-taking process: an implicit, automatic and fast process, and an explicit, intentional and slow process (Apperly & Butterfill, 2009; Happé et al., 2017). Implicit perspective-taking is performed non-verbally without prompt, and may be evident in children as young as 18-months-old (Knudsen & Liszkowski, 2012). Explicit perspective-taking is performed on demand, can be verbalised, and appears later in the development of children (Happé et al., 2017). Both are subject to an egocentric bias, meaning that one's own perspective impacts the processing of others' perspectives (Schneider et al., 2017). This framework applies to all modalities cited above: visual, cognitive, and affective.

The different developmental trajectories of these processes suggest that, if bilingualism can indeed impact perspective-taking, different bilingual experiences would differentially affect implicit and explicit mechanisms. For example, one can hypothesise that the early developing route of implicit processing would be relatively impervious to later language learning effects. However, direct evidence on the influence of different bilingual experiences on implicit versus explicit perspective-taking is critically sparse.

2. *Cognitive and affective perspective-taking processes*

The development of cognitive and affective perspective-taking is closely linked with language and executive abilities. Level 1 and level 2 processes appear at different developmental stages, respectively around the ages of 4 and 7 in typical development (see Apperly et al., (2009) for a review of the link between language, executive functions, and theory of mind). However, the ability to track beliefs has been recorded in preverbal infants aged between 13 and 18 months (Helming et al., 2014; Scott & Baillargeon, 2017; Senju et al., 2011). This suggests the existence of two systems: one early developing implicit route independent of language and executive skills and processing simple information, and a later developing, explicit route, linked to language and executive skills, able to process more complex situations, first developing level 1, then level 2 abilities (Apperly & Butterfill, 2009; Schneider et al., 2014, 2017).

Explicit cognitive perspective-taking has been extensively measured with false-belief tasks, or more complex social understanding tasks, notably the Strange Stories task (Happé, 1994a), but the measure of implicit processes has to-date relied on a narrow range of measures. Senju et al. (2009), using a false-belief and anticipatory-looking paradigm, showed that neurotypical adults' eye movements could, without prompt, anticipate someone else's behaviour in a first-order cognitive perspective-taking context. Thus, authors demonstrated that level 1 cognitive perspective-taking relies not only on explicit but also on implicit mechanisms, with the implicit, faster route supporting the first steps of perspective processing. As for level 2 cognitive perspective-taking, currently available studies have relied upon explicit tasks, making it impossible to conclude whether implicit processes also operate in this context. The same uncertainty exists about affective perspective-taking, as all studies to date rely only on explicit tasks. Crucially, and in line with the debate mentioned above regarding the existence of an implicit route, a recent preregistered large-scale attempt to replicate several well-established anticipatory-looking paradigms, including the one by Senju et al. (2009), found these paradigms less valid and reliable than previously thought, thus weakening their conclusions (Kulke et al., 2018).

However, authors have called into question this hypothesis of implicit versus explicit routes, and have argued that implicit mechanisms were not domain-specific mentalising (named here perspective-taking) processes, but rather a sub-mentalising, domain-general cognitive process simulating mentalising in social setting (see Heyes (2014) for an in-depth review).

3. *Visual perspective-taking processes*

Signs of the ability to track the visual information available to other people has been described in children as young as 14 months (Sodian et al., 2007), though Moll & Tomasello (2006) reported that level 1 perspective-taking developed between 18 and 24 months. First signs of level 2 perspective-taking appear later in development, around 36 months (Moll & Meltzoff, 2011), mirroring the developmental pattern observed in the cognitive and affective modalities, with simple skills developing early, and complex processes developing later (Apperly & Butterfill, 2009; Schneider et al., 2014, 2017).

In the case of the visual modality, while explicit mechanisms can be measured using different strategies, with participants indicating with words or actions what another person sees, implicit mechanisms have been measured via the interference caused by the irrelevant presence of another person. This interference was interpreted as the involuntary, implicit processing of the other person's perspective (Samson et al., 2010). Using this method, Surtees et al. (2016) proposed that an implicit component operated consistently in level 1 visual perspective-taking processes, but that its involvement in level 2 processes was context-dependent. This theory could explain why level 1 visual perspective-taking processes are faster than level 2 processes, which are far more dependent on conscious, explicit mechanisms (Surtees et al., 2016).

However, a growing body of literature is arguing that visual perspective-taking is not a social process, and does not rely on the same underlying mechanisms as other mentalising skills, such as cognitive and affective perspective-taking (see Cole & Millett (2019) for an up-to-date review). Several studies report that visual perspective-taking truly is a social mechanism, as when someone else is present in the scene, there is a spontaneous computation of their perspective. The existence of this "altercentric" interference has indeed been reported in both level 1 (Marshall et al., 2018; Samson et al., 2010) and level 2 (Böffel & Müsseler, 2020; Quesque et al., 2018) visual processes, with studies demonstrating that this automatic computation was greater when the target was human-like compared to a non-social item (Gunalp et al., 2019; Todd et al., 2017). However, as mentioned above, other authors have argued that this altercentric interference occurs consistently in level 1 but not always in level 2 visual processes where the phenomenon is constrained by the situation (Böffel & Müsseler, 2019; Surtees, Apperly, et al., 2016; Surtees, Samson, et al., 2016).

Opponents argue that when performing visual perspective-taking, the other person is not regarded as another mind that we try and understand, but as a mere direction cue, as this interference can be reproduced when replacing a human-like avatar with an arrow. These results have been reported in both level 1 (Cole et al., 2016; Santiesteban et al., 2014, 2017) and level 2 (Millett et al., 2019) processes. Notably, a recent extensive review by Cole & Millett (2019) highlighted the methodological flaws of several studies supporting the existence of the interference, and argued that it was in fact impossible to represent someone else's visual experience, and "see the world through their eyes". The review authors demonstrated that visual experiences are the result of sensory processes channelled by attention and knowledge, and that in the experimental studies currently available, participants only make assumptions of what the other knows, based on their own knowledge and on the apparent direction of the other's attention. In this regard, visual perspective-taking is not about representing in our own mind the visual experience of another through domain-specific mechanisms, as would be the case for cognitive and affective perspective-taking processes, but instead about re-computing our own experience through domain-general mechanisms and a shift of our attention due to environmental cues.

While the current study does not have the primary goal of solving this debate, identifying how each modality of perspective-taking responds to lived experiences, such as bilingualism, will take this question one step closer to an answer. Indeed, juggling between multiple languages relies on, and impacts, numerous cognitive processes, including social skills such as perspective-taking.

B. Perspective-taking and Bilingualism

1. *Current bilingualism research context*

As mentioned in Chapter 2, most of the research currently available on the non-linguistic cognitive consequences of bilingualism focus on executive function and cognitive control, driven by the theory that balancing two languages stimulates the development of cognitive skills such as attention, switching or inhibition (Green & Abutalebi, 2013). This field of research is now the scene of heated debate around the existence of the so-called bilingual advantage. Numerous meta-analysis, systematic reviews (Donnelly et al., 2019; Tabori et al., 2018; van den Noort et al., 2019) and large-scale studies (Dick et al., 2019) have attempted to provide answers to this debate, as well as future directions for research in the field of executive functions. Comparatively, social cognition has been somewhat omitted from this discussion, and fewer studies have investigated the impact of bilingualism on social processes, including perspective-taking. This is surprising considering that perspective-taking processes depend on both social and linguistic experiences and skills. Indeed, environments rich in social interactions and linguistic inputs are thought to stimulate the development of perspective-taking (Garfield et al., 2001), and bilingual exposure may enhance this mechanism. Nonetheless, just as in the field of executive functioning, what research there is has produced conflicting findings, particularly in adults, some studies finding a bilingualism advantage, while others do not find any differences between monolinguals and bilinguals.

2. *Perspective-taking and bilingualism: Studies with children*

Several cross-sectional studies with children have highlighted a generally positive influence of bilingualism upon several types of perspective-taking. In the visual modality, Fan et al. (2015) compared monolingual, bilingually-exposed but not bilingually-proficient, and bilingual 4- to 6-year-old children (with 24 children per language group), and showed that simple exposure to bilingualism was enough to improve level 1 visual perspective skills as much as actual bilingual proficiency. Measuring more complex perspective-taking skills in 45 monolingual and 37 bilingual 8-year-old children, Greenberg et al. (2013) also found a positive influence of bilingualism on level 2 visual perspective-taking, with bilingualism predicting accuracy on the perspective-taking task, after controlling for receptive language and non-verbal intelligence.

Regarding cognitive perspective-taking, Kovács (2009) reported a positive influence of bilingualism on false-belief performance (i.e. level 1 cognitive perspective-taking) in children as young as 3-years-old (with 32 children per language group). Controlling for age and verbal abilities, Farhadian et al. (2010), Nguyen & Astington (2014) and more recently Diaz & Farrar (2018), reached the same result with children aged 3 to 5 (respectively with 98 bilingual and 65 monolingual children, 24 bilingual and 48 monolingual children, and with 32 bilingual and 33 monolingual children). Goetz (2003) measured both level 2 visual perspective-taking and level 1 false-belief skills in 3 and 4-year-old English-Mandarin bilingual children, and compared these 40 bilinguals to 32 monolingual English and 32 monolingual Mandarin age-matched children, to account for the effect purely due to the nature of the languages. Interestingly, while monolingual groups had similar skills, both were outperformed by bilingual children.

Going further than a direct group comparison, Gordon (2016) found that monolingual and bilingual 4-year-old children differed in how their language proficiency predicted their cognitive and affective perspective-taking abilities. Comparing 26 Spanish-English bilinguals to 26 English monolinguals on a battery of 7 theory of mind tasks, the results show that, as expected, higher English proficiency was linked to higher perspective-taking skills in monolingual children, but surprisingly, the same was true for bilingual children only if they also had high proficiency in Spanish. As such, even though overall bilingual and monolingual children performed equally, the results suggest that in bilinguals, the development of perspective-taking is not linked to fluency in a single language, but to fluency in both. Furthermore, a recent longitudinal study (Diaz & Farrar, 2018a) also found different developmental pathways between monolingual and bilingual children regarding their false-belief skills. While in monolingual children, language and executive functioning at the age of 4 (n = 38) predicted their false-belief performances at the age of 5 (n = 25), in bilingual children it was their meta-linguistic awareness at 4 (n = 40) that predicted their false-belief performances at 5 (n = 22). While this study used a somewhat smaller sample, its longitudinal design is particularly valuable, and suggest the existence of different socio-cognitive developmental directories between monolingual and bilingual children.

However, a recent study by Dahlgren et al. (2017) did not replicate these findings, reporting no evidence for an effect of bilingualism on false-belief abilities, even after controlling for chronological and linguistic age. Still, these findings have to be considered in the light of the small sample size involved compared to the studies reported above (14 bilingual and 14 monolingual 4-year-old children). Also, the linguistic age variable controlled for in this study was only the receptive language, measured by the well-established Peaboby Picture Vocabulary Test (PPVT). While the same method was used by Nguyen & Astington (2014), Diaz & Farrar (2018) controlled for both receptive (again with the PPVT) and general language skills, including expressive language, as did Farhadian et al. (2010). As such, when comparing monolingual and bilingual children on their perspective-taking skills, controlling general – meaning both receptive and expressive – language skills is essential to draw meaningful conclusions.

Finally, a recently published meta-analysis (Schroeder, 2018) which assessed the effect of bilingualism on children's perspective-taking skills confirmed the existence of a positive influence of bilingualism. Reviewing first the 16 studies on the topic published at the time, including those reported above, and then only the 8 studies that also rigorously controlled for language proficiency, Schroeder found first a small, then medium-size bilingual advantage, and, importantly, no evidence for a publication bias.

3. *Perspective-taking and bilingualism: Studies with adults*

However, research on adults, undoubtedly scarcer, brings more inconsistent results. Across 3 complementary experiments (route-finding task, and item identification task in a grid, without and with eye-tracking), Ryskin et al. (2014) reported no effect of bilingualism on the accuracy of level 1 and level 2 visual perspective-taking in university students (19 to 32 participants in each language group across the 3 studies). On the other hand, Rubio-Fernández & Glucksberg (2012) reported that while monolingual and bilingual university students (23 in each group) performed as accurately on a false-belief task in terms of response time, eye-tracking data showed that bilinguals were less susceptible to egocentric bias than monolinguals. Thus, in young adults the bilingual effect may not be apparent in simple measures of accuracy but in the expression of implicit processes. Finally, a more recent large-scale study by Javor (2017) compared 120 Hungarian monolingual and 120 Hungarian-Serbian bilingual young adults (mean age of 20 years) on their level 1 and level 2 cognitive perspective-taking skills, and reported a bilingual advantage.

The discrepancy in these findings could be the result of methodological differences between studies, starting with the nature of the tasks involved, and by extension the type of perspective-taking processes measured. While Ryskin et al. (2014) measured visual perspective-taking, Rubio-Fernández & Glucksberg (2012) focused exclusively on level 1 cognitive perspective-taking, and Javor (2017) assessed both level 1 and level 2 cognitive perspective-taking. Thus, it is possible that only some modalities of perspective-taking have the potential to be impacted by bilingualism, and that this impact could only become more apparent in complex tasks. Second, both Ryskin et al. (2014) and Rubio-Fernández & Glucksberg (2012) relied on small sample sizes (a maximum of 32 participants per group in the former, and 23 in the latter) which could have impacted their statistical power, especially in light of the results by Javor (2017), which involved 120 participants in each language group. Third, these authors approached the distinction between bilinguals and monolinguals differently, an issue more prevalent in studies conducted with adults than with children. Ryskin et al. (2014) grouped participants based on the median split of a continuous measure of bilingualism, computed from the participants' non-English language proficiency, weekly use, and duration of exposure. This approach is highly influenced by sampling method and the language profile of the participants, and therefore lacks objectivity and reproducibility. Furthermore, it does not guarantee a statistical difference between the groups on language variables known to impact some cognitive processes (such as age of acquisition), and participants closest to the overall median are likely to present similar language profiles. As mentioned in Chapter 1 section II.A, Rubio-Fernández & Glucksberg (2012) relied on more reproducible criteria, using an age of acquisition (age of second language acquisition under age 9) and current language switching habits cut-offs to classify their participants. Javor (2017) also relied on the age of acquisition to classify their participants, though this study used a more stringent cut-off, with a maximum age of acquisition of the second language set at 6 years old to be qualified as bilingual, and observed that the percentage of daily use of the second language was between 25 and 50% for all bilinguals, and under 20% for all monolinguals. Relying on such cut-offs, while having the benefit of being clear and reproducible, also has weaknesses, as it does not ensure a significant difference between groups in other bilingualism variables that, as described above, could also influence the cognitive skills studied. Overall, while there seems to be an influence of bilingualism on some aspects of perspective-taking in young highly-educated adults, methodological issues such as small sample size and language group classification method suggest these results should be interpreted with caution.

Crucially, the reason for these contrasted findings could also be that detecting significant but small differences is ultimately more complex in an adult population without any cognitive condition, especially when most studies involve students or young adults from western, educated, industrialised, rich and democratic societies, who are expected to have high cognitive abilities (Hanel & Vione, 2016; Henrich et al., 2010). Therefore, in adult research, a lack of differences between bilinguals and monolinguals does not prove a complete absence of bilingualism effect, simply that in typical development people, especially young and highly educated adults, eventually reach a peak of cognitive abilities that bilingualism cannot drastically surpass. This point is crucial when researching the influence of bilingualism in adulthood, as it highlights the need for precise and rigorous methods, possibly moving beyond the frequent binary and categorical definition of bilingualism into a more multidimensional and naturalistic interpretation of this complex experience (Baum & Titone, 2014; Luk & Bialystok, 2013)

4. *Perspective-taking and bilingualism: Accounting for discrepancies*

The current body of research, whether in childhood or adulthood, does not portray a clear picture of the interplay between bilingualism and perspective-taking abilities, which could be due to two main factors. First, studies addressed different forms of perspective-taking, that may not be equally susceptible to the influence of bilingualism, as indeed they are unequal in front of other factors such as aging (Laillier et al., 2019). This matter is further complicated by the facts that most studies on cognitive perspective-taking only address false-belief, which is only one aspect of this process (Birch et al., 2017) and does not reflect its full complexity. Unfortunately, no task currently available can assess all forms of perspective-taking in a single, consistent paradigm, which would ensure that any difference between modalities is indeed related to the core nature of said modalities. Arguably, even the cognitive and affective modalities, both assessed via the understanding of social interactions, are rarely distinctly addressed in a single task, and the tasks that do assess both either fail to distinguish level 1 and level 2 processes (Baksh et al., 2018; Brewer et al., 2017; Dziobek et al., 2006), or adopt a support lacking in realism, such as text (Mckinnon & Moscovitch, 2007) or animated pictures (Baksh et al., 2018), instead of more "real-life" stimuli such as videos. This last point is particularly critical for research in adulthood, where naturalistic and ecologically valid measures are essential to capture nuanced and fine individual differences (Chevallier et al., 2015; Livingston et al., 2019; Turner & Felisberti, 2017).

Furthermore, most studies adopted an unnaturalistic binary framework regarding bilingualism, opposing monolinguals to bilinguals, while diverging in their definition of bilingualism and inclusion criteria. As reported in the field of executive function, it is likely that only some specific features of the bilingualism experience can influence perspective-taking, and that these features' effects are masked when bilingualism is regarded as a simple categorical variable. To rigorously assess the relationship between bilingualism and perspective-taking, it is necessary first to consider together, and compare within a same sample, all forms of perspective-taking with naturalistic, appropriate and comparable measures, and second to set aside the binary definition of bilingualism in favour of a multidimensional one, acknowledging the various features of bilingualism.

5. *Perspective-taking and bilingualism: Interfering factors*

Interpretation of the existing literature is further complicated by the fact that several studies describe a link between executive function and perspective-taking, since both involve switching and inhibition mechanisms, to suppress one's own perspective and shift to someone else's (see Apperly et al.(2009) for an in-depth review of the interplay between perspective-taking and executive skills). Qureshi & Monk (2018) found that executive processes were involved in both perspective selection and perspective calculation in level 1 visual perspective-taking, and Long et al. (2018) showed that in adults, the correlation between level 1 visual perspective-taking and executive function skills changed across the lifespan. However, Hamilton et al. (2009) found that in typically developing 4- to 8-year-old children (n = 38), level 2 visual perspective-taking scores were correlated with theory of mind abilities, but not with mental rotation abilities. This finding rejects the hypothesis that visual perspective-taking relies primarily upon executive skills. The role of executive skills has also been demonstrated in cognitive and affective perspective-taking skills. In a meta-analysis gathering 102 studies, Devine & Hughes (2014) showed that the development of false-belief tracking in childhood was predicted by executive functioning, and Laillier et al. (2019) reported that inhibition predicted affective perspective-taking skills in adulthood.

C. Research questions and predictions

There are conflicting findings in the field regarding the influence of bilingualism upon perspective-taking skills, and the role of executive functions. Disentanglement of both the various manifestations of bilingualism and the various types of perspective-taking may shed light on this debate. By relying on a multidimensional and continuous definition of bilingualism, as advised by Baum & Titone (2014), and by distinguishing all the possible modalities and levels of perspective-taking, this study seeks to provide a better understanding of the relationship between bilingualism and perspective-taking skills in adulthood. This study assessed the visual, cognitive, and affective perspective-taking skills of neurotypical adults with various degrees of bilingual experience, and aimed to address three research questions:

1) *Is there evidence that bilingualism (multi-dimensionally defined) enhances performance across modalities and levels of perspective-taking?*

In the visual modality, bilingualism was expected to negatively predict egocentrism (bias towards one's own perspective) and positively predict altercentrism (influence of the other's perspective). In the cognitive and affective modalities, bilingualism metrics would positively predict perspective-taking scores, but not the control question score, which does not require perspective-taking.

2) *Is perspective-taking performance shared across visual, cognitive, and affective modalities, suggesting the existence of a general perspective-taking process?*

If the three modalities described above rely on a common general perspective-taking process, then the different scores would be inter-correlated, showing a share of common variance. However, if, as suggested by the body of literature discussed above, visual perspective-taking is not a social cognitive mechanism similar to cognitive and affective perspective-taking, then cognitive and affective perspective-taking scores would be inter-correlated with each other, but not with visual perspective-taking bias scores.

3) *What is the validity of the new Adult-Theory of Mind-extended test as a cognitive and affective perspective-taking test in an adult population?*

If the Adult-Theory of Mind-extended test is an appropriate tool, then there would be an acceptable consistency ($\alpha \geq 0.7$) between the questions for each outcome measure, as well as a high (≥ 75%) inter-rater agreement.

II. Methods

A. Participants

The sample size needed to carry out this study was calculated using the *pwr* R package (Appendix II.1). A sample of 85 participants would allow me to conduct a multiple linear regression analysis with 80% power to detect a medium effect size from the predictors, at $\alpha = 0.05$, taking into account 5 predictors. Assuming that not all participants would complete the full task battery, a 12% increase was applied, for a final target sample size of 96.

Participants were aged between 16 and 60 to avoid age-related socio-cognitive decline (Love et al., 2015). While age-related cognitive changes (declines and improvements alike) occur in this age-range as well, especially in executive skills, these changes were adjusted for in the analysis by including chronological age and executive skills as control variables (see Chapter 3 section II.C). Participants were recruited in Edinburgh via advertisement to the universities' staff and students, and through social media. Participants were typically-developed adults with normal or corrected to normal vision and hearing, with no known neurological conditions. Participants were provided with the details of the study and gave informed consent. Participants received a £20 gift voucher for their participation, and their travel expenses to and from the appointment were covered. A detailed account of the participants' demographics and language profile can be found in Chapter 3 section III.A, Table 3.5, Table 3.6, and Table 3.7.

B. Materials and data processing

Prior to the data collection appointment, participants were sent a unique personal link to an online survey platform, Qualtrics, to complete the Demographic and Language Questionnaires. If participants failed to complete the questionnaires prior to the appointment, a computer was made available for them to complete the questionnaires at the end of the appointment. During the appointment, tests were administered in the following order: Visual Perspective-Taking task, Adult-Theory of Mind-extended test, Test of Everyday Attention, Wechsler Abbreviated Scale of Intelligence Second Edition.

1. *Self-reported questionnaires*

Procedure

Participants completed a Demographic Questionnaire to collect data about their age; gender; level of education; current occupation; country of birth and residency. They also completed a Language Questionnaire to capture information about: the number of languages known; the age of acquisition of each language; the self-rated proficiency in each language on four domains (written expression, written comprehension, oral expression, oral comprehension) on a 9-point scale from 0 (= "no proficiency") to 8 (= "excellent proficiency"). The questionnaire also captured daily language switching experiences, or extent to which, on a daily basis, they use several languages within a same context, self-rated on a 7-point scale from 0 (= "never") to 6 (= "always"). The Language Questionnaire also asked about the learning history for each language: context of learning (home, school, or community), past and current diversity of interlocutors, past and current diversity of context and activity of use. A final section in the Language Questionnaire included open-ended questions focusing on the participants' bilingual experiences. Those answers are not included in the present study. The Demographic and Language Questionnaires (Digard & Fletcher-Watson, 2020) were created in Qualtrics and are available to view at https://osf.io/ns7ma/.

Data processing

The direct measures from the Language Questionnaire were processed as follow.

Language order – While participants were asked to report their languages by age of acquisition, some failed to do so. Languages were all reordered by age of acquisition, with the second language being the first language learned after the native language. In the case of several native languages, the order provided by the participant was used.

Number of languages reported (N language R) – Number of languages reported by each participant, ranging from 2 to 7. Participants could give details about up to 7 languages, but they were offered the possibility to list more languages, if applicable. This variable was further converted into a categorical variable (N language R-group) for analysis: bilingual (two languages reported) and multilingual (three languages or more reported). Both versions of this outcome measure were included as candidate predictors in the multiple regression analysis (see Chapter 3 section II.C.1.a for further details).

Age of acquisition (Lx age) – Participants were asked "how old were you when you first encountered L2" and the answer to this question was defined as age of acquisition. L2 age was included as candidate predictor in the multiple regression analysis, and the absence of outliers was verified, with exclusion of values more than 2.5 standard deviations away from the mean. This led to the exclusion of two values, which were converted as missing values in the multiple regression analysis.

Proficiency (Lx proficiency) – Internal consistency between the self-rated scores in all four language components was assessed across all participants, for each language. Each language had a Cronbach's α above 0.90, except for the 5th language, which had a Cronbach's α of 0.82. These scores indicated good internal consistency, and as a result self-rated scores in all four language components were averaged for each language for each participant (see Table 3.1 for an example), to create a general proficiency score in each language of each participant. L2 proficiency was included as candidate predictor in the multiple regression analysis, and the absence of outliers was verified, with exclusion of values more than 2.5 standard deviations away from the mean. This led to the exclusion of two values for L2 proficiency, which were converted as missing values in the multiple regression analysis.

Table 3.1 - Calculation of language proficiency scores

	Language 1					Language 2				
	Oral Exp	Oral Comp	Written Exp	Written Comp	L1 pro	Oral Exp	Oral Comp	Written Exp	Written Comp	L2 pro
P01	6	6	6	6	6	6	6	5	6	5.75
P02	6	6	6	6	6	4	5	4	5	4.5

Note. Example of calculation of language proficiency scores. For each participant (P), each language overall proficiency (Lx pro), is calculated as the average of the self-rated scores for all four language components: oral expression (Oral Exp), oral comprehension (Oral Comp), written expression (Written Exp), and written comprehension (Written Comp).

Number of languages known with medium to high proficiency (N language P) – This variable was calculated for each participant as the number of languages with an overall proficiency equal to or above 4 (= "adequate"). This proficiency cut-off was chosen as it indicated that the participant had a more than basic grasp of the language. This discrete variable ranged from 1 to 7. This was further converted into a categorical variable (N language P-group) for analysis: monolingual (proficient in one language), bilingual (proficient in two languages) and multilingual (proficient in three or more languages). Both versions of this outcome measure were included as candidate predictors in the multiple regression analysis.

Proficiency balance (Lx/L1 balance) – Relative proficiency between the first (L1) and second (L2) languages was calculated as the absolute difference between the first and second language proficiencies. A score of 0 indicated a balanced proficiency, a score of 7 indicated a complete dominance in one of the languages. The L2/L1 balance score was included as candidate predictor in the multiple regression analysis, and the absence of outliers further than 2.5 standard deviations away from the mean was verified.

Language switching experience (Language switching) – This variable was taken directly from the Language Questionnaire, as the self-rated extent to which participants use several languages within a same context, scored on a 7-point scale from 0 (= "never") to 6 (= "always"). The Language switch score was included as candidate predictors in the regression analysis, and the absence of outliers further than 2.5 standard deviations away from the mean was verified.

Acquisition context – For each language, participants indicated frequency of use with different interlocutors and in different contexts. The home environment included 5 item scores (parent 1, parent 2, siblings, other people in the household, other members of the family), the school environment included 1 item (school), and the community environment included 2 item scores (friends, community). Not all respondents assigned a score to all items (e.g. respondents without siblings did not report a score for this item). The maximum score reported in an environment was the score assigned to that environment. The main context of acquisition was identified as the environment with the highest score. When the main (highest-scoring) context had a score strictly under 3 (= "Occasionally"), the main context was re-coded as "independent", highlighting the fact that the respondent mostly learned the language independently, and did not use it in the home, the school, or the community.

Current context of use – The main context of current use was identified in the same manner as the main context of acquisition. For this variable, the home environment included 7 item scores (parent 1, parent 2, siblings, partner, children, other members of the family, flatmates), the school/work environment included 1 item (school/work), and the community environment included 2 item scores (friends, community). For the respondents' first language (L1) only, the community environment featured only one item (community) due to an error when building the online survey. When the main context had a score strictly under 3 ("Occasionally"), the main context was re-coded as "independent", as above.

2. *Visual perspective-taking – VPT task*

Stimuli

The Visual perspective-taking task (VPT task) is similar to that introduced by Surtees et al. (2016). Picture stimuli show an avatar next to a table and surrounded by either balls or digits. For level 1 stimuli, one to three balls are visible: consistent stimuli show all the balls in front of the avatar, while in inconsistent stimuli at least one ball is behind the avatar. For level 2 stimuli a digit, either 6 or 9, is positioned on the table next to the avatar. In consistent stimuli the digit is standing upright on the table, while for inconsistent stimuli the digit is lying flat on the table. Examples of stimuli can be found in Figure 3.2.

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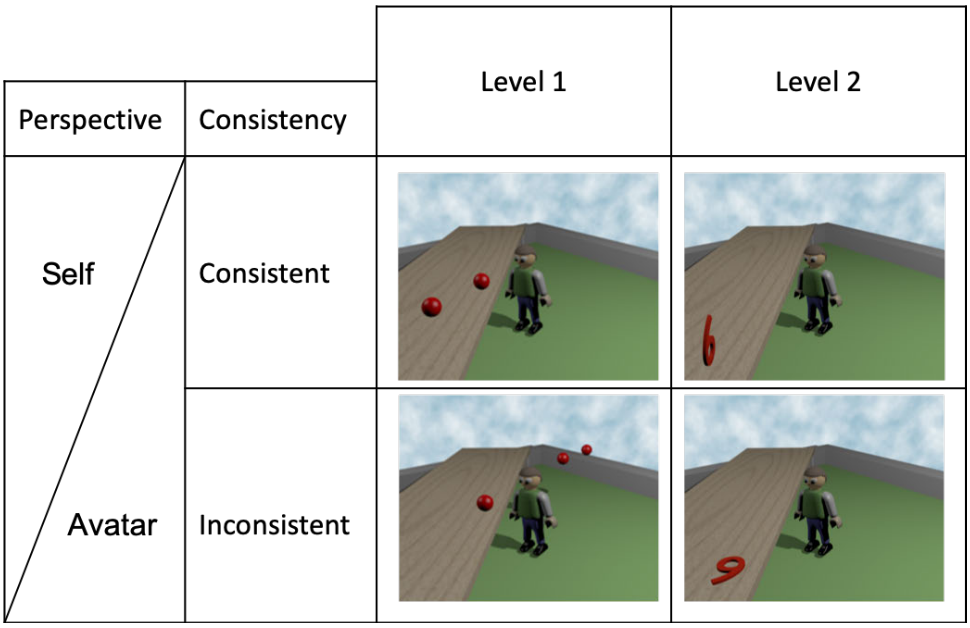
Figure 3.2 - Conditions in the VPT task



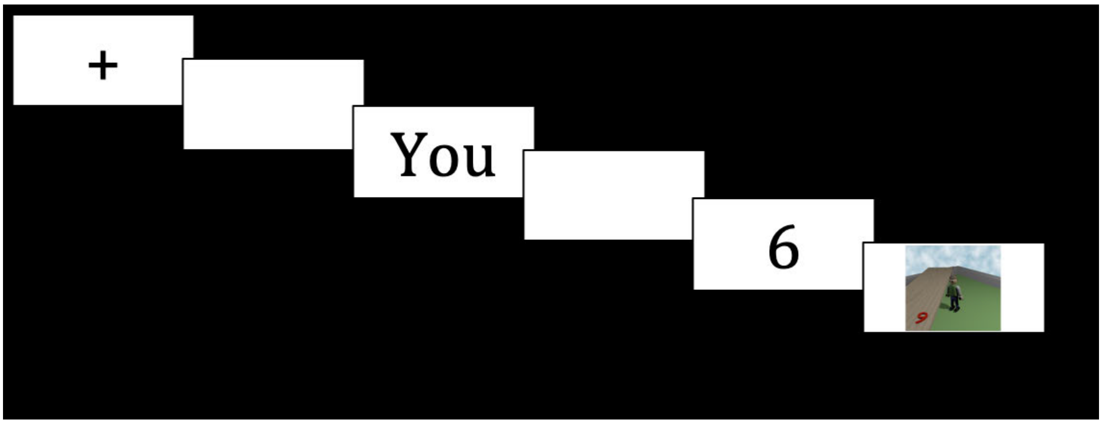
Note. Summary of the 4 conditions presented in the level 1 and level 2 VPT task, alongside examples of the stimuli used.

Procedure

The VPT task was built within the online experiment builder Gorilla (https://gorilla.sc). Participants completed the task on a computer, under the supervision of the experimenter. Participants completed first the level 1 sub-task, and then the level 2 sub-task. For each sub-task, participants were first given self-paced instructions on the screen, with an example, and were allowed to ask the experimenter for further information. Participants then completed a block of practice trials gathering all the possible trial conditions (26 trials for the level 1 condition, and 24 trials for the level 2 condition), to get used to the task. Next, participants were presented with 208 trials in the level 1 condition (in 8 randomised blocks of 24 trials and 1 randomised block of 16 trials), and 192 trials in the level 2 condition (in 8 randomised blocks of 24 trials). The higher number of level 1 trials was due to the inclusion of 16 filler trials, so that there was no probability bias towards a “yes” or “no” response. On each trial participants saw a fixation cross, then a cue as to whose perspective to take (“Avatar” or

“You”), followed by a response option: “0”, “1”, “2”, or “3” for the level 1 condition, and “6” or “9” for the level 2 condition. After these cues the picture stimulus was presented for up to 2 seconds, during which participants had to click on one of two keys on the computer keyboard to respond “Yes” or “No” to whether the response option matched the picture stimuli. For half the trials the response option matches the content of the picture stimulus, for the other half they do not. The stimuli would disappear and the following trial start after a maximum of 2 seconds, or when the participant answered. There was no feedback given as to the correctness of the answer. Level 1 and level 2 trials were presented in separate blocks. Within each level condition, all four conditions were presented in a mixed design. The full procedure is presented in Figure 3.3.

Figure 3.3 - VPT task procedure



Note. Procedure of the level 1 and level 2 VPT task. The rectangles represent the sequence of displays on the computer screen, with the duration of each display in milliseconds, and the final instruction “Press Yes or No”, displayed on the screen under the picture stimulus during the task.

Data processing and specific analysis plan

For each participant, the direct measures included the reaction times (RT) for each trial, and the error rate across trials by perspective type (self versus avatar) and consistency type (consistent versus inconsistent trials). For the following analysis, only the reaction times were considered, as this measure offered a wider range of individual variability between participants than their accuracy. A lower threshold of 100ms for individual response times was set to eliminate anticipatory responses. There was no correct trial with a response time (RT) under 100ms in the full set of individual trials. The data from the VPT task was processed in two steps: first, the effect of the condition was measured to verify the existence of biases, thus reproducing the findings by Surtees, Samson & Apperly (2016); second, the direct measures were processed to create the bias scores, used as outcome measures in the multiple regression analysis to assess the relationship between visual perspective-taking and bilingualism. Rigorous scrutiny of the normality of the underlying variables was performed prior to each step of the analysis.

For the first step of the analysis, for each participant and each condition, the mean RT for correct trials was calculated and used in analysis. One participant did not have a single correct trial in the Avatar-Inconsistent condition, which therefore left 95 participants' data available for analysis. As per the analysis described by Surtees, Samson & Apperly (2016), for each condition participants with mean RT further than 2.5 standard deviations away from the condition mean were excluded for the first step of the analysis, comparing mean RT across conditions, but were included for the construction of the biases. Indeed, while a participant could be an outlier in some conditions, their biases – the difference between conditions – could be in the same range as the other participants. This resulted in a total of 95 participants in each condition. Mean response times to each condition were compared using a 2x2 repeated measures ANOVA with Perspective (Avatar, Self) and Consistency (Consistent, Inconsistent) as within subject factors. To obtain a balanced design, the 4 participants identified as outlying from any individual condition (on the basis of response times) were fully excluded from this analysis, which was carried out on the 92 remaining participants.

For the second step of the analysis, bias scores were calculated in each Perspective condition as the difference between inconsistent mean RT and consistent mean RT. Higher mean RT in Inconsistent trials compared to Consistent trials produced a positive bias index. The altercentric bias was derived from response times in the Self condition: when occurring in trials where the participant is asked to judge their own perspective, a positive bias index indicated an altercentric bias, with longer inconsistent trials mean RT compared to consistent trials being interpreted as the participant involuntarily processing the avatar's perspective and having to inhibit it. The egocentric bias was derived from response times in the Avatar condition: when occurring in trials where participants were asked to judge the avatar's perspective, this positive index indicated an egocentric bias, with longer inconsistent trials mean RT compared to consistent trials being interpreted as the participant having to inhibit their own perspective.

As the calculation of these bias scores would not be possible for the outlying participants whose data were excluded from one of the conditions, these bias scores were calculated for all participants. As per the first step of the analysis, outlying participants were excluded in each bias score on the basis of being 2.5 standard deviations away from this bias score's mean. This led to this exclusion of one participant for the altercentric bias score, and no outlier was identified for the egocentric bias score. Therefore, these final bias scores each included 95 participants. These bias scores were then used as outcome measures in the multiple regression analysis. Direct and outcome measures are reported in Table 3.2.

Note that while theoretically it would be possible for an individual participant to show both egocentric bias on avatar-focused trials and an altercentric bias on self-focused trials, these are opposite approaches to the task.

Table 3.2 - Direct and outcome measures of the VPT task

	Level 1				**Level 2**			
	Self		Avatar		Self		Avatar	
Direct measures	Con	Incon	Con	Incon	Con	Incon	Con	Incon
Outcome measures	Alter bias		Ego bias		Alter bias		Ego bias	

Note. Direct measures included the mean response time of consistent (Con) and inconsistent (Incon) trials during the assessment of the participant's own (Self) or the avatar's (Avatar) perspective in level 1 and level 2 perspective-taking context. Outcome measures will be the altercentric (Alter) and egocentric (Ego) biases calculated as follow: Incon – Con.

3. *Cognitive and affective perspective-taking – Adult-Theory of Mind-extended*

Stimuli

The cognitive and affective perspective-taking task was an adaptation of the *Adult-Theory of Mind* test (A-ToM, designed by Brewer et al. (2017)). The A-ToM comprised six social videos and six physical control videos, lasting 24 to 62 seconds. The social videos included one faux-pas item, two sarcasm items, one white lie item, one bluff or persuasion item, and one misunderstanding item. All physical items were based on, or adapted from, items described by Happé (1994a), depicting simple physical interactions (e.g. two children doing a swimming race in the sea). A full transcript of the videos is available in Appendix III.1.

Procedure

The 12 scenarios were presented in a random order via a VLC Media Player playlist. Each physical video was followed by one control physical question. Each social video was followed by the original A-ToM question, as well as four new questions designed for the purpose of this study to capture level 1 and level 2 cognitive and affective perspective-taking. In the resulting Adult-Theory of Mind-extended (A-ToM-e) task, the questions associated with the social videos were as followed: one general social insight question from the original A-ToM, one level 2 cognitive perspective-taking question, one level 2 affective perspective-taking question, one level 1 cognitive perspective-taking question, and one level 1 affective perspective-taking question. The questions were presented in order of difficulty (hardest to easiest) to avoid building up the participant's knowledge with successive questions from easiest to most difficult. The questions relating to each scenario were displayed on screen following the video for 30 seconds each. Participants answered each question out loud and these answers were audio-recorded. Participants were informed at the beginning of the task that they would watch short videos and be asked short questions about them, that they would answer out loud. Participants' responses were transcribed and rated on a 3-point scale where 0, 1, and 2 corresponded to incorrect, partially correct, and correct, respectively. For the control and general questions the scoring followed the criteria described by Brewer et al. (2017). For the newly-designed questions the scoring adopted similar criteria to those described by Mckinnon & Moscovitch (2007) for the Social Scenarios Task, a text-based level 1 and level 2 cognitive and affective theory of mind task. Full details of the scoring criteria and inter-rater reliability are available in Appendix III.2 and Appendix III.3, respectively.

Data processing

The outcome measures were as detailed in Table 3.3. One participant was excluded from this task due to technical issues recording their responses. For each participant, the physical score was calculated as the average of the participant's six physical items' answers, and the same calculation was applied to the general, level 1 cognitive, level 2 cognitive, level 1 affective, and level 2 affective scores. For each participant, the overall cognitive score was calculated as the average of the participant's 12 cognitive items' answers, and the same calculation was applied to the overall affective score. For each participant, the overall social score was calculated as the average of all the participant's social items' answers. As a result, all the outcome measures ranged between 0 and 2. As some participants missed questions or complete videos due to technical issues, the number of answers available for each sub-score was verified. No participant had more than 1 missing answer out of 6 for the physical, level 1 cognitive, level 2 cognitive, and level 1 affective, and general scores, but one participant had 2 out of 6 answers missing for level 2 affective scores. No participant had more than 3 out of 12 missing answers for the overall cognitive and affective scores. No participant had more than 6 out of 30 missing answers for the overall social scores. Thus, as no participant had less than 50% available answers for each score, no participant was excluded on the basis of missing answers, and for each score the final outcome scores were calculated from the answers available. Rigorous scrutiny of the normality of the underlying variables was performed prior to each step of the analysis. The results of each step are reported in Chapter 3 section III.D. For consistency with the visual perspective data processing method, outlying participants were excluded in each score on the basis of being 2.5 standard deviations away from the score mean, resulting in a total of 94 participants with level 2 cognitive, level 1 affective, overall cognitive, and physical scores, 93 participants with level 1 cognitive, level 2 affective, overall affective, and overall social scores, and 92 participants with general scores. The final scores were used as outcome measures in the following analysis.

As mentioned above, the outcome measures did not include solely the measures directly related to the questions (general, level 1 and level 2 cognitive, level 1 and level 2 affective), but also the overall cognitive, overall affective, and overall social scores, as these measures allowed me to assess the relationship between bilingualism and each modality as a whole, as well as in the overall social perspective-taking mechanisms, regardless of spurious results purely due to data distribution. Indeed, even though overall scores lost precision regarding the complexity or modality of the task, they involved a richer range of possible scores, and therefore a finer representation of individual differences in perspective-taking abilities. Furthermore, it was to be expected that some of the level sub-scores would have a narrower or wider spread of distribution than others, thus limiting, or over-expressing, the possibility to assess their relationship with the predicting variables, and potentially leading to conclusions on results only present, or absent, because of the spread of the data. Finally, the overall social score allowed me to verify the overall pattern of the results, confirming the relevance of key predictor on a global scale.

Table 3.3 - Details of the scores and sub-scores of the Adult-Theory of Mind-extended

Score	**Range**	**Sub-scores**	**Range**	**Sub-scores**	**Range**
Physical					0.00 – 2.00
Social	0.00 – 2.00	General			0.00 – 2.00
		Cognitive	0.00 – 2.00	Level 1	0.00 – 2.00
				Level 2	0.00 – 2.00
		Affective	0.00 – 2.00	Level 1	0.00 – 2.00
				Level 2	0.00 – 2.00

Note. Range of the scores and sub-scores of the A-ToM-e. Each answer the participant gave was scored 0, 1 or 2 points. Physical, general, level 1 cognitive, level 2 cognitive, level 1 affective, and level 2 affective sub-scores were calculated for each participant as the average of all respective answers across the 6 videos. Cognitive and affective scores were calculated for each participant as the average of all respective answers across the 6 videos. The social score was calculated for each participant as the average of all the answers available for the social videos. To ensure no detail is lost when reported the data, all the scores are reported with two decimals.

4. *Executive function – Test of Everyday Attention*

Stimuli

The Test of Everyday Attention (TEA, Robertson et al., (1996)) was used to capture executive processes. The TEA measures aspects of attention and executive function based on Posner & Petersen (1990) multi-system attentional model. The TEA separates attention into theoretically distinct factors – sustained attention, selective attention, and attentional switching – and offers an acute method of assessing someone's executive function skills.

Procedure

The TEA test was administered by the examiner, who played a recording of the task to the participants. Participants were instructed to envision having entered a lift on the ground floor, and that – because the floor indicator does not work – one must count the auditory tones to track the lift's location. Each trial consisted of a series of auditory tones; followed by a recorded voice asking which floor they ended up on. The experimenter recorded the verbal answers of the participants. Specific instructions for each of the 3 subtests was as followed:

TEA 1, Elevator Task – sustained attention (referred to as "TEA attention" in the rest of this study): participants counted tones of the same pitch presented at irregular intervals (7 trials); *TEA 2, Elevator Task with Distraction – selective attention / inhibition* (referred to as "TEA inhibition"): participants counted low tones and ignored interspersed high tones (10 trials); *TEA 3, Elevator Task with Reversal – attentional switching* (referred to as "TEA switching"): participants presented with high, medium and low tones, and had to only count medium tones. High tones indicated the lift was moving up, and thus following medium tones would increase the floor count. Low tones indicated the lift was moving down, and thus following medium tones would decrease the floor count (10 trials).

Data processing

Performance on each subtest was measured as the number of trials with a correct response. The total TEA score (hereafter: TEA total) was calculated for each participant as the sum of the three sub-scores, and was included in the list of candidate predictors to account for the overall executive function skills of the participant. However, when internal consistency between the 3 subtests was assessed, the resulting Cronbach's alpha of 0.28 indicated a low internal consistency. A Pearson correlation test across the subtests indicated that in the present sample, TEA attention scores were not significantly correlated with TEA inhibition or TEA switching scores (p = 0.84 and p = 0.95, respectively), but TEA inhibition and TEA switching were significantly correlated (p = 0.00015), though the correlation coefficient was low (r = 0.38). These results indicated that the TEA total score, combination of these three weakly correlated sub-scores, might not be a robust approach to control for the participants executive function skills in the present analysis. As a result, each sub-score was also individually considered as candidate predictors in the following analysis. For each score, participants with a score further than 2.5 standard deviations away from the mean had their score removed in the following multiple regression analysis. One participant was found to have outlying TEA inhibition, one participant had both outlying TEA switching and TEA total, and one participant had outlying TEA inhibition, TEA switching and TEA total.

5. *Non-verbal Intelligence Quotient – Wechsler Abbreviated Scale of Intelligence, 2nd Edition*

Stimuli

Because of the nature of the study and the participation of non-native English speakers, intelligence quotient (IQ) was only measured in terms of non-verbal intelligence. To do so, participants were administered the Block Design and Matrix Reasoning subtests of the Wechsler Abbreviated Scale of Intelligence – 2nd Edition (WASI-II).

Procedure

The Block Design subtest consisted of 2 practice trials and up to 11 experimental trials, during which participants were presented with a figure on a sheet of paper that they had to reproduce with the coloured cubes provided. Trials increased in difficulty throughout the task, with figures using 2, 4, and finally 9 cubes, with maximum time allowed to complete the figure ranging from 30 to 120 seconds. Each trial was scored based on the time taken by the participant to complete the figure, with the final scores ranging from 0 to 2 for the first 2 experimental trials, and from 4 to 7 for the following trials, with a score of 0 for failed trials. Participants were asked to stop the task after two consecutive failed trials. The maximum score for the Block Design subtest was 71.

The Matrix Reasoning subtest consisted of 2 practice trials and up to 27 experimental trials increasing in difficulty, the first 3 practice trials being skipped for adult participants. For each trial, participants were presented with a sheet of paper with a grid of figures or patterns that included a missing element, represented with a question mark, and a row of 5 possible items to complete the grid. Participants had 30 seconds to indicate to the experimenter which item was the missing piece. Each trial was marked 0 or 1 based on the accuracy of the answer, and participants were asked to stop the test after 3 consecutive inaccurate answers. The maximum score for the Matrix Reasoning subtest was 30.

Data processing

For each participant, both scores were summed up to obtain the Perceptual Reasoning score, which was then converted into the Perceptual Reasoning Index (PRI) composite score, a standardised measure of non-verbal intelligence, hereafter called non-verbal IQ. The non-verbal IQ score was included as candidate predictor in the regression analysis. The three participants with a score further than 2.5 standard deviations away from the mean had their score removed in the following multiple regression analysis.

C. Analysis plan

1. *Relationship between bilingualism and perspective-taking*

To answer the first research question, a multiple linear regression analysis was conducted on each outcome measure on the full sample of participants.

a. Candidate predictors

The number of languages reported (N language R) and the number of languages reported with a high self-rated proficiency (N language P) corresponded to the full available scale, ranging from 1 to 7. As explained above (Chapter 3 section II.B.1), to achieve a more balanced distribution in these variables and increase their weight, both were converted to represent mono-, bi-, and multilinguals. As a consequence of the exclusion criteria, the number of languages reported – by group (N language R-group) was a binary variable with 2 (bilinguals) to 3 (multilinguals) as possible values, while the number of languages reported with a high self-rated proficiency – by group (N language P-group) ranged from 1 (monolinguals) to 3 (multilinguals). These converted, more balanced variables were used in the models.

Beyond the variables related to the number of languages known, the language predictors were those related to the second language and overall bilingual experience: the age of acquisition (L2 age), overall proficiency (L2 proficiency), proficiency balance between L1 and L2 (L2/L1 balance), and the language switching habits (Language switching). All the language predictors were taken directly from outcome measures of the Language Questionnaire (Chapter 3 section II.B.1)

The control variables taken from the Demographic Questionnaire (Chapter 3 section II.B.1), the Test of Everyday Attention (Chapter 3 section II.B.4) and the Wechsler Abbreviated Scale of Intelligence – 2nd Edition (Chapter 3 section II.B.5) were the participant's chronological age, TEA attention, TEA inhibition, TEA switching, TEA Total, and non-verbal IQ.

As reported previously, the absence of outliers was verified for each potential predictor, and values more than 2.5 standard deviations away from the mean were excluded. As a result, some participants had missing data in some predictors only, and models applied to a same sample of participants relied on a different number of observations if the model involved predictors with removed outliers. Table 3.4 summarises all the candidate predictors, and a visual representation of these predictors is available in Appendix IV.

Table 3.4 - Candidate predictors

	Bilingualism	Control
Predictors	- N language R-group	- Chronological age
	- N language P-group	- TEA attention
	- L2 age	- TEA inhibition
	- L2 proficiency	- TEA switching
	- L2/L1 balance	- TEA total
	- Language switching	- Non-verbal IQ

Note. Summary table of the candidate predictors. L2 age = age of acquisition of the second language; L2 proficiency = overall proficiency in the second language ; L2/L1 balance = proficiency balance between the first language and the second language; Language switching = language switching habits; N language R = number of language reported; N language R-group = number of language reported, by group; N language P = number of language known with a medium to high proficiency; N language P-group = number of language known with a medium to high proficiency, by group; age = chronological age of the participant.

b. Multiple linear regression models

Linear regression models computed using R (version 3.5.3) and R studio (version 1.2.1335) were used to determine how language profiles predicted each outcome measure. Due to the exploratory nature of this research, and limited power due to sample size, no interactions were included in the models.

For each model all the available predictors were first entered, and a stepwise regression with both forward and backward selection was then applied to obtain the optimal model, using the stepAIC function of the MASS R package. There are however two main limitations to using only the stepAIC function with this particular dataset. First, this function selects its optimal model based on the AIC score of the models, instead of indicators more relevant to the nature of this exploratory study, such as the R^2 adjusted, or the *p*-value. Also, this selection of the model with the highest AIC score does not test for any significant difference between the highest AIC and the others. This means that it is possible that this function results in a particular model with a high number of predictors simply because its AIC value is slightly higher than the second highest AIC value, even though the inclusion of some of these predictors does not significantly improve the fit of the model, and even lowers the reliability of the model. Second, this function can only be applied in datasets without any missing data in the outcome variable and the first-entered potential predictors. As explained above, due to the exclusion of outlying values in some predictors, the stepAIC function required the complete exclusion of any participant with at least one missing value in the whole set of potential predictors. Not only did this requirement lower the sample size and variability of the data, but this also meant that the influence of each predictor and each combination of predictors were not computed on the full set of data available for said predictor or combination of predictors, but on this subset of data without any missing values. Because of these limitations, the stepAIC function was used in combination with a second R package, olsrr, to confirm the optimal model with 1, 2, 3, 4, and 5 predictors (up to the limit defined by the sample size power calculation). These models were compared with ANOVAs to identify the optimal model. Finally, each optimal model was validated using 10-fold cross-validation. The use of these multiple methods to identify the optimal model ensured that the final combination of predictors selected was reliable and meaningful, and reduced the risk of a selection due to noise, variability, or over-fitting.

Performance of the models was measured with several indicators (more details about the statistical thresholds used in this study are reported in Appendix II.2):

- *p*-value, representing the overall significance level of the model;
- *F*-statistic, measuring the relationship between the predictors and the outcome measure;
- multiple R^2, the proportion of variance in the data explained by the model, representing how well the model fits the data;
- adjusted R^2, a more stringent R^2 measure taking into account the number of predictors used in the model, in order to avoid over-fittingness. Considering the highly exploratory nature of this study, the adjusted R^2 was used over the multiple R^2 when calculating the effect size f2 and post-hoc power;
- Cohen's f2, measuring the effect size of the model based on R^2 (adjusted R^2 in the present study);
- Observed power, probability calculated post-hoc of correctly identifying a true positive and rejecting the null hypothesis, based on R^2 (adjusted R^2 in the present study). While the use of post-hoc power calculation is highly debated, especially when used to discuss non-significant findings (Levine & Ensom, 2001), it was used in

the present study due to its exploratory nature and, in the following Chapter 4, low sample size, to discuss the selection (or absence) of certain predictors.

Before conducting each final multiple linear regression, the following assumptions were verified. Linearity between each used predictor and each outcome measure was verified graphically using a scatterplot. The normal distribution of residuals of the regression was tested using a Q-Q plot. Homoscedasticity was tested by plotting the residuals of the model against the values predicted by the model and verifying the random distribution of the data. Variance in each predictor was checked visually using a scatter plot of the data. Importantly, in order to retain a realistic representation of the bilingual experience, predictors were allowed to inter-correlate in the models.

2. *Correlation between perspective-taking modalities*

To answer the second research question, a correlation analysis using Pearson's correlation coefficient was used between the visual perspective-taking bias scores, and the outcome measures of the A-ToM-e. The threshold to conclude on the existence of a general perspective-taking process, common to all perspective-taking modalities, was set to Pearson's $r \geq \pm 0.50$.

3. *Reliability of the Adult-Theory of Mind-extended test*

To answer the third research question, internal consistency tests were conducted on each outcome measure of the A-ToM-e, using Cronbach's Alpha, with a threshold of Cronbach's $\alpha \geq 0.7$ defined as indicating good internal consistency between the items involved. This analysis allowed me to identify whether some videos were consistently lowering the validity of the test. The inter-rater agreement was also calculated across each outcome measure, to assess the accuracy of the coding scheme in the neurotypical sample specifically. As each answer was coded 0, 1, or 2, agreement was measured as the percentage of answers with the exact same code, without margins of error.

III. Results

A. Participants

The final sample included 96 participants, after exclusion of three participants aged over 60. The mean age was 28.5 years (range: 19 – 59). The gender distribution was 71.9% female, 27.1% male, and 1.0% not listed or not disclosed. All participants were residents in the United Kingdom. The sample's demographics are reported in Table 3.5, and their language profiles in Table 3.6,and Table 3.7.

Even though all participants were United Kingdom residents, thus using English daily, English proficiency (measured as the average of the English oral and written comprehension and expression) was verified to ensure all participants were able to fully understand the tasks and complete the A-ToM-e. Mean English proficiency across the sample was 7.33 (over the proficiency scale ranging from 0 to 8), with a standard deviation of 0.75, ranging from 4.75 to 8, which confirmed the participants were all proficient in English.

Table 3.5 - Neurotypical participants' demographics (n = 96)

Age in years, M (SD, range)	28.5 (7.8, 19 – 59)
Gender, n (%)	
Female	69 (71.9)
Male	26 (27.1)
Other gender identity / Not disclosed	1 (1.0)
Non-verbal IQ, n (SD, range)	109.2 (10.8, 72 – 140)
Highest Education, n (%)	
Less than an undergraduate degree	13 (13.5)
Undergraduate degree or higher	83 (86.5)
Country of birth, n (%)	
UK	15 (15.6)
Non-UK, English-speaking [a]	12 (12.5)
Europe, non-English speaking [b]	54 (56.3)
Outside Europe, non-English speaking [c]	15 (15.6)
Non-UK-born UK-residents, n (%)	81 (84.4)
Age of arrival in the UK, M (SD, range)	20.4 (10.1, 0 – 50)

Note: Summary table of the neurotypical participants' demographic characteristics.
a = Canada (6), Ireland (2), South Africa (1), USA (3).
b = Albania (1), Austria (1), Belgium (1), Bulgaria (1), Finland (1), France (12), Germany (4), Greece (7), Hungary (2), Italy (13), Latvia (1), The Netherlands (2), Poland (1), Romania (2), Slovakia (1), Spain (2), Switzerland (1), Ukraine (1).
c = Chile (1), China (1), Colombia (1), Cuba (1), Egypt (1), Kazakhstan (1), Madagascar (1), Malaysia (1), Mexico (2), Singapore (3), Taiwan (1), Venezuela (1).

Table 3.6 - Neurotypical participants' language characteristics (n = 96)

a. Number of languages			b. Age of acquisition and proficiency		
	R, n (%)	P4, n (%)	Languages (n)	Age in years, M (SD, range)	Proficiency, M (SD, range)
1 lang.	0 (0.0)	2 (2.1)	L1 (96)	0.0 (0.0, 0.0 - 0.0)	7.5 (1.2, 1.0 - 8.0)
2 lang.	26 (27.1)	49 (51.0)	L2 (96)	4.7 (3.7, 0.0 - 14.0)	6.5 (1.6, 1.0 - 8.0)
3 lang.	37 (38.5)	32 (33.3)	L3 (70)	11.7 (6.8, 0.0 - 49.0)	4.9 (2.1, 0.0 - 8.0)
4 lang.	15 (15.6)	10 (10.4)	L4 (33)	16.1 (9.4, 0.0 - 51.0)	4.5 (2.1, 0.8 - 8.0)
5 lang.	7 (7.3)	3 (3.1)	L5 (18)	18.0 (10.7, 2.0 - 51.0)	3.3 (1.6, 0.3 - 6.5)
6 lang.	8 (8.3)	0 (0.0)	L6 (11)	20.5 (13.4, 3.0 - 53.0)	3.1 (2.4, 0.5 - 8.0)
7+ lang.	3 (3.1) [a]	0 (0.0)	L7 (3)	18.0 (10.8, 9.0 - 30.0)	2.1 (1.6, 0.5 - 3.8)

c. Age of acquisition – Age groups distribution, n (%)						
Language (n) [b]	Birth (age = 0)	Early childhood (age = 1 - 5)	Late childhood (age = 6 - 10)	Adolescence (age = 11 - 17)	Early adulthood (age = 18 - 30)	Adulthood (age > 30)
L1 (96)	96 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
L2 (96)	16 (16.7)	44 (45.8)	28 (29.2)	8 (8.3)	0 (0.0)	0 (0.0)
L3 (70)	1 (1.4)	9 (12.9)	20 (28.6)	29 (41.4)	10 (14.3)	1 (1.4)
L4 (33)	1 (3.0)	2 (6.1)	4 (12.1)	14 (42.4)	10 (30.3)	2 (6.1)
L5 (18)	0 (0.0)	2 (11.1)	2 (11.1)	4 (22.2)	9 (50.0)	1 (5.6)
L6 (11)	0 (0.0)	1 (9.1)	2 (18.2)	1 (9.1)	6 (54.5)	1 (9.1)
L7 (3)	0 (0.0)	0 (0.0)	1 (33.3)	1 (33.3)	1 (33.3)	0 (0.0)

Note. Summary table of the neurotypical participants' language characteristics. Some percentages do not sum up to 100% due to cumulative rounding effects.
a. Number of languages: Number and proportion of respondents who reported (R) or were proficient (i.e. with an average self-rated proficiency equal or above 4, where 4 = "Adequate") (P4) in 1, 2, 3, 4, 5, 6, or 7 or more languages (lang.).
b. Age of acquisition and proficiency: Age of acquisition (Age) and proficiency reported by the respondents in languages (L) 1 to 7.
c. Age of acquisition – Age groups distribution: Number and proportion of respondents who acquired their languages (L) 1 to 7 in each age group.
[a] Reported sample sizes (N) reflect the number of respondents who provided useable age of acquisition data (in years).

Table 3.7 - Neurotypical participants' acquisition and current contexts of use.

Lang.	a. Acquisition context, n (%)				b. Current context, n (%)			
	Home	School	Com.	Indep.	Home	School / Work	Com.	Indep.
L1	95 (99.0)	1 (1.0)	0 (0.0)	0 (0.0) [a]	95 (99.0)	1 (1.0)	0 (0.0)	0 (0.0)
L2	36 (37.5)	28 (29.2)	5 (5.2)	27 (28.1)	57 (59.4)	19 (19.8)	10 (10.4)	10 (10.4)
L3	7 (10.0)	16 (22.9)	8 (11.4)	39 (55.7)	23 (32.9)	10 (14.3)	5 (7.1)	32 (45.7)
L4	5 (15.2)	3 (9.1)	3 (9.1)	22 (66.7)	8 (24.2)	5 (15.2)	7 (21.2)	13 (39.4)
L5	1 (5.6)	1 (5.6)	3 (16.7)	13 (72.2)	3 (16.7)	1 (5.6)	3 (16.7)	11 (61.1)
L6	0 (0.0)	1 (9.1)	0 (0.0)	10 (90.9)	3 (27.3)	0 (0.0)	0 (0.0)	8 (72.2)
L7	0 (0.0)	1 (33.3)	0 (0.0)	2 (66.7)	1 (33.3)	0 (0.0)	0 (0.0)	2 (66.7)

Note. Summary table of the neurotypical participants' context of acquisition and current use for each of their languages. Some percentages do not sum up to 100% due to cumulative rounding effects
a. Acquisition context: Number and proportion of respondents who acquired their languages (L) 1 to 7 mostly at home, at school, in the community (Com.), or independently (Indep.), and total number (Tot.) of respondents who indicated a context of acquisition for the language.
b. Current context: Number and proportion of respondents who use their languages (L) 1 to 7 mostly at home, at school or at work (S/W), in the community (Com.), or independently (Indep.), and total number (Tot.) of respondents who indicated a current context of use for the language.

B. Visual perspective-taking, level 1

Full details of the task methodology and data pre-processing are given in Chapter 3 section II.B.2. Briefly, the level 1 visual perspective-taking (L1VPT) sub-task included four conditions in a 2 x 2 design: Perspective (Avatar, Self) x Consistency (Consistent, Inconsistent). Each condition comprised 48 trials and the analysis focused on the response times. For each participant and each condition, the mean RT for correct trials was calculated and used in analysis (Table 3.8).

Table 3.8 - Mean response time per condition in the L1VPT task for neurotypical participants

	Avatar-Consistent	**Avatar-Inconsistent**	**Self-Consistent**	**Self-Inconsistent**
Number of participants	95	95	95	95
Mean (SD, range)	788.28 (138.80, 527.52 - 1143.75)	892.63 (155.27, 580.36 - 1266.26)	791.14 (136.73, 487.74 - 1100.11)	844.49 (160.86, 528.36 - 1227.35)
Normality of the distribution	W = 0.97, p = 0.024	W = 0.98, p = 0.23	W = 0.98, p = 0.11	W = 0.98, p = 0.27
Skewness	0.51	0.27	0.35	0.23

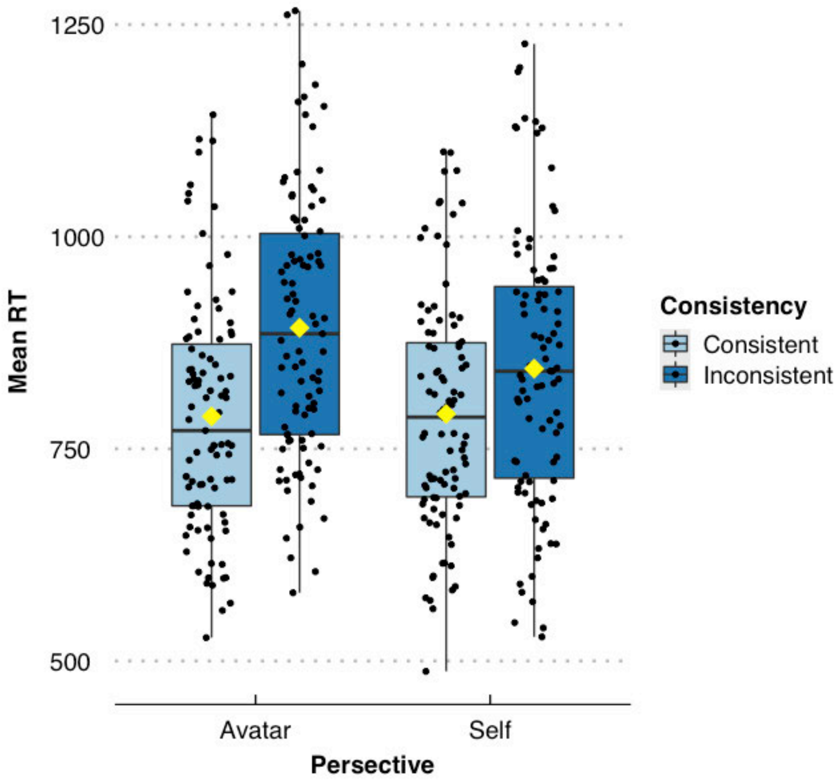
Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the 4 L1VPT conditions, in the neurotypical sample.

1. *Effects of Perspective and Consistency on response time*

As detailed in Chapter 3 section II.B.2, the first step of the visual perspective-taking data analysis aimed at verifying the existence of the egocentric and altercentric biases described by Surtees, Samson & Apperly (2016). Mean response times were compared between conditions using a 2x2 repeated measures ANOVA with Perspective (Avatar, Self) and Consistency (Consistent, Inconsistent) as within-subject factors, with a balanced sample of 92 participants.

There was a main effect of Consistency with a large effect size ($F(1,91) = 293.2$, $p < 0.0001$, $\eta_p^2 = 0.76$; Consistent < Inconsistent), as well as a main effect of Perspective with a large effect size ($F(1,91) = 21.65$, $p < 0.0001$, $\eta_p^2 = 0.19$; Self < Avatar). The interaction between Perspective and Consistency was significant (Figure 3.4) with a large effect size ($F(1,91) = 56.64$, $p < 0.0001$, $\eta_p^2 = 0.38$), further investigated using pairwise t-tests for repeated measures with Bonferroni correction: there was no significant difference between RT in Self and Avatar trials in the Consistent condition ($p = 1$), but in the Inconsistent condition mean RT was significantly higher in the Avatar trials compared to the Self trials ($p < 0.0001$). Mean RT in Inconsistent trials were significantly higher than in Consistent trials, in both the Self ($p < 0.0001$) and Avatar ($p < 0.0001$) conditions.

Figure 3.4 - Mean response times in level 1 visual perspective-taking for neurotypical participants



Note. Box-plot and scatter-plot diagrams showing the mean response times (RT) in milliseconds in the four conditions of the level 1 visual perspective-taking task. Each dot of the scatter-plot represents one participant, yellow lozenges represent the means of each condition.

2. *Bias scores*

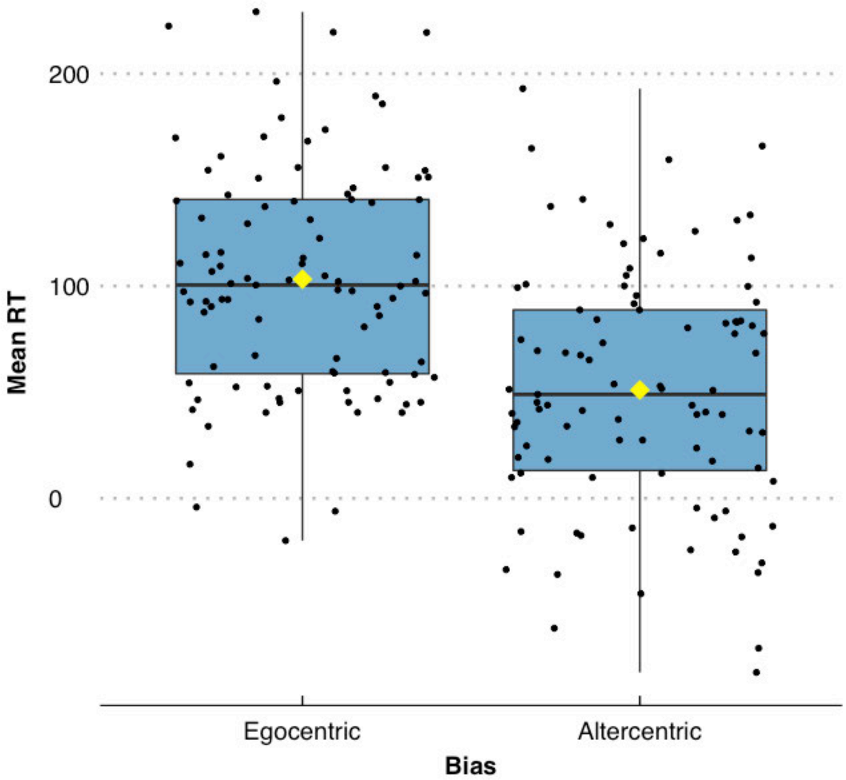
Having established a main effect of Consistency, bias scores were calculated in each Perspective condition as the difference between the Inconsistent mean RT and Consistent mean RT. As described in Chapter 3 section II.B.2, higher RT in Inconsistent trials compared to Consistent trials produced a positive bias index. The altercentric bias is derived from response times in the Self condition, while the egocentric bias is derived from response times in the Avatar condition. These bias scores (Table 3.9 and Figure 3.5) were used as outcome measures in the multiple regression analysis.

Table 3.9 - Mean response time per bias in the L1VPT task for neurotypical participants

	Egocentric bias	Altercentric bias
Number of participants	95	95
Mean (SD, range)	103.20 (53.06, -19.9 - 229.15)	51.04 (65.53, -81.96 - 192.95)
Normality of the distribution	W = 0.98, *p* = 0.18	W = 0.99, *p* = 0.97
Skewness	0.21	0.02

Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the level 1 egocentric and altercentric bias, in the neurotypical sample.

Figure 3.5 - Level 1 egocentric and altercentric biases for neurotypical participants



Note. Box-plot and scatter-plot diagrams showing the mean response times (RT) in milliseconds in the two biases of the level 1 visual perspective-taking task. Each dot of the scatter-plot represents one participant, yellow lozenges represent the means of each condition.

3. *Regression models*

The regression models were built following the same method as above (see Chapter 3 section II.C.1). All the models are presented in Table 3.10.

a. *Egocentric bias*

Model 1ERT (level 1, egocentric, response time) was applied to the full sample of participants (n = 95) to investigate how specific features of the bilingual experience predicted the egocentric bias scores of neurotypical bi- and multilingual adults. Predictors available for these participants were: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; language switching.

The final model 1ERT included the following predictors: non-verbal IQ and L2 age of acquisition; and involved 90 participants (three participants had outlying or missing non-verbal IQ scores, two had outlying L2 age of acquisition). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Non-verbal IQ significantly predicted egocentric bias (β = -1.34, p = 0.029), but L2 age of acquisition did not (β = 0.64, p = 0.68). The results of the regression indicated that model 1ERT explained 3.4% of the variance, and was not a significant predictor of level 1 egocentric bias (R^2 = 0.055, R^2_{adj} = 0.034, $F(2,87)$ = 2.55, p = 0.084), with a small effect size (f2 = 0.035). The post-hoc power was low, at 32%.

b. *Altercentric bias*

Model 1ART (level 1, altercentric, response time) was applied to the full sample of participants (n = 95) to investigate how specific features of the bilingual experience predicted the altercentric bias scores of neurotypical bi- and multilingual adults. Predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model 1ART included the following predictors: non-verbal IQ; TEA inhibition; TEA switching; and involved 89 participants (three participants had outlying or missing non-verbal IQ scores, one had outlying TEA inhibition scores, one had outlying TEA switching scores, one had outlying score for both TEA inhibition and TEA switching). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA switching significantly predicted altercentric bias (β = -6.60, *p* = 0.025), but non-verbal IQ (β = -0.97, *p* = 0.15) and TEA inhibition (β = 6.40, *p* = 0.11) did not. The results of the regression indicated that model 1ART explained 7.4% of the variance and was a significant predictor of level 1 altercentric bias (R^2 = 0.11, R^2_{adj} = 0.074, $F(3,85)$ = 3.34, *p* = 0.023), with a small effect size f2 = 0.08. The post-hoc power was medium, at 57%.

Table 3.10 - Regression models for level 1 and level 2 biases for neurotypical participants

	1ERT					1ART					2ERT					2ART				
n, M (SD, range)	95, 103.2 (53.06, -19.9 – 229.15)					95, 51.04 (56.53, -81.96 – 192.95)					94, 175.56 (89.8, 4.37 – 391.97)					95, 128.1 (64.34, -28.05 – 273.83)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
(Intercept)	246.22	66.34	114.36 – 378.09	3.71	**<0.001**	151.51	68.08	16.14 – 286.88	2.23	**0.029**	286.05	55.08	176.61 – 395.49	5.19	**<0.001**	143.36	44.45	55.03 – 231.69	3.22	**0.002**
Nv IQ	-1.34	0.60	-2.53 – -0.14	-2.22	**0.029**	-0.97	0.67	-2.30 – 0.35	-1.46	0.149										
L2 age	0.64	1.56	-2.46 – 3.74	0.41	0.682															
TEA inh.						6.40	3.98	-1.51 – 14.32	1.61	0.111										
TEA swi.						-6.60	2.90	-12.37 – -0.83	-2.27	**0.025**	-7.50	4.55	-16.54 – 1.53	-1.65	0.10	-5.81	3.03	-11.83 – 0.20	-1.92	0.058
Age											-1.88	1.23	-4.33 – 0.56	-1.53	0.13					
N lang. R-grp																39.24	18.05	3.37 – 75.12	2.17	**0.032**
N lang. P-grp																-32.25	14.54	-61.15 – -3.35	-2.22	**0.029**
Obs.	90					89					92					93				
R^2 / R^2 adj.	0.055 / 0.034					0.11 / 0.074					0.044 / 0.023					0.093 / 0.063				
F	2.553					3.339					2.07					3.05				
p	0.08					**0.023**					0.13					**0.033**				
f2	0.035					0.080					0.023					0.067				
pwr	32%					57%					23%					52%				

Note: Table summarising the regression models for visual perspective-taking scores. Coef. = coefficients. *β* = estimates of regression β coefficients. SE = standard errors. CI = confidence intervals at 95%. Stats. = t-statistics. *p* = *p*-value. Int. = intercept. nv IQ = non-verbal IQ. L2 age = L2 age of acquisition. TEA inh. = TEA inhibition. TEA swi. = TEA switching. Age = chronological age. N lang. R-grp = number of languages reported, by group. N lang. P-grp = number of languages known with a high proficiency, by group. Obs. = observations. adj. = adjusted. *F* = *F*-statistic. f2 = effect size f2. pwr = post-hoc power. Number of participants (n) after removal of outliers in the outcome variable, means (M), standard deviation (SD) and range of the outcome variable are reported for the whole group. Observations (Obs.) indicate the number of participants with available data in the selected predictors.

C. Visual perspective-taking, level 2

Full details of the task methodology and data pre-processing are given in Chapter 3 section II.B.2. Briefly, the level 2 visual perspective-taking (L2VPT) sub-task included four conditions in a 2 x 2 design: Perspective (Avatar, Self) x Consistency (Consistent, Inconsistent). Each condition comprised 48 trials, and the analysis focused on response time to these trials. For each participant and each condition, the mean RT for correct trials was calculated and used in analysis (Table 3.11).

Table 3.11 - Mean response time per condition in the L2VPT task for neurotypical participants

	AC	**AI**	**SC**	**SI**
Number of participants	95	96	95	96
Mean (SD, range)	896.07 (149.57, 642.73 - 1278.02)	1077.35 (179.15, 732.25 - 1485.03)	822.18 (150.21, 530.83 - 1178.3)	958.43 (176.18, 570.66 - 1332.93)
Normality of the distribution	W = 0.96, *p* = 0.0052	W = 0.98, *p* = 0.098	W = 0.97, *p* = 0.018	W = 0.98, *p* = 0.12
Skewness	0.42	0.12	0.42	0.11

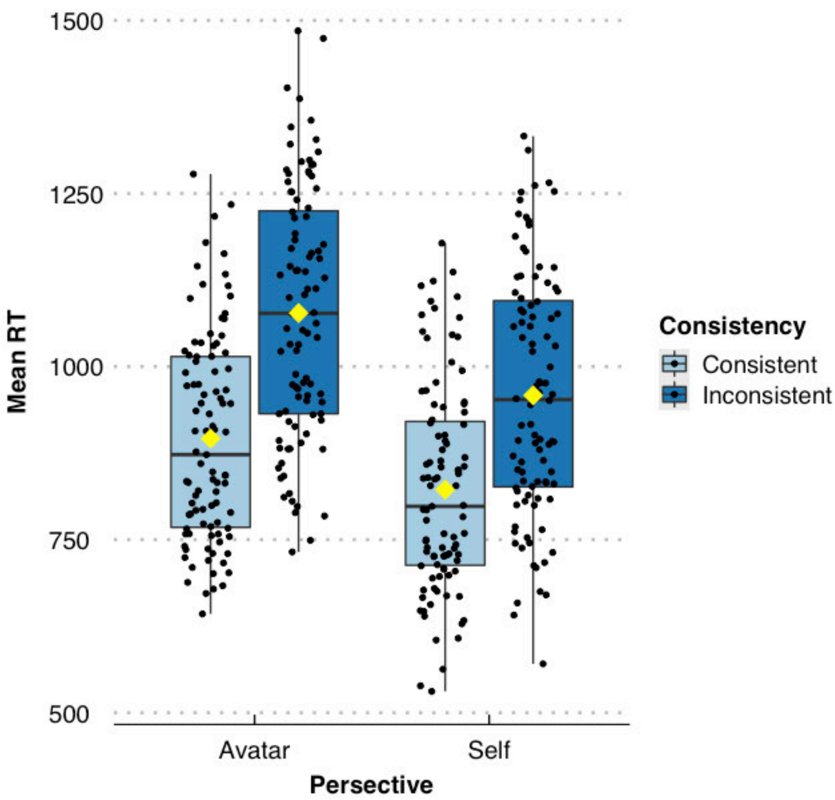
Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the 4 L2VPT conditions, in the neurotypical sample.

1. *Effect of Perspective and Consistency on response time*

As detailed in Chapter 3 section II.B.2, the first step of the visual perspective-taking data analysis aimed at verifying the existence of the egocentric and altercentric biases described by Surtees, Samson & Apperly (2016). Mean response times were compared between conditions using a 2x2 repeated measures ANOVA with Perspective (Avatar, Self) and Consistency (Consistent, Inconsistent) as within-subject factors, with a balanced sample of 95 participants.

There was a main effect of Consistency with a large effect size ($F(1,94) = 456.9$, $p < 0.0001$, ηp2 = 0.83; Consistent < Inconsistent), as well as a main effect of Perspective with a large effect size ($F(1,94) = 163.6$, $p < 0.0001$, $\eta_p^2 = 0.64$; Self < Avatar). The interaction between Perspective and Consistency was significant (Figure 3.6) with a large effect size ($F(1,94) = 18.7$, $p < 0.0001$, $\eta_p^2 = 0.17$), further investigated using pairwise T-tests for repeated measures with Bonferroni correction: mean RT was significantly higher in the Avatar trials compared to the Self trials, in both the Consistent ($p < 0.0001$) and Inconsistent ($p < 0.0001$) conditions. Mean RT in Inconsistent trials were significantly higher than in Consistent trials, in both the Self ($p < 0.0001$) and Avatar ($p < 0.0001$) conditions.

Figure 3.6 - Mean response times in level 2 visual perspective-taking for neurotypical participants



Note. Box-plot and scatter-plot diagrams showing the mean response times (RT) in milliseconds in the four conditions of the level 2 visual perspective-taking task. Each dot of the scatter-plot represents one participant, yellow lozenges represent the means of each condition.

2. *Bias scores*

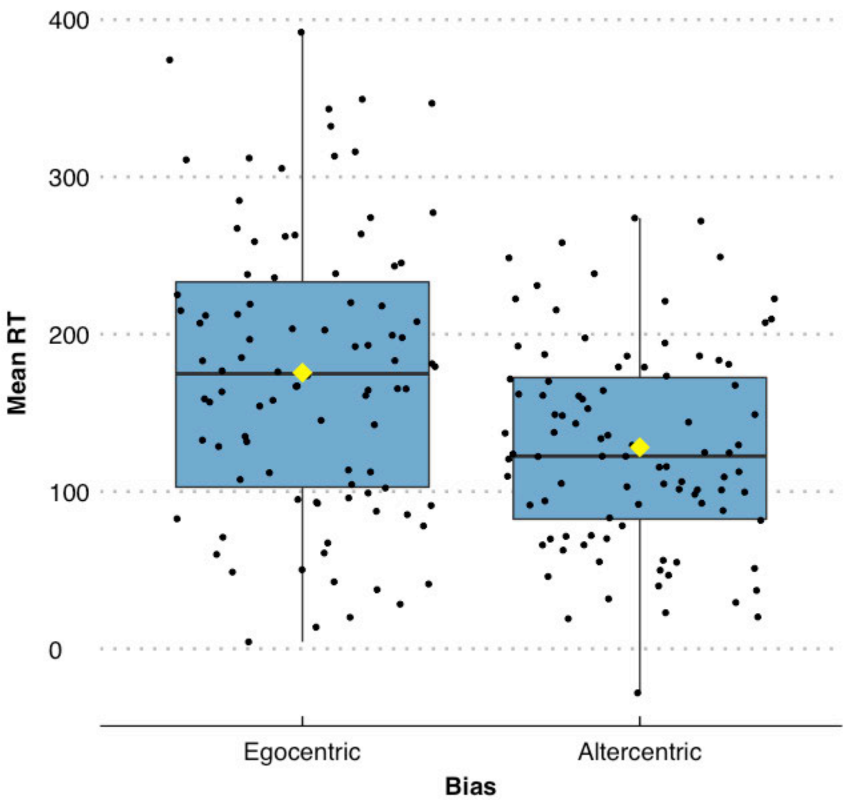
Having established a main effect of Consistency, bias scores were calculated in each Perspective condition, as the difference between the inconsistent mean RT and consistent mean RT. As described in Chapter 3 section II.B.2, higher RT in Inconsistent trials compared to Consistent trials produced a positive bias index. The altercentric bias is derived from response times in the Self condition, while the egocentric bias is derived from responses times in the Avatar condition. These bias scores (Table 3.12 and Figure 3.7) were used as outcome measures in the multiple regression analysis.

Table 3.12 - Mean response time per bias in the L2VPT task for neurotypical participants

	Egocentric bias	**Altercentric bias**
Number of participants	94	95
Mean (SD, range)	175.56 (89.8, 4.37 – 391.97)	128.1 (64.34, -28.05 - 273.83)
Normality	W = 0.98, *p* = 0.29	W = 0.99, *p* = 0.62
Skewness	0.24	0.19

Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the level 2 egocentric and altercentric bias, in the neurotypical sample.

Figure 3.7 - Level 2 egocentric and altercentric biases for neurotypical participants



Note. Box-plot and scatter-plot diagrams showing the mean response times (RT) in milliseconds in the two biases of the level 2 visual perspective-taking task. Each dot of the scatter-plot represents one participant, yellow lozenges represent the means of each condition.

3. *Regression models*

The regression models were built following the same method as (see Chapter 3 section II.C.1). All the models are presented in Table 3.10.

a. *Egocentric bias*

Model 2ERT (level 2, egocentric, response time) was applied to the full sample of participants (n = 94) to investigate how specific features of the bilingual experience predicted the egocentric bias scores of neurotypical bi- and multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model 2ERT included the following predictors: age; TEA switching; and involved 92 participants (two participants had outlying TEA switching scores). Data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Neither age (β = -1.88, p = 0.13) nor TEA switching (β = -7.50, p = 0.10) significantly predicted level 2 egocentric bias. The results of the regression indicated that model 2ERT explained 2.3% of the variance and was not a significant predictor of level 2 egocentric bias (R^2 = 0.044, R^2_{adj} = 0.023, $F(2,89)$ = 2.07, p = 0.13), with a small effect size (f2 = 0.023), and the post-hoc power was low, at 23%.

b. *Altercentric bias*

Model 2ART (level 2, altercentric, response time) was applied to the full sample of participants (n = 95) to investigate how specific features of the bilingual experience predicted the altercentric bias scores of neurotypical bi- and multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model 2ART included the following predictors: N language R-group; N language P-group; TEA switching; and involved 93 participants (two participants had outlying TEA switching scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. N language R-group significantly predicted altercentric bias (β = 39.24, p = 0.032), and so did N language P-group (β = -32.25, p = 0.029), while TEA switching did not (β = -5.81, p = 0.058). The results of the regression indicated that model 2ART explained 6.3% of the variance and was a significant predictor of level 2 altercentric bias (R^2 = 0.093, R^2_{adj} = 0.063, $F(3,89)$ = 3.05, p = 0.033), with a small effect size (f2 = 0.067), and the post-hoc power was medium, at 52%.

D. Cognitive perspective-taking, level 1 and level 2

Full details of the A-ToM-e task and data pre-processing are given in Chapter 3 section II.B.3. Scores used in the following analysis are reported in Table 3.13, Figure 3.8, and Figure 3.9.

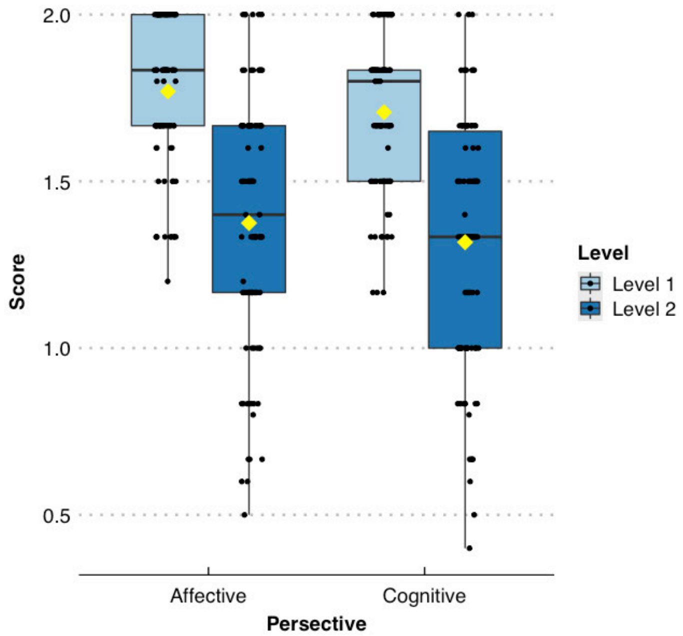
Table 3.13 - Scores of the A-ToM-e task for neurotypical participants

	L1C	**L2C**	**L1A**	**L2A**
Number of participants	93	94	94	93
Mean (SD, range)	1.71 (0.22, 1.17 - 2.00)	1.32 (0.37, 0.40 - 2.00)	1.77 (0.22, 1.20 - 2.00)	1.37 (0.38, 0.50 - 2.00)
Normality of the distribution	W = 0.91, p < 0.001	W = 0.96, p = 0.011	W = 0.87, p < 0.001	W = 0.96, p = 0.0052
Skewness	-0.55	-0.3	-0.69	-0.32

	C	**A**	**G**	**S**	**P**
Number of participants	94	93	92	93	94
Mean (SD, range)	1.51 (0.27, 0.83 - 1.92)	1.57 (0.24, 1.00 - 2.00)	1.61 (0.24, 1.00 - 2.00)	1.55 (0.21, 1.07 - 1.90)	1.26 (0.33, 0.67 - 1.83)
Normality of the distribution	W = 0.95, p = 0.0023	W = 0.98, p = 0.081	W = 0.93, p < 0.001	W = 0.97, p = 0.050	W = 0.95, p = 0.0018
Skewness	-0.42	-0.14	-0.6	-0.31	0

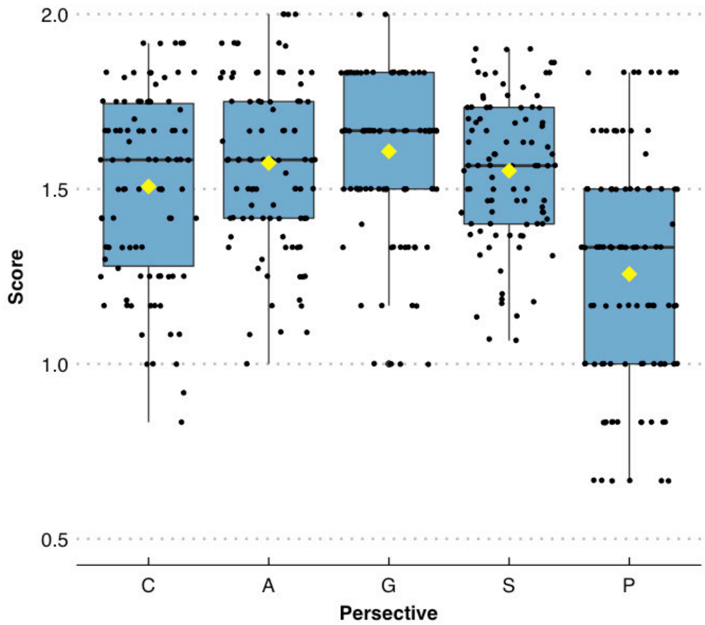
Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the outcome measures of the A-ToM-e task in the neurotypical sample. These outcome measures are level 1 (L1) and level 2 (L2) cognitive (C) and affective (A) perspective-taking, general (G) perspective-taking, overall social (S) score, and control physical score (P).

Figure 3.8 - Level 1 and level 2 cognitive and affective perspective-taking scores for neurotypical participants



Note. Box-plot diagram showing the level 1 and level 2 cognitive (C) and affective (A) perspective-taking scores in the neurotypical sample, without outliers.

Figure 3.9 - Cognitive, affective, general, and overall social perspective-taking scores and control physical scores for neurotypical participants



Note. Box-plot diagram showing the control physical (P) scores, cognitive (C), affective (A), general (G), and overall social (S) perspective-taking scores in the neurotypical sample, without outliers.

1. *Reliability of the A-ToM-e*

Internal consistency (Appendix III.4) was tested across all videos for each outcome measure to identify whether all video items addressed the same core skill. Internal consistency was mostly unacceptable to poor. While the internal consistency of the overall social score was acceptable (α = 0.72), and was not improved by the elimination of any single question, internal consistency in the general score and overall cognitive and affective scores were poor (α = 0.44, α = 0.53, and α = 0.45, respectively). Level sub-scores showed an even lower internal consistency, ranging from α = 0.26 (level 1 cognitive) to 0.38 (level 2 affective), with the exception of level 1 affective scoring particularly low (α = 0.08). The control physical score also showed unacceptable internal consistency, with α = 0.12.

Regarding the cognitive modality, excluding one high-scoring video (Hat – white lie, see Appendix III.1 for a full transcript of the videos) increased α to 0.32 for level 1 scores and 0.37. Eliminating the same item in level 2 scores only also increased α to 0.55 in the overall cognitive score. For the affective modality, no item elimination increased α for the level 2 scores, but eliminating two low-scoring videos (Bunnies – persuasion, Spaghetti – sarcasm) increased α to 0.35. Eliminating the level 1 score of the Bunnies video also increased α to 0.49 for the overall affective score. Finally, regarding the original general score, eliminating one low-scoring item (Burglar, misunderstanding) increased α to 0.52. Overall, no single video systematically lowered the internal consistency score, and elimination of one or two videos did not increase α to an acceptable range.

Inter-rater agreement for the full dataset, assessed across both the participants groups involved in the current study and the study reported in Chapter 4, was calculated for 37 participants (27% of the total sample), and is available in Appendix III.3. This subsample included 31 neurotypical participants (32% of the neurotypical sample). Inter-rater agreement was also calculated for each sub-score in this specific population. Overall, inter-rater agreement ranged from 77% to 82% across all outcome measures. The lowest scoring video was identified for each level sub-score and the general sub-score. For both level 1 cognitive and level 2 affective scores, the same video (Spaghetti – sarcasm) had the lowest inter-rater agreement (respectively 65% and 70%), but all other scores had different videos as item with the lowest agreement.

As no video was consistently identified as lowering the internal consistency or inter-rater agreement of the sub-scores, they were all maintained in the final outcome measures.

2. *Regression models*

The regression models followed the same method as above (Chapter 3 section II.C.1), and are presented in Table 3.14.

a. Level 1 cognitive perspective-taking

Model 1C (level 1, cognitive) was applied to the full sample of participants (n = 93) to assess how features of the bilingual experience predicted level 1 cognitive scores in neurotypical bi- and multilingual adults. Relevant predictors were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model 1C included the following predictors: L2 age of acquisition; TEA inhibition; TEA switching; and involved 88 participants (two participants had outlying L2 age of acquisition, one participant had outlying TEA inhibition score, one participant had outlying TEA switching score, one participant has both outlying TEA inhibition and level 3 scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA inhibition significantly predicted L1C (β = 0.037, p = 0.020), but TEA switching (β = 0.017, p = 0.14) and L2 age of acquisition (β = -0.011, p = 0.11) did not. The results of the regression indicated that model 1C explained 10.2% of the variance and was a significant predictor of L1C (R^2 = 0.13, R^2_{adj} = 0.10, F(3,84) = 4.29, p = 0.0072), with a medium effect size (f2 = 0.11), and the post-hoc power was medium, at 74%.

b. Level 2 cognitive perspective-taking

Model 2C1 (level 2, cognitive) was applied to the full sample of participants (n = 94) to assess how specific features of the bilingual experience predicted the level 2 cognitive scores of neurotypical bi- and multilingual adults. Relevant predictors were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model 2C included only TEA inhibition as predictor, and involved 92 participants (two participants had outlying TEA inhibition score). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA inhibition significantly predicted L2C (β = 0.053, p = 0.031). The results of the regression indicated that model 2C explained 4.0% of the variance and was a significant predictor of L2C

(R^2 = 0.051, R^2_{adj} = 0.040, $F(1,90)$ = 4.80, p = 0.031), with a medium effect size (f2 = 0.042), and the post-hoc power was low, at 49%.

c. Overall cognitive perspective-taking

Model C (cognitive) was applied to the full sample of participants (n = 94) to investigate how specific features of the bilingual experience predicted the overall cognitive scores of neurotypical bi- and multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model C included the following predictors: L2 age of acquisition; TEA inhibition; TEA switching; and involved 89 participants (one participant had outlying TEA inhibition, one participant had outlying TEA switching, one participant had both outlying TEA inhibition and level 3, two participants had outlying L2 age of acquisition). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA inhibition significantly predicted C scores (β = 0.047, p = 0.010), but TEA switching (β = 0.024, p = 0.073) and L2 age of acquisition (β = -0.011, p = 0.15) did not. The results of the regression indicated that model C explained 12.3% of the variance and was a significant predictor of L2C (R^2 = 0.15, R^2_{adj} = 0.12, $F(3,85)$ = 5.12, p = 0.0026), with a medium effect size (f2 = 0.14), and the post-hoc power was high, at 84%.

E. Affective perspective-taking, level 1 and level 2

1. *Summary*

Full details of the A-ToM-e task methodology and data pre-processing are given in Chapter 3 section II.B.3. A summary of the affective perspective-taking scores is presented in Table 3.13, Figure 3.8, and Figure 3.9.

2. *Regression models*

The regression models were built following the same method as above (see Chapter 3 section II.C.1), and are presented in Table 3.14.

a. Level 1 affective perspective-taking

Model 1A (level 1, affective) was applied to the full sample of participants (n = 94) to investigate how specific features of the bilingual experience predicted the level 1 affective scores of neurotypical bi- and multilingual adults. Relevant predictors were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model 1A included the following predictors: N language R-group; age; non-verbal IQ; and involved 91 participants (three participants had outlying non-verbal IQ). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Non-verbal IQ significantly predicted L1A (β = 0.0072, p = 0.0047), but age (β = -0.0048, p = 0.10) and N language R-group (β = 0.058, p = 0.25) did not. The results of the regression indicated that model 1A explained 8.7% of the variance and was a significant predictor of L1A (R^2 = 0.12, R^2_{adj} = 0.087, $F(3,87)$ = 3.87, p = 0.012), with a medium effect size (f2 = 0.096), and the post-hoc power was medium, at 67%.

b. Level 2 affective perspective-taking

Model 2A (level 2, affective) was applied to the full sample of participants (n = 93) to investigate how specific features of the bilingual experience predicted the level 2 affective scores of neurotypical bi- and multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model 2A included the following predictors: age; TEA inhibition; L2 age of acquisition; N language P-group; and involved 89 participants (two participants had outlying TEA inhibition, and two participants had outlying L2 age of acquisition). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Age significantly predicted L2A (β = -0.015, p = 0.0037), and so did TEA inhibition (β = 0.067, p = 0.0067) and L2 age of acquisition (β = -0.023, p = 0.035). However, N language P-group (β = -0.14, p = 0.060) did not. The results of the regression indicated that model 2A explained 19.2% of the variance and was a significant predictor of L2A (R^2 = 0.23, R^2_{adj} = 0.19, $F(4,84)$ =

6.22, *p* = 0.00020), with a medium effect size (f2 = 0.24), and the post-hoc power was medium, at 96%.

c. *Overall affective perspective-taking*

Model A (affective) was applied to the full sample of participants (n = 93) to investigate how specific features of the bilingual experience predicted the overall affective scores of neurotypical bi- and multilingual adults. Relevant predictors were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model A included the following predictors: age; non-verbal IQ; and involved 90 participants (three participants had outlying non-verbal IQ). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Age significantly predicted A scores (β = -0.010, *p* = 0.0023), and so did non-verbal IQ (β = 0.0058, *p* = 0.044). The results of the regression indicated that model A explained 9.5% of the variance and was a significant predictor of A scores (R^2 = 0.12, R^2_{adj} = 0.095, $F(2,87)$ = 5.69, *p* = 0.0048), with a medium effect size (f2 = 0.11), and the post-hoc power was medium, at 78%.

Table 3.14 - Regression models for cognitive and affective perspective-taking (level 1 and level 2) for neurotypical participants

	a. Cognitive perspective-taking														
	1C					**2C**					**C**				
n, M (SD, range)	93, 1.71 (0.22, 1.17 - 2)					94, 1.32 (0.37, 0.4 - 2)					94, 1.51 (0.27, 0.83 - 1.92)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
Int.	1.31	0.14	1.02 – 1.59	9.23	**<0.001**	0.85	0.21	0.43 – 1.28	3.97	**<0.001**	0.97	0.16	0.65 – 1.30	5.93	**<0.001**
TEA inh.	0.04	0.02	0.01 – 0.07	2.37	**0.020**	0.05	0.02	0.00 – 0.10	2.19	**0.031**	0.05	0.02	0.01 – 0.08	2.62	**0.010**
L2 age	-0.01	0.01	-0.02 – 0.00	-1.64	0.105						-0.01	0.01	-0.03 – 0.00	-1.46	0.149
TEA swi.	0.02	0.01	-0.01 – 0.04	1.48	0.142						0.02	0.01	-0.00 – 0.05	1.82	0.073
Obs	88					92					89				
R^2 / R^2adj	0.133 / 0.102					0.051 / 0.040					0.153 / 0.123				
F	4.29					4.80					5.12				
p	**0.0072**					**0.031**					**0.0026**				
f2	0.11					0.042					0.14				
pwr	74%					49%					84%				

	b. Affective perspective-taking														
	1A					**2A**					**A**				
n, M (SD, range)	94, 1.77 (0.22, 1.2 - 2)					93, 1.37 (0.38, 0.5 - 2)					93, 1.57 (0.24, 1 - 2)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
Int.	0.96	0.28	0.41 – 1.51	3.45	**0.001**	1.66	0.28	1.10 – 2.23	5.84	**<0.001**	1.23	0.30	0.63 – 1.82	4.11	**<0.001**
N lang R-group	0.06	0.05	-0.04 – 0.16	1.16	0.249										
Age	-0.00	0.00	-0.01 – 0.00	-1.66	0.100	-0.02	0.01	-0.03 – -0.01	-2.99	**0.004**	-0.01	0.00	-0.02 – -0.00	-3.14	**0.002**
nv IQ	0.01	0.00	0.00 – 0.01	2.90	**0.005**						0.01	0.00	0.00 – 0.01	2.04	**0.044**
TEA inh.						0.07	0.02	0.02 – 0.11	2.78	**0.007**					
L2 age						-0.02	0.01	-0.04 – -0.00	-2.15	**0.035**					
N lang P-group						-0.14	0.07	-0.28 – 0.01	-1.91	0.060					
Obs	91					89					90				
R^2 / R^2adj	0.118 / 0.087					0.229 / 0.192					0.116 / 0.095				
F	3.87					6.22					5.69				
p	**0.012**					**0.00020**					**0.0048**				
f2	0.096					0.24					0.11				
pwr	67%					96%					78%				

Note: Table summarising the regression models for cognitive (a) and affective (b) perspective-taking scores. Coef. = coefficients. *β* = estimates of regression β coefficients. SE = standard errors. CI = confidence intervals at 95%. Stats. = t-statistics. *p* = *p*-value. Int. = intercept. TEA inh. = TEA inhibition. L2 age = L2 age of acquisition. TEA swi. = TEA switching. N lang. R-grp = number of languages reported, by group. nv IQ = non-verbal IQ. N lang. P-grp = number of languages known with a high proficiency, by group. Obs. = observations. adj. = adjusted. *F* = *F*-statistic. f2 = effect size f2. pwr = post-hoc power. Number of participants (n) after removal of outliers in the outcome variable, means (M), standard deviation (SD) and range of the outcome variable are reported for the whole group. Observations (Obs.) indicate the number of participants with available data in the selected predictors.

F. Overall social perspective-taking

1. *Summary*

The A-ToM-e task and data pre-processing are fully detailed in in Chapter 3 section II.B.3. A summary of the general and social perspective-taking scores is presented in Table 3.13, Figure 3.8, and Figure 3.9.

2. *Regression models*

The regression models were built following the same method as above (Chapter 3 section II.C.1), and are presented in Table 3.15.

a. General perspective-taking

Model G (general) was applied to the full sample of participants (n = 92) to investigate how bilingualism features predicted the general scores of neurotypical bi- and multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model G included the following predictors: N language R-group; L2 age of acquisition; TEA total; and involved 88 participants (two participants had outlying L2 age of acquisition, and two participants had outlying TEA total scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors individually significantly predicted G scores (N language R-group: β = 0.095, p = 0.10; L2 age of acquisition: β = -0.012, p = 0.12; TEA total: β = 0.011, p = 0.19), but taken together they explained 5.6% of the variance and the model G was a significant predictor of G scores (R^2 = 0.089, R^2_{adj} = 0.056, $F(3,84)$ = 2.73, p = 0.049), with a small effect size (f2 = 0.060), and the post-hoc power was medium, at 44%.

b. Overall social perspective-taking

Model S (social) was applied to the full sample of participants (n = 93) to investigate how specific features of the bilingual experience predicted the overall social scores of neurotypical bi- and multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model S included the following predictors: age; L2 age of acquisition; TEA inhibition; and involved 89 participants (two participants had outlying L2 age of acquisition, and two participants had outlying TEA inhibition scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA inhibition significantly predicted S scores (β = 0.033, p = 0.013). However, age (β = -0.0048, p = 0.10) and L2 age of acquisition (β = -0.0083, p = 0.18) did not. Taken together, these predictors explained 9.2% of the variance and the model S was a significant predictor of S scores (R^2 = 0.12, R^2_{adj} = 0.092, $F(3,85)$ = 3.96, p = 0.011), with a medium effect size (f2 = 0.10), and the post-hoc power was medium, at 69%.

G. Control items

1. *Summary*

The A-ToM-e task and data pre-processing are fully detailed in in Chapter 3 section II.B.3. A summary of the control physical scores is presented in Table 3.13, Figure 3.8, and Figure 3.9.

2. *Regression models*

The regression model was built following the same method as above (Chapter 3 section II.C.1). The model is presented in Table 3.15.

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Table 3.15 - Regression models for general perspective-taking, overall social perspective-taking, and control scores for neurotypical participants

	G					S					P				
n, M (SD, range)	92, 1.61 (0.24, 1 - 2)					93, 1.55 (0.21, 1.07 - 1.9)					94, 1.26 (0.33, 0.67 - 1.83)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
Int.	1.14	0.24	0.67 – 1.61	4.78	**<0.001**	1.44	0.15	1.15 – 1.73	9.76	**<0.001**	-0.85	0.95	-2.75 – 1.04	-0.89	0.373
N lang R-group	0.09	0.06	-0.02 – 0.21	1.65	0.103										
L2 age	-0.01	0.01	-0.03 – 0.00	-1.57	0.119	-0.01	0.01	-0.02 – 0.00	-1.37	0.175					
TEA T	0.01	0.01	-0.01 – 0.03	1.33	0.186										
Age						-0.00	0.00	-0.01 – 0.00	-1.66	0.102					
TEA inh.						0.03	0.01	0.01 – 0.06	2.53	**0.013**					
TEA att.											0.30	0.14	0.03 – 0.58	2.21	**0.029**
Obs	88					89					94				
R^2 / R^2adj	0.089 / 0.056					0.123 / 0.092					0.051 / 0.040				
F	2.73					3.96					4.90				
p	**0.049**					**0.011**					**0.029**				
f2	0.060					0.10					0.042				
pwr	44%					69%					50%				

Note: Table summarising the regression models for general perspective-taking, social perspective-taking, and Control physical scores. Coef. = coefficients. *β* = estimates of regression β coefficients. SE = standard errors. CI = confidence intervals at 95%. Stats. = t-statistics. *p* = *p*-value. Int. = intercept. N lang. R-grp = number of languages reported, by group. L2 age = L2 age of acquisition. TEA T = TEA total. Age = chronological age. TEA inh. = TEA inhibition. TEA att. = TEA attention. Obs. = observations. adj. = adjusted. *F* = *F*-statistic. f2 = effect size f2. pwr = post-hoc power. Number of participants (n) after removal of outliers in the outcome variable, means (M), standard deviation (SD) and range of the outcome variable are reported for the whole group. Observations (Obs.) indicate the number of participants with available data in the selected predictors.

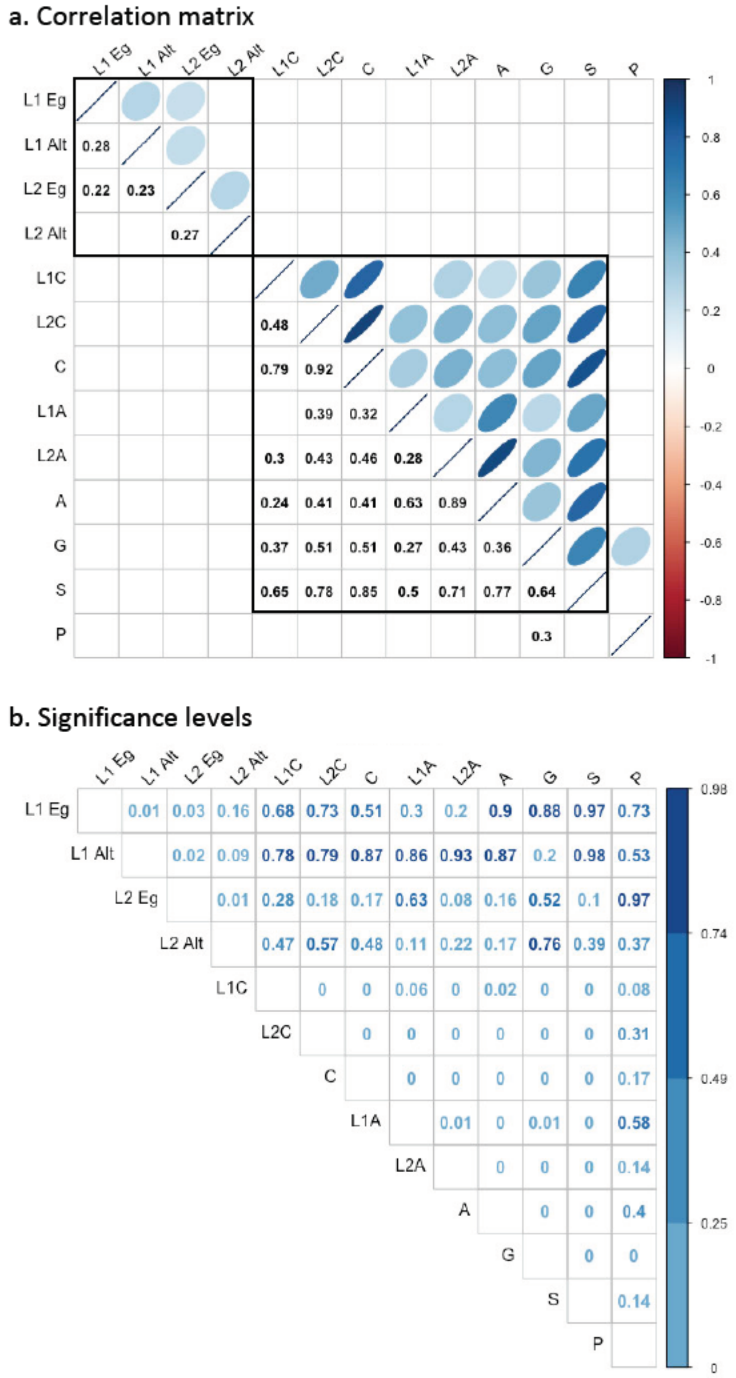
Model P (physical) was applied to the full sample of participants (n = 94) to investigate how specific features of the bilingual experience predicted the control physical scores of neurotypical bi- and multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L switch.

The final model P included only TEA attention as predictor and involved all 94 participants. The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA attention significantly predicted P scores ($\beta = 0.30$, $p = 0.029$). The results of the regression indicated that model P1 explained 4.0% of the variance and the model P was a significant predictor of P scores ($R^2 = 0.051$, $R^2_{adj} = 0.040$, $F(1,92) = 4.90$, $p = 0.029$), with a small effect size (f2 = 0.042), and the post-hoc power was medium, at 50%.

H. Correlation between perspective-taking modalities

A correlation analysis using Pearson's correlation coefficient was used between the bias scores, the cognitive sub-score, and the affective sub-score (Figure 3.10). The level 1 egocentric bias was significantly correlated with the level 1 altercentric bias ($p = 0.0071$, $r = 0.28$) and the level 2 egocentric bias ($p = 0.033$, $r = 0.22$), though the correlations were weak. level 1 altercentric bias was also significantly correlated with the level 2 egocentric bias, though the correlation was weak ($p = 0.024$, $r = 0.23$). The level 2 egocentric bias was also significantly correlated with the level 2 altercentric bias ($p = 0.0080$, $r = 0.27$), though the correlation was weak. None of the visual perspective-taking biases were significantly correlated with any of the A-ToM-e outcome scores. However, the overall cognitive and affective scores were significantly correlated with each other, with a moderate strength ($p = 0.000059$, $r = 0.41$).

Figure 3.10 - Correlation between perspective-taking outcome measures for neurotypical participants



Note. Correlation matrices between perspective-taking scores. L1 = level 1, L2 = level 2, Eg = egocentric, Alt = altercentric, C = cognitive, A = affective, G = general, S = social, P = physical.
a. Correlation matrix between all the perspective-taking and control (P) outcome measures. Pearson's correlation coefficient values *r* are reported numerically in the lower left corner and as ellipses in the upper right corner. Extreme *r* values are represented in dark blue narrow ellipses, while *r* values close to 0 are represented as white circles. Only statistically significant correlation coefficients are reported. Black squares outline the visual modality and the cognitive and affective modalities.
b. Significance levels of each Pearson's correlation test, with *p*-values close to 0 coloured from light blue and *p*-values close to 1 coloured from dark blue.

I. Results summary

The main goal of this study was to explore the relationship between bilingualism and perspective-taking skills in neurotypical adults. This study included 96 neurotypical bilingual adults with a wide range of language profiles (Chapter 3 section III.A).

The visual perspective-taking task results showed an effect of the Consistency in both Level 1 (Chapter 3 section III.B.2) and Level 2 (Chapter 3 section III.C.2) processes, when the participants were asked to take either their own or the avatar's perspective, which allowed the creation of egocentric and altercentric biases (Chapter 3 section III.B.3 and Chapter 3 section III.C.3). The influence of different bilingualism variables upon these biases was investigated in the full sample of participants (Chapter 3 section III.B.4 and Chapter 3 section III.C.4) and revealed that switching skills were most influential on bias scores.

Validity of the new A-ToM-e task was verified (Chapter 3 section III.D.1), and the influence of the bilingualism variables on the different outcome measures of the A-ToM-e was investigated, again in both the full sample of participants and a subsample of multilingual participants (Chapter 3 section III.D to III.G). The results of all the regression models on the full sample of neurotypical participants are summarised in Table 3.16 and show that age of acquisition of the second language and inhibition skills have the greatest influence on A-ToM-e scores.

A correlation analysis was conducted to analyse the relationship between the three modalities of perspective-taking at the centre of this study, which demonstrated no link between the visual and social modalities, but a group of significant correlations between the cognitive and affective modalities (Chapter 3 section III.H).

Table 3.16 - Summary of the regression models in the neurotypical sample

	Predictors	L1Ego	L2Ego	L1Alter	L2Alter	L1C	L2C	C	L1A	L2A	A	G	S	P
Bilingualism	N lang. R-				+				+			+		
	N lang. P-				-				-					
	L2 age	+				-		-		-		-	-	
	L2 pro.													
	L2/L1 bal..													
	L switch													
Controls	Age		-						-	-	-		-	
	nv IQ	-		-					+		+			
	TEA att.													+
	TEA inh.			+		+	+	+		+			+	
	TEA swi.		-	-	-	+		+						
	TEA tot.											+		
Indicators	R^2 adj.	3%	2%	7%	6%	10%	4%	12%	9%	19%	10%	6%	9%	4%
	p													
	f2	0.035	0.023	0.080	0.067	0.11	0.042	0.14	0.096	0.24	0.11	0.060	0.10	0.042
	pwr	32%	23%	57%	52%	74%	49%	84%	67%	96%	78%	44%	69%	50%

Note. Summary of the regression models applied to the full sample of neurotypical participants. Each column represents an outcome measure and its associated final model, and each row represents a candidate predictor (grouped in bilingualism or control variables, the later in grey text), or a performance indicator of the models. For each outcome measure, predictors selected in the final model are coloured in blue (selected but not significant) or green (selected and significant), and the direction of their relationship with the outcome variable are represented with a + (positive relationship) or a – (negative relationship) sign. The significance level of each model is coloured in blue when $p > 0.05$, and green when $p \leq 0.05$. The observed power of each model was coloured in grey when < 50%, in blue when ≥ 50% and < 80%, and in green when ≥ 80%. For outcome measures: L1 = level 1; L2 = level 2; Ego = egocentric bias; Alter = altercentric bias; C = cognitive; A = affective; G = general; S = social; P = physical. For predictors: N lang. R-grp = number of languages reported, by group; N lang. P-grp = number of languages known with a high proficiency, by group; L2 age = age of acquisition of the second language; L2 pro. = second language proficiency; L2/L1 bal. = proficiency balance between the first and second languages; L switch = language switching score; nv IQ = non-verbal IQ; TEA att. = TEA attention; TEA inh. = TEA inhibition; TEA swi. = TEA switching. TEA tot. = TEA total score. For the model performance indicators: R^2 adj. = adjusted R^2; p = p-value; f2 = effect size f2; pwr = post-hoc power.

IV. Discussion

A. Bilingualism and perspective-taking

1. *Differential influence of bilingualism on perspective-taking*

The primary goal of this study was to explore the relationship between bilingualism and perspective-taking skills in neurotypical adults, investigating the evidence of a positive influence of bilingualism on perspective-taking skills across modalities and levels. To do so, a novel approach was used, relying on a multidimensional definition of both bilingualism and perspective-taking, disentangling the various features of the bilingual experience and the multiple processes encapsulated in perspective-taking. My hypotheses regarding the potential link between bilingualism and perspective-taking were that, if a bilingualism effect was found, bilingualism variables related to high bilingual skills (such as young age of acquisition or high proficiency) would negatively predict the egocentric bias scores and positively predict the altercentric bias scores in the visual modality, but positively predict the cognitive and affective perspective-taking scores.

The two main findings of the multiple linear regression analysis are that in a neurotypical mind, not all forms of perspective-taking respond uniformly to the influence of bilingualism. Moreover, when it is a question of whether being bilingual is linked to higher perspective-taking skills, not all bilingual experiences are equal. Specifically, cognitive and affective perspective-taking processes are more susceptible to the influence of bilingualism than visual perspective-taking. As such, the results did not support the hypothesis regarding the visual modality, but they validated the hypothesis regarding the cognitive and affective modalities. Furthermore, these results provide some explanations about the discrepancies between previous findings. Indeed, as reported above in Chapter 3 section I.B.3, Ryskin et al. (2014) did not find an effect of bilingualism upon visual perspective-taking skills, while both Rubio-Fernández & Glucksberg (2012) and Javor (2017) did find an effect of bilingualism upon cognitive perspective-taking skills. Taken together, their results and this new evidence suggests that the cognitive and affective modalities are influenced by bilingualism, but the visual modality is not. Moreover, my results also show that the main driver of this influence of bilingualism is the age of acquisition of the second language, both in cognitive and affective perspective-taking. Beyond this overall relationship pattern, it is also relevant to look specifically into each individual modality of perspective-taking, to understand how bilingualism impacts them above and beyond other well described control variables.

2. *Overall pattern in the relationship between bilingualism and perspective-taking*

As introduced above, the different perspective-taking modalities were not equally susceptible to the effects of the candidate predictors in general, and to the effects of bilingualism in particular. Importantly, the visual models were overall less successful than the other models, especially those focusing on the egocentric biases, indicating that skills not included here may play a more important role in visual processes, such as working memory (Qureshi & Monk, 2018) or interoceptive accuracy (Erle, 2019). Visual measures were most frequently predicted by attention switching skills, as well as non-verbal IQ for level 1 measures, but no consistent pattern was found for bilingualism variables. On the contrary, cognitive and affective measures were most frequently predicted by inhibition skills, and by the age of acquisition of the second language.

Indeed, as will be discussed further below, the bilingualism variable that was most frequently selected across all the models was the age of acquisition of the second language, but it was minimally influential for visual models. Turning our attention to the control variables, again the visual models show a contrasting pattern: on the one hand, the executive function variable most frequently selected overall is the inhibition measure, present in six models, including five social models where it consistently significantly predicted the outcome measure, with a positive relationship. However, it was only present in one visual model, where its positive effect did not reach significance. On the other hand, the second most frequently selected executive function variable was attention switching, present in five models, but with an opposite pattern: this variable was present in all but one visual models, but only two social models.

3. *Modality-specific patterns in the relationship between bilingualism and perspective-taking*

The present study is especially interested in the overall pattern of relationship between bilingualism and perspective-taking processes, but a closer review of each modality also sheds light on the way various types of perspective-taking are susceptible to the influence of bilingualism.

Both models focusing on level 1 and 2 egocentric biases did not significantly predict the bias scores. While it could be possible to extrapolate on the meaning of each specific predictor included, the overall extremely poor performances of the models indicate instead that the egocentric bias, regardless of the difficultly of the task, is at most only faintly related to the variables considered here, including bilingualism. On the contrary, models 1ART and 2ART significantly predicted level 1 and 2 altercentric biases, though this explained only a small share of the variance in the data. Again, considering the poor performances of the models, I will not extrapolate on the meaning of every single predictor involved. However, as these models are significant, it is possible to address the role of the most consistently selected predictor across all visual models, attention switching. This variable was selected for both altercentric biases and level 2 egocentric bias, and was a significant predictor of level 1 altercentric bias. This could mean that its effect is not dependant on the target of the unintentional perspective (our own or the other person's), but on the overall mechanism of unintentionally processing visual perspectives. Beyond the role of attention switching, my results do not show the expected role of inhibition, which has been described as one of the main enablers during the development of visual perspective-taking in children (Nilsen & Graham, 2009).

The social models showed a higher performance compared to the visual models in terms of significance level and variance explained. The pattern across the cognitive models was also highly consistent. Model 2C, predicting level 2 cognitive scores underperformed compared to the other two models, which could be due to a wider spread of the level 2 scores compared to the level 1 and overall cognitive scores. These cognitive models indicated that higher inhibition skills significantly predicted higher performances in cognitive perspective-taking, which could be interpreted as an increased ability to suppress our own perspective to process the other person's. There was also a positive though non-significant link between attention switching and the cognitive scores, suggesting that cognitive perspective-taking is supported by both inhibition skills, to suppress our own perspective, and switching skills, to efficiently shift to the other person's. Especially relevant here is the negative though non-significant relationship between cognitive scores and the age of acquisition of the second language, illustrating that acquiring the second language at a younger age could lead to higher cognitive perspective-taking skills. Arguably, this predictor did not reach significance, but its recurrent selection and the overall high performance of the models suggest that this relationship is worth noting and investigating. Notably, when interpreting this relationship, it is essential to bear in mind the somewhat narrow spread of ages of acquisition of the second language in the present sample.

The models predicting affective perspective-taking were less consistent, though there was a recurrent, and mostly significant negative relationship between age and affective scores, indicating that older participants were less accurate in their responses than young participants. This fits with the body of literature describing an age-related decline in affective perspective-taking (Baksh et al., 2020; Laillier et al., 2019). There was also a significant positive relationship between non-verbal IQ and affective scores, though this predictor was not selected in the model focusing on level 2 processes, suggesting that affective perspective-taking is also linked to non-verbal intelligence. Model 1A also included a surprising pattern between the number of languages variables and level 1 affective perspective-taking, with each variable showing an opposite influence on the outcome measure, while the number of languages mastered – by group, was simply a more rigorous count of the number of languages known – by group. Therefore, this change in direction could be due to the handful of participants moved between groups, and therefore an artefact of the data. Also, as these predictors only appear in two models, it is unlikely that they greatly influence the processes at hand. As for the cognitive models, Model 2A showed a positive significant relationship with inhibition skills, reinforcing the hypothesis that higher inhibition skills allow for more efficient perspective-taking processes in social modalities. In this model was also found, as for the cognitive models, a negative, and this time significant, relationship with age of acquisition of L2, supporting the hypothesis that acquiring a second language at a younger age is linked to higher social perspective-taking skills. Importantly, this model was the one with the highest performance across all models presented in this chapter, strengthening its results.

Models G and S respectively significantly predicted the general and overall social scores. While model G had an overall low performance, it highlighted again the role of age of acquisition of the second language described above. Finally, model S allowed me to assess this social perspective-taking mechanism as a whole, regardless of results purely due to distribution differences. It reiterated the positive and significant influence of inhibition skills of social perspective-taking processes, as well as the negative though non-significant role of the chronological age and the age of acquisition of the second language, reinforcing the findings discussed above.

Model P predicting the control score included only a positive significant influence of sustained attention, which validates the role of this score as a control measure for the task. As control questions only required observation of the videos and logical reasoning about non-social actions, it was indeed expected that neither inhibition nor switching skills would be involved. The absence of the age, non-verbal IQ, and bilingualism predictors allows me to conclude that their presence in the social models was not due to the overall nature of the task, but to the specific mechanisms involved in social skills.

B. Visual and social perspective-taking

The second goal of this study was to investigate the existence of general perspective-taking process, underlying all three modalities, addressing the debate of the place of visual perspective-taking. To do so, I compared the modalities directly with a correlation analysis, and indirectly with regression models, assessing their susceptibility to the influence of bilingualism and other control variables. Multiple hypotheses were proposed regarding the possible combination of correlations between the cognitive, affective, egocentric and altercentric sub-scores. The results showed no relationships between the visual modality and the cognitive and affective modalities. While my results do not exclude shared underlying mechanisms, they indicate that the closeness between the cognitive and affective perspective-taking processes is not present with visual processes.

1. *Biases in visual perspective-taking*

Before addressing these key findings, it is necessary to consider the intermediate results in the visual modality leading to these conclusions. The findings support the hypothesis of the existence of a fast and unintentional component of visual perspective-taking, sufficient to efficiently process other's perspectives in the simplest settings, but not more complex ones. This is demonstrated by the faster processing of the participant's own perspective compared to the avatar's in all conditions but the simplest (level 1 consistent trials). These findings go further than those by Surtees et al. (2016), who did not directly compare trials targeting the self versus an avatar. In my study, the automaticity of perspective-taking is supported by the systematic advantage found when both avatar and participant perspectives were identical. Importantly, this automaticity extends to automatic processing of another's perspective, even when it was irrelevant and explicitly not required. Since bias scores reflect unintentional processes, they allowed me to assess more finely whether the cognitive consequences of bilingualism shape social processes beyond the conscious and deliberate level.

2. *Direct comparisons between visual, cognitive, and affective perspective-taking*

Focusing first on the results in the visual modality, the correlation between these biases in each level supports the evidence for an underlying automatic process, through a share of common variance. The significant correlation between levels found in egocentric biases but not altercentric biases could be explained by the difficulty of the task: the processing effort involved in level 2 egocentric bias seems to be closer to that involved in level 1 than it is in the case of altercentric biases. Even though my results did find an altercentric interference in level 2 visual perspective-taking processes, this contrast between level 1 and level 2 processes adds to the body of literature arguing for the existence of an automatic computing of other people's point of view only in level 1 processes (Surtees, Samson, et al., 2016), especially as level 1 altercentric bias was significantly correlated with both egocentric biases, indicating a shared mechanism between the egocentric interference and the level 1 altercentric interference. A difference between levels of complexity also appeared between the outcome measures of the A-ToM-e, but again there was some degree of correlation across level, suggesting a share of common capacity underlying these skills, in spite of the contrasting complexity of the tasks.

The most compelling result of the correlation analysis was that multiple cognitive and affective measures correlated with each other, while not a single significant correlation was found between these measures and the visual modality. Arguably, this could be due to the fact that the measures of visual perspective-taking assessed unintentional processes, while the cognitive and affective measures could only address explicit processes, or to the fact that these cognitive and affective measures were acquired within a single task. However, the reason for this discrepancy could also be explained by the growing body of literature arguing that visual perspective-taking is not a social process to the same extend as the cognitive and affective modalities.

3. *Indirect comparisons between visual, cognitive, and affective perspective-taking*

As discussed above, the modalities were strikingly different in their susceptibility to bilingualism and the other candidate predictors. In short, while the cognitive and affective measures were in majority linked with inhibition skills and the age of acquisition of the second language, the visual measures were hardly explained by the variables considered here, and the most relevant predictor in this modality was attention switching. This suggests that the visual and social modalities rely on distinct underlying executive skills, and that bilingualism seems to influence the development of the social (cognitive and affective) modalities only. This indirect comparison between modalities reinforces the findings of the direct comparison and supports the body of literature arguing for a distinction between the visual and social modality, questioning the validity of visual perspective-taking as a genuine social cognitive mechanism.

C. The Adult-Theory of Mind-extended test

The third goal of this study was to assess the validity of the A-ToM-e as a reliable tool to measure the different forms of social perspective-taking in neurotypical adults, and by extension, its validity in addressing my first two research questions. To do so, I conducted an internal consistency analysis, and considered its results in light of the correlation analysis results. I hypothesised that there would be an acceptable internal consistency ($\alpha \geq 0.7$) between the questions for each outcome measure, and a high (≥ 75%) inter-rater agreement. The results did not validate my first hypothesis, showing mostly low internal consistency across the videos in each outcome measure, even though the internal consistency of the overall social score was indeed acceptable ($\alpha = 0.72$). On the contrary, the results validated my second hypothesis, with high inter-rater agreement across all outcome measures.

The low internal consistency could be due to the fact that each video addressed a different type of social interaction, and therefore might have different intrinsic difficulty (i.e. white lie may be easier to understand than persuasion). It is also possible that regardless of the type of social interaction, some scenarios were more complex than others (i.e. the Spaghetti – sarcasm video relied only on a very short, three-sentences-long exchange, and provided few cues). However, the authors of the original Adult-Theory of Mind task (Brewer et al., 2017) relied on a rigorous method to select the final items, using a principal components analysis, assessing inter-rater reliability and test-retest stability, thus ensuring the validity of the items selected. Furthermore, maintaining a wide range of difficulty across the entire task allows for the wide range of perspective-taking abilities visible in adulthood, and helps preventing a floor or ceiling effect in the task. As such, in spite of the low internal consistency which should be taken into consideration when using this task, my results suggest that the A-ToM-e is an appropriate tool to assess social perspective-taking processes, if the goal is to assess the various forms of perspective-taking using a naturalistic method.

However, it is necessary to note that designing a new standardised social cognitive task was not the primary goal of this study. Therefore a complete battery of psychometric tests, such as a test-retest reliability as used by Dziobek et al. (2006) to assess the Movie for the Assessment of Social Cognition, or a construct validity evaluation as used by Aykan & Nalçacı (2018) to assess the Theory of Mind – Humor Comprehension and Appreciation Test, was not performed here, but should be before the task is used more widely.

D. Implications of the findings

1. *Theoretical implications*

Taken together, my results support a body of literature arguing for a distinction between visual and more social (cognitive and affective) perspective-taking processes, and they also bring new evidence for the theoretical overlap between perspective-taking and bilingualism.

The present findings have considerable implications regarding the development of social perspective-taking processes. The results report that a younger age of acquisition of a second language predicted higher social perspective-taking performances, indicating that bilingualism does have the potential to stimulate the development of these processes. This supports the theory that language skills, and a rich linguistic environment, are essential to support the development of perspective-taking skills in childhood, but that in adulthood perspective-taking processes do not rely on language abilities (Apperly et al., 2009; Emen & Aslan, 2019). In this framework, bilingualism enhances perspective-taking only during the phase in which both language and perspective-taking processes are intertwined: in childhood, though its developmental benefits remain visible until adulthood. This mirrors previous findings showing that in children, the development of language and perspective-taking skills are linked. However, I did not find consistent evidence that this developmental impact of bilingualism affected level 1 and level 2 processes differently, even though these are acquired at different developmental stages. While it is possible that this lack of difference is due to the distribution of the data, age of acquisition or perspective-taking scores alike, another hypothesis is that bilingualism impacts a common pathway shared by both processes, therefore allowing them both to benefit from the stimulating effect of early bilingualism.

Also, one must consider the factors of the bilingualism experience that were not selected in the models. Indeed, while proficiency is often used as the selection criteria in studies on bilingualism, this variable, directly measured or calculated as a balance ratio, was not selected in a single model. While this does not exclude its influence on these mechanisms, it indicates that it is not the most impactful aspect of the bilingualism experience, at least when considering social cognitive skills. The language switching habit has not been selected in a single model either. This is especially relevant when considering that the field of research on the effect of bilingualism on executive function skills is moving towards the Adaptive Control Hypothesis (Green & Abutalebi, 2013), that proposes that the effect of bilingualism depends primarily on the way in which bilinguals use and switch between their languages. However, it is possible that in the data, this effect of proficiency or language switching on perspective-taking skills was entirely mediated by executive functions. Still, my findings – which controlled for executive functions – are particularly relevant when considering the direct, non-mediated by executive functions, influence of bilingualism on social processes. The results therefore suggest a striking difference between social processes and executive functions in the way they are impacted by the bilingual experience. Indeed, my findings suggests that the stimulating effect of bilingualism on social processes is not linked to the mastering of multiple languages, or the juggling between languages, but to the exposure of multiple languages during critical periods of the development.

Lastly, these findings indicate that while cognitive and affective perspective-taking largely overlap, they do also have their own specificities in the way they are impacted by co-existing factors, such as age or executive functions (Baksh et al., 2020). This follows previous research describing how differently each process can be impacted in normal aging (Fernandes et al., 2019) or in clinical conditions such as Borderline Personality disorders (Tay et al., 2017), Obsessive Compulsive Disorder (Liu et al., 2017), or Progressive Multiple Sclerosis (Lancaster et al., 2019). On the contrary, my results do not illustrate a clear contrast between level 1 and level 2 mechanisms, especially in the cognitive modality. The distinction between both processes has been described in the literature mostly in terms of developmental stages (Perner & Wimmer, 1985; Valle et al., 2015) and implicit versus explicit mechanisms, which are not addressed in this study. Therefore, the results can only show that these two levels do not seem to be impacted differently by bilingualism and executive skills.

2. *Practical implications*

These findings carry practical ramifications, especially in terms of research methods, educational practices, and parental support. I recommend that future studies investigating the link between bilingualism and social processes should not rely on proficiency as the selection criteria for their bilingual sample, but on the age of acquisition of the second language, or better, on a continuous and multifactorial view of bilingualism. Furthermore, my results show that to benefit from the positive cognitive influence of bilingualism in terms of social skills, the learning of multiple languages should be encouraged from birth and early childhood. As a result, educational practices should reinforce the teaching of foreign languages in young children, which could support the development of their social cognitive abilities. Parents who wish to raise their children bilingually should also be encouraged to do so and adequately supported if needed.

E. Limitations

It is essential to consider these results in the light of the limitations of the study. First, this study was the first of its kind to rely on an innovative and multidimensional definition of both bilingualism and perspective-taking. Grounding my study in this multidimensional framework meant investigating this relationship with a highly exploratory approach, which impacted the analysis strategy. This study involved a large number of multiple regression models, which could not be designed according to standard methods of theory-based predictors selection. Instead, a two-step method was used to build the models, and then analyse their results. Even though great care and rigorous, standardised strategy was used, the large number of analyses might have led to artefact results. Aware of this weakness, my responsibility as a researcher led me to discuss these results in terms of patterns across the data, thus avoiding over-interpretation of single findings. As such, I am confident in the findings presented, but it is possible that some effects were under-estimated.

Second, as discussed above, considering the nature of the visual and social measures, the likelihood that these differences are due to the distinction between implicit and explicit processes cannot be excluded. It is conceivable that the influence of bilingualism only applies to explicit skills, and does not reach implicit, automatic mechanisms, however this would go against previous findings describing an influence of bilingualism on the implicit processing of a level 1 cognitive task but not its explicit processing (Rubio-Fernández & Glucksberg, 2012).

Third, while the control variables were directly measured in the participants, the bilingualism variables were self-reported by the participants. This means that their own positive or negative bias, and their own interpretation of the questions, may have impacted the results. As discussed in Chapter 2, for proficiency ratings for example, participants may have had a heterogenous understanding of what is an average or high language proficiency. Still, studies have shown that self-rated proficiency is generally accurate compared to standardised language testing (Brantmeier et al., 2012; Edele et al., 2015), which would support confidence in these results.

Finally, multiple confounds have not been included in the analysis. Again, the exploratory nature of the study and the sample size involved compelled me to select, based on the available literature, the most critical candidate confounds: age, non-verbal IQ, and executive skills. Arguably, it would have been relevant to also include measures of working memory (Laillier et al., 2019; Maylor et al., 2002; Qureshi & Monk, 2018; Valle et al., 2015), or gender (Baksh et al., 2020; Giovagnoli, 2019; Wacker et al., 2017). Also, to allow me to draw more meaningful conclusions regarding visual perspective processes, the addition of a control task with an arrow instead of the avatar would have indicated whether or not the biases measured here were indeed led by the social aspect of the stimuli.

F. Future directions

These results raise numerous questions, regarding the underlying mechanisms of perspective-taking and the relationship between these mechanisms and bilingualism. First, as discussed in the section *Theoretical implications* above, future research on perspective-taking should move away from the inclusion of visual perspective-taking as a social cognitive mechanism. While it is possible that social factors are involved in some aspects of visual perspective-taking, the present data illustrates a striking divide between the visual modality and the cognitive and affective modalities.

Second, while these results were not able to highlight clear differences between level 1 and level 2 social processes, investigating these on an implicit level could reveal unique interactions between perspective-taking and the other factors involved in the study. The A-

ToM-e indeed had the benefit of allowing me to detangle level 1 and level 2 skills, but not implicit and explicit routes. Previous studies have described how these two routes developed differently in childhood (Apperly & Butterfill, 2009), and how they could be impacted differently by factors such as normal aging (Grainger et al., 2018). As the results suggest a developmental impact of bilingualism, it is now essential to understand how these routes, that follow distinct developmental paths, are susceptible to early versus late bilingualism.

Third, because of the highly exploratory nature of this study, several investigation leads had to be discarded, and should now be addressed. Considering the highly-researched link between bilingualism and executive function, and the diversity of bilingual profiles (i.e. highly proficient late bilinguals, or lowly proficient early bilinguals), it would be relevant to further the results with the addition of interaction mechanisms. This would allow us to answer new questions about the developmental impact of bilingualism in different cognitive profiles, for example comparing bilinguals with high versus low switching abilities. This study also had to withdraw from specific aspects of the bilingual experience. For instance, the present analysis considered proficiency as a whole, while it would be relevant to investigate the specific impact of oral comprehension and expression on social mechanisms, as these language skills are developed through social interactions. Finally, this study measured the age of acquisition of a language as the age of first exposure to the language. Going further, it is essential to also consider the other stages of language learning – such as the age when the language was actively used, or the age when the language was mastered to an average or high proficiency language – and consider the impact of these stages of language development on social processes. Also, it would be particularly informative here to reproduce this analysis with a wider range of ages of acquisition of the second language, including very late bilinguals. Indeed, considering the distribution of the data in the current sample, the mere selection of this variable, across models, reinforces the hypothesis that age of acquisition of the second language influences cognitive perspective-taking.

Finally, and more importantly in the context of this research, it is essential to investigate the stimulating potential of bilingualism in the context of atypical development of perspective-taking that is autism. As discussed in Chapter 1, one of the main characteristics of autism is an atypical or impaired development of social processes during childhood. However, as described in Chapter 2, bilingualism influences, at least from a self-perspective, the quality of the social life of autistic adults, suggesting that in the context of autism there is also a relationship between bilingualism and social mechanisms. Taken together with these new findings regarding the developmental impact of bilingualism, this raises the question of whether early bilingualism could also stimulate the development of perspective-taking processes in autism.

Chapter 4: Relationship between bilingualism and perspective-taking in autistic adults

I. Introduction

Chapter 2 described how bilingualism shaped and improved the perceived social life quality of autistic adults, suggesting the existence of a relationship between bilingualism and social mechanisms in autism. However, it is unknown whether this relationship also exists at the behavioural level. Chapter 3 highlighted that in typical development, bilingualism has a long-lasting developmental influence on cognitive and affective perspective-taking, social cognitive processes particularly involved in social functioning. Together, these results raise the question of whether this influence of bilingualism on perspective-taking processes also exists in autism.

A. Defining social cognition and perspective-taking in autism

1. *Why study perspective-taking in autism?*

The distinct social cognitive profile of autism includes a different development of skills such as perspective-taking. Several theories have been proposed to explain the social process difficulties generally seen in autism, such as the Theory of Mind Deficit theory, or the Social Motivation theory (see Brighenti et al. (2018) for a recent review). Each theory has some evidence in its favour, but to date, none has been established as a definitive and comprehensive account of the social processes in autism. Moreover, it is worth noting that recent evidence has challenged the well-established position that autistic individuals are uniquely impaired in social cognition (Gernsbacher & Yergeau, 2019), leading to the argument that the picture of the autistic social profiles needs to be reconsidered.

Nevertheless, it remains valuable to investigate social cognition in autism, and in particular complex perspective-taking skills. These skills are associated with better social functioning (Bottema-Beutel et al., 2019), and lower social difficulties, as reported by Bishop-Fitzpatrick et al. (2017) in a large cross-sectional study involving 108 autistic children and young adults. Importantly, the way social cognitive processes operate in relation to each other to support social functioning seems to differ between autistic and neurotypical people.

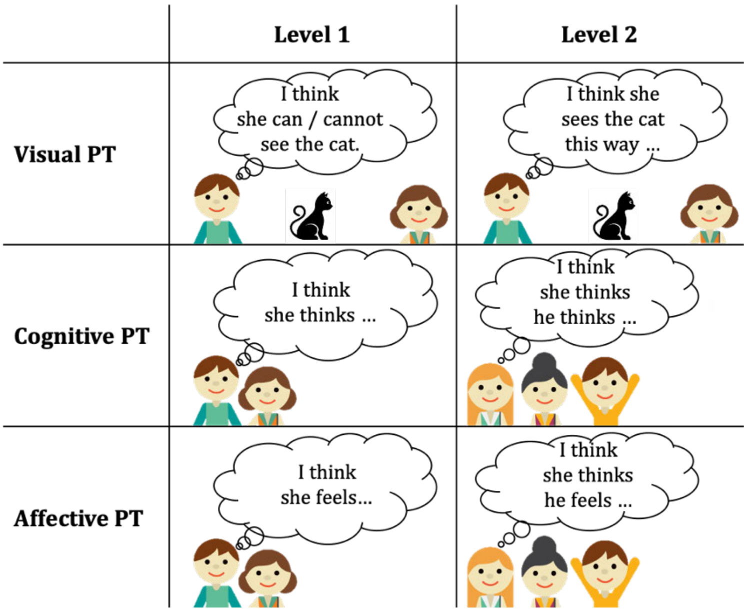
Indeed, using a graph analysis, Vagnetti et al. (2020) described high interconnection between the components of social cognition in neurotypical adults, especially for cognitive perspective-taking, but high disconnection between these different modules in autistic adults. This poor connection between social cognitive processes could be involved in the difficulties experienced by autistic people during social interactions, with each process being less reliant on the others to produce a complete representation of the social context. In neurotypical participants, perspective-taking appeared to occupy a key crossroad between social cognitive processes, thus highlighting the importance of this process in general social functioning. In participants with autism, perspective-taking did not take this role, further illustrating how this process differs between autistic and neurotypical populations. The discrepancy between populations in terms of social cognitive networks reinforces the need to research perspective-taking mechanisms within groups of autistic people, regardless of the patterns observed in their neurotypical peers. Indeed, perspective-taking skills do contribute to the social functioning and social outcomes of autistic people (Bishop-Fitzpatrick et al., 2017; Sasson et al., 2020), but the way in which they do may be drastically different from the relationship existing in neurotypical people. Therefore, reaching a deeper understanding of these mechanisms is essential to understand the functioning of the autistic mind, and to better appreciate the autistic experience.

2. *Cognitive and affective perspective-taking*

a. *Definition and terminology*

As defined in Chapter 3 section I.A, perspective-taking occurs in different modalities and with different levels of difficulty (Figure 4.1). Cognitive and affective perspective-taking refer to the ability to understand what another person thinks or feels, and can be separated into simple level 1 (or first-order) and complex level 2 (or second-order) processes (see Chapter 3 section I.A.2 for further details). Cognitive and affective perspective-taking have been extensively researched in autism, as their impairment has long been considered one of the defining features of autism.

Figure 4.1 - Examples of visual, cognitive, and affective perspective-taking.



Note. Examples of the different modalities and levels of difficulty existing in perspective-taking processes.

As mentioned in Chapter 3, both these processes, and particularly the cognitive modality, are often referred to in the autism literature as “mindreading” (Turner & Felisberti, 2017), “mentalising” (Arioli et al., 2018) or “Theory of Mind” (Birch et al., 2017; Wimmer & Perner, 1983). To be more precise, Theory of Mind is a global and multidimensional construct, and refers to the knowledge that others have a mind different to our own, and the consequent ability to reason about others’ thoughts, beliefs and feelings, as a whole (Premack & Woodruff, 1978). In the literature, the term Theory of Mind has been used to encompass specific skills that are highly different from one another, such as emotion recognition from static pictures, behaviour prediction via false-belief understanding from text stories or cartoons, or anthropomorphisation of videos of moving shapes (Schaafsma et al., 2015). As such, perspective-taking, or the ability to take another’s perspective, and understand what they think or feel in a specific situation, is only one of the processes involved in Theory of Mind. As argued by Schaafsma et al. (2015), it is necessary to disentangle these processes to better understand them individually and collectively, which is why this research exclusively uses the term perspective-taking, and further distinguishes between modalities (cognitive versus affective) and complexities (level 1 versus level 2).

Still on the matter of terminology, and even more importantly in the context of autism, it is also important to note that affective perspective-taking does not refer to empathy – a complex, multi-component, and admittedly poorly defined, construct involving both perceiving and responding to others' emotions (Fletcher-Watson & Bird, 2020; Song et al., 2019). Affective perspective-taking only refers to one of the many steps of the empathetic process, as it concerns the correct identification of others' emotional state, just as cognitive perspective-taking concerns the correct identification of others' mental state.

b. Findings in childhood and adolescence

In autistic children, impairments in the development of level 1 cognitive perspective-taking skills have been famously described using the false-belief Sally-Anne task (Baron-Cohen et al., 1985). More recently, cross-sectional findings by Mazza et al. (2017) and Pino et al. (2017) reported lower cognitive and affective perspective-taking skills in autistic children aged 5 to 13 compared to their neurotypical peers (each study involving respectively 52 and 37 autistic participants). Importantly, in a recent longitudinal study assessing the development of cognitive perspective-taking over 1.5 years, Peterson & Wellman (2019) described that while autistic children (aged 3 to 11, n = 43) consistently performed lower than their neurotypical peers, most of them did show progress over time, suggesting a delayed development of perspective-taking. However, in their study measuring overall explicit theory of mind across different age groups (ranging from 6 to 20 years old), Scheeren et al. (2013) reported contradicting findings. Using five social stories similar to the A-ToM-e task used here, authors found that autistic participants performed equally to their neurotypical peers, and that advanced perspective-taking skills were associated with age, verbal and general reasoning abilities, but not with diagnosis. Together, these results suggest that autistic children and adolescents experience difficulties with perspective-taking, which may be moderated by individual characteristics such as verbal skills.

c. Findings in adulthood

Despite extensive research on cognitive and affective perspective-taking skills in autism, findings in adulthood are somewhat inconsistent (see Appendix V for a table summarising the experimental studies reported below). Using an eye-tracking and false-belief paradigm to assess implicit and explicit level 1 cognitive perspective-taking studies found that autistic and non-autistic adults had similar explicit performance, but that unlike their neurotypical peers, autistic adults did not show signs of implicit mechanisms (Senju et al., 2009), even after a learning opportunity of multiple trials (Schneider et al., 2013). On the contrary, using a video-based level 1 cognitive perspective-taking with an eye-tracker, Cole et al. (2018) showed that autistic adults were impaired in explicit, but not implicit processes, with autistic participants (n = 17) displaying similar fixation patterns to their neurotypical peers (n = 17).

This specific result showing neurotypical-like explicit perspective-taking in autistic adults goes against a large body of evidence showing that autistic adults do encounter difficulties in the completion of complex, naturalistic, explicit perspective-taking tasks. Indeed, a meta-analysis and systematic review gathering 75 studies on the social and non-social cognitive functioning of autistic adults (Velikonja et al., 2019) reported large difficulties in cognitive perspective-taking ("theory of mind" in the review), and emotion perception and processing. This dovetails with findings by Happé (1994a) using the Strange Stories task, who reported that autistic adults failed to produce context-appropriate mental state explanations to the stories, compared to neurotypical adults. These results were since reproduced in other studies using the original Strange Stories task (Jolliffe & Baron-Cohen, 1999), adapted video versions of the task such as the Strange Stories Film Task (Murray et al., 2017) or the Adult-Theory of Mind task used here (Brewer et al., 2017), and other complex naturalistic tasks such as the Awkward Moment test (Heavey et al., 2000).

In a recent study measuring explicit overall cognitive and affective perspective-taking across three well-established tasks of advanced theory of mind, Booules-Katri et al. (2019) found that autistic adults (n = 30) underperformed compared to their neurotypical peers (n = 36), and showed similar skills in both modalities. These findings coincide with results by Pedreño et al. (2017), who assessed autistic (n = 35) and neurotypical (n = 35) adolescents and adults aged between 12 and 42 on a battery of three advanced cognitive and affective perspective-taking tasks, and found that autistic participants consistently underperformed compared to the control group. Finally, Rosenblau et al. (2015) used another naturalistic video-based task to assess autistic adults' overall cognitive and affective perspective-taking with prompts – by asking them to describe the characters thoughts or feelings, or without prompts – by asking them to choose the most likely ending to the story. Autistic participants (n = 28) performed similarly in both conditions, showing consistent difficulties compared to their neurotypical peers (n = 23) regardless of the type of answer requested.

The occasionally recorded absence of difficulties in perspective-taking processes could be interpreted as the use of compensatory mechanisms, but could also be due to methodological differences. Indeed, Morrison et al. (2019) recently addressed this matter and evaluated eleven widely-used social cognitive tasks in a large sample of 103 autistic and 95 neurotypical adults, and found that neurotypical participants outperformed the autistic group in eight tasks, though with the largest group difference in two cognitive and affective perspective-taking tasks, the Awareness of Social Inference task (McDonald et al., 2003) and the Hinting Task (Corcoran et al., 1995).

Overall, findings in adulthood strongly suggest that autistic adults experience perspective-taking difficulties compared to their neurotypical peers, but there are still inconsistent findings regarding the specific pattern of impairments, specifically concerning explicit versus implicit processes (as illustrated by the opposing results found by Cole et al. (2018) and Senju et al. (2009)).

d. Beyond group differences

This overview of the literature clearly outlines the presence of difficulties in cognitive and affective perspective-taking in autism, compared to typical development.

However, most of these tasks do not disentangle the different modalities or levels of perspective-taking, instead measuring perspective-taking abilities as a whole. Addressing each process separately as well as the overall skill, could allow the field to move towards a more individualised understanding of the strengths and difficulties of autistic people regarding social cognitive processes. As highlighted by Morrison et al. (2019) and Bottema-Beutel et al. (2019), examination of multiple tasks and aspects of social cognition reveals new insight into the social functioning of autistic people, and applying this multidimensional approach to perspective-taking would allow us to better understand this specific process. This approach has also been recently put forward by Livingston et al. (2019) in a thorough review of the currently available tools to assess Theory of Mind and perspective-taking in autistic adults. Considering the inconsistent findings in the literature and the contrasting reports from autistic people depicting clear challenges in real life social interactions, authors rightfully argue for an increased use of naturalistic tasks, and for a more personalised conception of autistic social cognitive skills.

Theory of mind, as discussed above, involves several distinct and overlapping mechanisms, and considering the diversity of cognitive profiles in autism is it likely, as argued by Livingston et al. (2019), that not all autistic people experience the same pattern of specific difficulties. This variability amongst autistic people is crucial in the present research. Indeed, Chapter 3 showed that in typical development, bilingualism enhanced perspective-taking skills not via an explicit, conscious, and deliberate learning of social abilities, but via implicit and unintentional learning during the early stages of development. However, if autism were truly characterised by distinctive and consistent perspective-taking deficits, then it could be expected that this core "deficient" perspective-taking mechanism would not be susceptible to the implicit and incidental influence of bilingualism, and especially of early bilingualism. However, the variability in the patterns of strengths and difficulties present in the autistic population suggests that there are important individual differences between autistic people, allowing for a potential implicit influence of bilingualism.

The way individual differences relate to cognitive and affective perspective-taking skills has not been as extensively studied as the overall differences between autistic and neurotypical populations. Still, previous findings have described that, beyond the effect of age on the development of these skills (Kimhi et al., 2014; Scheeren et al., 2013), perspective-taking abilities were also linked with overall intellectual abilities (Happé, 1994b; Scheeren et al., 2013), and especially verbal intelligence and abilities (Happé, 1995; Kimhi et al., 2014; Pino et al., 2017; Scheeren et al., 2013). Studies have showed that in autism, perspective-taking abilities are also linked with executive functioning (Kimhi et al., 2014). These findings highlight that individual differences shape the perspective-taking abilities of autistic people, but also point out the necessity to consider these factors when assessing the influence of other individual features, such as bilingualism experiences.

In sum, there is undeniable evidence that cognitive and affective perspective-taking operates differently across autistic and neurotypical populations. Research has also shown that inclusion of multiple measures of social cognitive processes adds value and reveals new insights about the exact nature of autistic social processes. However, relatively little research has investigated individual differences between autistic people in their abilities, and especially has not examined what features may govern the development of these abilities.

3. *Visual perspective-taking*

Perspective-taking can also operate in a purely visual, as opposed to cognitive or affective, modality. As defined in Chapter 3 section I.A.3, visual perspective-taking likewise includes level 1 and level 2 processes (Figure 4.1), where the former involves simple line-of-sight processing, and the latter relies on more complex mechanisms. In this modality, explicit mechanisms are generally measured by asking participants to indicate what another person sees with words or actions, while implicit mechanisms are measured via the interference caused by the irrelevant presence of the other person.

Visual perspective-taking has not been as extensively studied in autism as cognitive or affective modalities, and the existing literature depicts rather inconsistent findings (see Pearson et al. (2013) for a comprehensive review). Hamilton et al. (2009) described impairments in 8-year-old autistic children compared to their neurotypical peers when performing level 2 visual perspective-taking and reported that these difficulties in the visual modality were linked with their performance in the cognitive modality. Another study showed that autistic children appear to have specific difficulties in the development of implicit, but not explicit level 2 mechanisms, when compared between the ages of 6 and 8 (Asaoka et al., 2019). Neurotypical-like explicit level 2 skills were also observed in adulthood by David et al. (2010), although authors admitted that the design used might have been too simple to properly assess this ability. This pattern of impaired implicit, but spared explicit routes has also been described in level 1 processes in adulthood, with autistic adults showing signs of egocentric but not altercentric implicit biases (Doi et al., 2020).

However, these neurotypical-like explicit mechanisms have to be considered in the light of earlier findings regarding processing strategies. Indeed, studies have reported that when performing explicit level 2 visual perspective-taking, autistic adolescents relied on a mental rotation strategy – which is based on mentally rotating the object towards them, while their neurotypical peers relied on an embodied strategy – meaning that they imagined themselves in the place of the other person (Conson et al., 2015; Pearson et al., 2016; Russo et al., 2018). This suggests that similar performance between groups could in reality be achieved by drastically different mechanisms.

Contrarily to the findings of impaired implicit processes discussed above, Zwickel et al. (2011) reported a congruency effect in both autistic and neurotypical adult participants using a simple animated shape task, and concluded that autistic adults did not have impairments in implicit visual perspective-taking skills. This was also found by Schwarzkopf et al. (2014), who described intact implicit level 1 processes in a sample of 16 autistic adults compared to 15 neurotypical adults, but also selective difficulties in explicit processes only. Still, these findings are limited by the nature of the task, and it has been argued that this paradigm only required processing of the orientation of the shapes (Pearson et al., 2013).

These conflicting findings could be due to the nature of the tasks used, but low power also has to be considered as a possible explanation. Indeed, all these studies involved between 18 and 30 participants in the autistic group, and most did not report effect sizes. Therefore, these studies may have been too under-powered to provide robust findings, and a well-powered study providing a comprehensive assessment of visual perspective-taking skills in autism is not yet available.

B. Perspective-taking and bilingualism in autism

As mentioned above in section I.A.2, one individual difference that may be relevant in shaping the perspective-taking abilities of autistic people is language experience, and in particular bilingualism. The link between bilingualism and perspective-taking has been scrutinised in the neurotypical population, and the results reported in Chapter 3 add to the body of evidence describing how bilingualism can enhance some aspects of perspective-taking. This research indeed showed that, in typical development, it is early bilingualism that particularly improves cognitive and affective perspective-taking abilities, with long-lasting benefits measurable in adulthood. However, to the best of my knowledge there is currently no research available on this question in autism.

Considering social functioning more broadly, a recent study measuring the social skills of a large sample of 297 monolingual and 165 bilingual autistic toddlers reported no differences in social interaction, peer relationships, and social reciprocity between the groups, suggesting at least no detrimental effect of bilingualism. In addition, Iarocci et al. (2017) reported that in a large sample of 174 children and adolescents aged 6 to 16, exposure to a second language did not delay the development of parent-rated executive functions and functional communication of autistic participants. Moreover, in their sample, a smaller proportion of bilingual participants had scores falling within the clinical range, compared to their monolingual peers, suggesting a benefit of childhood bilingualism. These findings agree with the results of an extensive systematic review by Uljarević et al. (2016) covering 50 studies assessing the clinical impact of bilingualism in different developmental conditions, that reported in the case of autism a positive influence of bilingualism on communication and social functioning. Finally, the results reported in Chapter 2 indeed showed that in a large sample of autistic adults, bilingualism can improve perceived social life quality.

In summary, the currently available findings only focus on overall social functioning in childhood or adolescence, but hint towards a non-detrimental relationship between bilingualism and social processes in autism, and potentially to some positive influence in adolescence.

C. Research questions and predictions about perspective-taking and bilingualism

As detailed above (section I.A), most studies focusing on the perspective-taking skills of autistic people have addressed them in terms of group differences between autistic and neurotypical populations. In contrast, the role of individual differences within each population, especially in terms of language experiences, is still poorly understood. The goal of the present study was not to assess potential impairments in perspective-taking skills in autistic adults compared to their neurotypical peers, but to investigate whether bilingualism shapes perspective-taking in autism, independently of the pattern identified in the neurotypical population (Chapter 3). The research currently available limited my ability to make concrete predictions regarding the influence of bilingualism upon the perspective-taking skills of autistic adults, and it remained to be seen whether the stimulating effect of early bilingualism described in the neurotypical population (Chapter 3) also extends to autism. Relying on the same multidimensional definition of both bilingualism and perspective-taking, this study aimed to provide a first step in the understanding of this relationship, experienced by a large number of autistic people around the world.

This study aimed to address three research questions mirroring those addressed in Chapter 3. In the absence of clear information leading me to expect the contrary, the prior hypotheses also repeated those tested in Chapter 3. While some of following hypotheses were adjusted to address the findings in Chapter 3, no evidence allowed me to assume that the relationship between bilingualism and perspective-taking would be identical between autism and typical development. As a result, the following research questions and related hypotheses concern the autistic population, regardless of the results described in the neurotypical population (Chapter 3):

1) *Is there evidence that bilingualism (multi-dimensionally defined, as introduced in Chapter 3) enhances performance across modalities and levels of perspective-taking in autism?*

Bilingualism was predicted to reduce egocentrism (bias towards one's own perspective) and increase altercentrism (influence of the other's perspective), in the visual modality. In the cognitive and affective modalities, bilingualism metrics would positively predict perspective-taking scores, but not the control question score, which does not require perspective-taking.

2) *Is perspective-taking performance shared across visual, cognitive, and affective modalities, suggesting the existence of a general perspective-taking process in autism?*

As discussed above, the performances of autistic people can greatly vary across tasks, especially within the cognitive and affective modalities. Therefore, as a single task was used here to address both modalities, it was expected to find that the cognitive and affective modalities would significantly correlate with each other. Furthermore, even though the debate regarding the place of visual perspective-taking in social processes has not been as widely research in autism as it has been in typical development, following the findings in typical development reported in Chapter 3, it was expected that the visual modality would not significantly correlate with the other modalities.

At the same time, as an assessment of the novel methods being deployed, the study asked:

3) *What is the validity of the modified Adult-Theory of Mind test as a cognitive and affective perspective-taking test in a population of autistic adults?*

If the Adult-Theory of Mind-extended test is an appropriate tool, then there would be an acceptable consistency ($\alpha \geq 0.7$) between the questions for each outcome measure, as well as a high ($\geq 75\%$) inter-rater agreement.

II. Methods

A. Participants

Participants had to have a pre-existing clinical diagnosis of autism, be United-Kingdom residents fluent in English, be aged between 16 and 65, and have at least minimal knowledge of at least one other language, all ascertained by self-report. The upper age limit of 60 set in the previous chapter was increased to compensate for the recruitment difficulty likely to occur with this specific population. Participants had to have normal or corrected to normal vision and hearing, and no known neurological conditions.

Participants were recruited in three phases, with advertisement across universities, autism networks, and social media. The first recruitment phase focused on Edinburgh and Scotland, and participants were invited to take part in the study at the University of Edinburgh. The second recruitment phase focused on England and especially South-East England, and participants were invited to travel to the University of Cambridge or to the

University of Edinburgh to take part in the study. The third phase focused on participants unable to travel to either Cambridge or Edinburgh, and offered an opportunity for participants to take part in the study online, via a Skype appointment. Importantly, all appointments but one (online appointment) were conducted by the same researcher.

Participants were provided with the details of the study and gave informed consent. Participants received a £20 gift voucher for their participation, and their travel expenses to and from the appointment were covered. A detailed account of the participants' demographics and language profile can be found in Chapter 4 section III.A.

The sample size needed to carry out this study was calculated using the *pwr* R package (Appendix II.1). A sample size of 77 participants would have allowed me to conduct a multiple linear regression analysis with 80% power to detect a medium effect size from the predictors, at $\alpha = 0.05$, taking into account 3 predictors. Assuming that not all participants complete the full task battery, applying a 12% increase set a target sample size of 86 participants. Unfortunately, in spite of the three recruitment phases and the increased upper age limit (which allowed for the inclusion of two 61-years-old participants), the target sample size was not reached, and the final sample size included 39 participants, after exclusion of one self-identified autistic participant who did not have a clinical diagnosis of autism.

In total, 22 participants were tested in Edinburgh, 13 participants were tested in Cambridge during a 3 weeks research visit, and 4 participants were tested during online appointments. Prior to data analysis, it was calculated that this more modest sample size would allow me to detect a large effect size using 3 predictors with 80% power at $\alpha = 0.05$. Considering the exploratory nature of the study, the same analysis strategy described in Chapter 3 section II.C was repeated with this sample, with increased rigor during interpretation of the moderately-powered results.

B. Materials and data processing

The full task battery and data processing were identical to those described in Chapter 3 section II.B. Below are reported brief summaries of the data processing steps, and information unique to data from the autistic sample, such as proportion of outliers. A summary of the tasks and their outcome measures is provided in Table 4.1.

Table 4.1 - Task battery and outcome measures

<table>
<tr><th>Task</th><th colspan="3">Outcome measures</th></tr>
<tr><td rowspan="4">Visual perspective-taking</td><td colspan="3">Level 1 egocentric bias (response time)</td></tr>
<tr><td colspan="3">Level 2 egocentric bias (response time)</td></tr>
<tr><td colspan="3">Level 1 altercentric bias (response time)</td></tr>
<tr><td colspan="3">Level 2 altercentric bias (response time)</td></tr>
<tr><td rowspan="6">A-ToM-e</td><td colspan="3">Physical</td></tr>
<tr><td rowspan="5">Social</td><td colspan="2">General</td></tr>
<tr><td rowspan="2">Cognitive</td><td>Level 1</td></tr>
<tr><td>Level 2</td></tr>
<tr><td rowspan="2">Affective</td><td>Level 1</td></tr>
<tr><td>Level 2</td></tr>
<tr><td rowspan="3">TEA</td><td rowspan="3">Total TEA score</td><td colspan="2">Sustained attention</td></tr>
<tr><td colspan="2">Attention inhibition</td></tr>
<tr><td colspan="2">Attention switching</td></tr>
<tr><td>WASI-II</td><td colspan="3">Non-verbal IQ</td></tr>
<tr><td>Demographic questionnaire</td><td colspan="3">Age</td></tr>
<tr><td rowspan="6">Language questionnaire</td><td colspan="3">Number of languages reported</td></tr>
<tr><td colspan="3">Number of languages known with medium to high proficiency</td></tr>
<tr><td colspan="3">Age of acquisition of the second language</td></tr>
<tr><td colspan="3">Overall proficiency in the second language</td></tr>
<tr><td colspan="3">Proficiency balance between the first and second language</td></tr>
<tr><td colspan="3">Language switching habits</td></tr>
</table>

Note. Summary table of the 6 tasks and 25 outcome measures involved the study. The 4 visual perspective-taking measures and 9 A-ToM-e measures were then used as outcome variables in the multiple linear regression models, while the measures from the TEA, WASI-II, Demographic and Language questionnaires were included in the list of candidate predictors for the models. All the bilingualism metrics were taken from the Language questionnaire, while the TEA, WASI-II and Demographic questionnaire provided control variables.

1. *Visual perspective-taking – VPT task*

Data processing and specific analysis plan

For each participant, the direct measures included the mean reaction times (RT) across correct trials for each Perspective condition (self versus avatar) and each Consistency condition (consistent versus inconsistent). There was no correct trial with a response time

(RT) under 100ms in the full set of individual trials. As described in Chapter 3 section II.B.2, the data from the VPT task were processed in two steps: first, the effect of Consistency was measured to verify the existence of biases; second, the direct measures were processed to create bias scores, used as outcome measures in the multiple regression analysis assessing the relationship between visual perspective-taking and bilingualism (see Chapter 3 section II.C.1.b). Rigorous scrutiny of the normality of the underlying variables was performed prior to each step of the analysis, and outliers (further than 2.5 standard deviations away from the mean) were excluded. Results of each step are reported in Chapter 4 section III.B.

For the first step of the analysis, one outlier was removed from the Avatar-Inconsistent condition, resulting in 38 participants. All other conditions retained data from all 39 participants. Mean response times to each condition were compared using a 2x2 repeated measures ANOVA with Perspective (Avatar, Self) and Consistency (Consistent, Inconsistent) as within-subject factors. To obtain a balanced design, the participant identified as outlying in the Avatar-Inconsistent condition was fully excluded from this analysis, which was carried out on the 38 remaining participants.

For the second step of the analysis, one outlying participant was excluded from the level 1 altercentric bias score, and two outlying participants were excluded from the level 2 egocentric bias score.

2. *Cognitive and affective perspective-taking – Adult-Theory of Mind-extended*

Data processing

As some participants missed questions or failed to complete videos due to technical issues, the number of answers available for each sub-score was verified. No participant missed answers for the physical score, and no participant reported more than 2 missing answers out of 6 for level 1 cognitive, level 2 cognitive, level 1 affective, level 2 affective, and general scores. No participant had more than 4 out of 12 missing answers for the overall cognitive and affective scores. Apart from one participant with 10 missing answers and one participant with 5 missing answers, no other participant had more than 2 out of 30 missing answers for the overall social scores. Thus, as no participant had fewer than 50% available answers for each score, no participant was excluded on the basis of missing answers, and for each score the final outcome scores were calculated from the answers available. Rigorous scrutiny of the normality of the underlying variables was performed prior to each step of the analysis. Outlying participants were excluded in each score on the basis of being 2.5 standard deviations away from the condition mean (the total number of participants for each score is reported in Table 4.10). The final scores were used as outcome measures in the following analysis.

3. *Executive function – Test of Everyday Attention*

Data processing

Importantly, due to technical issues, two of the four participants who attended online appointments were entirely unable to complete this task, and one participant was only able to complete the TEA attention sub-test. Performance on each sub-test was measured as the number of trials with a correct response. The total TEA score (hereafter: TEA total) was calculated for each participant as the sum of the three sub-scores, and was included in the list of candidate predictors to account for the overall executive function skills of the participant. However, as in Chapter 3, when internal consistency between the 3 subtests was assessed, the resulting Cronbach's alpha of 0.63 indicated a questionable internal consistency. A Pearson correlation test across the subtests indicated that in the present sample, there was a weak significant correlation between TEA attention and TEA inhibition scores (p = 0.023, r = 0.37), and a moderate significant correlation between TEA inhibition and TEA switching scores (p < 0.0001, r = 0.61), but no significant correlation between TEA attention and TEA switching scores (p = 0.23). As in Chapter 3, these results indicated that the TEA total score, combination of these three weakly correlated sub-scores, might not be a robust approach to control for the participants executive function skills in the analysis. As a result, each sub-score was also individually considered as candidate predictors in the following analysis.

For each score, participants with a score further than 2.5 standard deviations away from the mean had their score removed in the following multiple regression analysis.

4. *Non-verbal Intelligence Quotient – Wechsler Abbreviated Scale of Intelligence, 2nd Edition*

Data processing

There was no participant with non-verbal IQ scores further than 2.5 standard deviations away from the mean, but the four participants who completed the data collection appointment online were not able to complete this task, resulting in missing data.

C. Analysis plan

The analysis plan was identical to the one described in Chapter 3 section II.C, except for an additional step in the multiple linear regression analysis. First, the optimal models obtained with the neurotypical sample (see Chapter 3 section III) were applied to the autistic sample, in order to assess the validity in an autistic population of the relationship newly described in typical development between bilingualism and perspective-taking. Second, the method followed to obtain the optimal models in the neurotypical sample (see Chapter 3 section II.C.1) was reproduced with the autistic sample, in order to highlight any aspect of the bilingualism – perspective-taking relationship that would be specific to an autistic population. This allowed me to investigate whether the autistic population experienced a different influence of bilingualism on perspective-taking processes.

III. Results

A. Participants

The final sample included 39 participants, after exclusion of one participant who self-identified as autistic but did not have a clinical diagnosis of autism. The mean age was 34.5 years (range: 16 – 61), and the mean age at clinical diagnosis of autism was 26.6 years (range: 3 – 56). The gender distribution is 41.0% female, 35.9% male, and 23.1% not listed or not disclosed. All participants were residents in the United Kingdom and had to be 16 years or over to participate. The demographic characteristics of the sample are reported in Table 4.2, and their language profiles in Table 4.3 and Table 4.4 (but see Appendix IV for visual representations).

Even though all participants were United Kingdom residents, thus using English daily, English proficiency (measured as the average of the English oral and written comprehension and expression) was verified to ensure all participants were able to fully understand the tasks. Mean English proficiency across the sample was 7.58 (over the proficiency scale ranging from 0 to 8), with a standard deviation of 0.80, ranging from 4.50 to 8.00.

Table 4.2 - Autistic participants' demographics (n = 39)

Age in years, M (SD, range)	34.5 (12.8, 16 – 61)
Age at diagnosis in years, M (SD, range)	26.6 (14.4, 3 – 56)
Gender, N (%)	
Female	16 (41.0)
Male	14 (35.9)
Other gender identity / Not disclosed	9 (23.1)
Non-verbal IQ, M (SD, range)	119.8 (10.4, 101 – 145)
Highest Education, N (%)	
Less than an undergraduate degree	12 (30.8)
Undergraduate degree or higher	26 (66.7)
Country of birth, N (%)	
UK	19 (48.7)
Non-UK, English-speaking [a]	5 (12.8)
Europe, non-English speaking [b]	9 (23.1)
Non-Europe, non-English speaking [c]	5 (12.8)
Non-UK-born UK-residents, N (%)	19 (48.7)
Age of arrival in the UK, M (SD, range)	21.4 (11.1, 2 – 38)

Note: Summary table of the autistic participants' demographic characteristics. One data point was missing for the "Highest Education" question.
a = Canada (1), India (1), New Zealand (1), South Africa (1), USA (1).
b = France (2), Germany (3), Norway (3), Ukraine (1).
c = Argentina (1), China (1), Macau (1), Russia (1), South Korea (1)

Table 4.3 - Autistic participants' language characteristics (n = 39)

a. Number of languages			**b. Age of acquisition and proficiency**		
	R, n (%)	P4, n (%)	Languages (N)	Age in years, M (SD, range)	Proficiency, M (SD, range)
1 lang.	0 (0.0)	6 (15.4)	L1 (39)	0 (0, 0 – 0)	7.2 (1.4, 2.8 – 8)
2 lang.	9 (23.1)	20 (51.3)	L2 (39)	7.5 (9.7, 0 – 58)	5.8 (2.1, 0 – 8)
3 lang.	15 (38.5)	10 (25.6)	L3 (30)	13.1 (8.4, 0 – 36)	3.7 (2.2, 0.3 – 8)
4 lang.	5 (12.8)	2 (5.1)	L4 (15)	13.4 (7.3, 0 – 24)	3.3 (2.4, 0 – 7)
5 lang.	5 (12.8)	0 (0.0)	L5 (10)	22.8 (9.8, 5 – 38)	2.0 (1.7, 0.5 – 6)
6 lang.	3 (7.7)	0 (0.0)	L6 (5)	23.2 (11.8, 12 – 43)	2.7 (1.6, 1 – 4.8)
7+ lang.	2 (5.1)	1 (2.6)	L7 (2)	27 (8.5, 21 – 33)	3.3 (1.4, 2.3 – 4.3)

c. Age of acquisition – Age groups distribution, n (%)						
Language (N)	Birth (age = 0)	Early childhood (age = 1 – 5)	Late childhood (age = 6 – 10)	Adolescence (age = 11 – 17)	Early adulthood (age = 18 – 30)	Adulthood (age > 30)
L1 (39)	(100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
L2 (39)	5 (12.8)	12 (30.8)	13 (33.3)	8 (20.5)	0 (0.0)	1 (2.6)
L3 (30)	2 (6.7)	3 (10.0)	5 (16.7)	14 (46.7)	5 (16.7)	1 (3.3)
L4 (15)	1 (6.7)	2 (13.3)	1 (6.7)	5 (33.3)	6 (40.0)	0 (0.0)
L5 (10)	0 (0.0)	1 (10.0)	0 (0.0)	2 (20.0)	5 (50.0)	2 (20.0)
L6 (5)	0 (0.0)	0 (0.0)	0 (0.0)	1 (20.0)	3 (60.0)	1 (20.0)
L7 (2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (50.0)	1 (50.0)

Note. Summary table of the autistic participants' language characteristics. Some percentages do not sum up to 100% due to cumulative rounding effects. Reported sample sizes (N) reflect the number of respondents who provided useable age of acquisition data (in years).
a. Number of languages: Number and proportion of respondents who reported (R) or were proficient (i.e. with an average self-rated proficiency equal or above 4, where 4 = "Adequate") (P4) in 1, 2, 3, 4, 5, 6, or 7 or more languages (lang.).
b. Age of acquisition and proficiency: Age of acquisition (Age) and proficiency reported by the respondents in languages (L) 1 to 7.
c. Age of acquisition – Age groups distribution: Number and proportion of respondents who acquired their languages (L) 1 to 7 at birth, during early childhood, late childhood, adolescence, early adulthood and late adulthood.

Table 4.4 - Autistic participants' acquisition and current contexts of use.

Lang.	a. Acquisition context, N (%)				b. Current context, N (%)			
	Home	School	Com.	Indep.	Home	School / Work	Com.	Indep.
L1 (39)	38 (97.4)	1 (2.6)	0 (0.0)	0 (0.0)	35 (89.7)	1 (2.6)	2 (5.1)	1 (2.6)
L2 (39)	11 (28.2)	11 (28.2)	6 (15.4)	11 (28.2)	19 (48.7)	8 (20.5)	2 (5.1)	10 (25.6)
L3 (30)	4 (13.8)	6 (20.7)	1 (3.4)	18 (62.1)	6 (20.0)	6 (20.0)	2 (6.7)	16 (53.3)
L4 (15)	4 (28.6)	0 (0.0)	1 (7.1)	9 (64.3)	1 (6.7)	1 (6.7)	7 (46.7)	6 (40.0)
L5 (10)	1 (10.0)	0 (0.0)	1 (10.0)	8 (80.0)	2 (20.0)	1 (10.0)	1 (10.0)	6 (60.0)
L6 (5)	1 (20.0)	1 (20.0)	0 (0.0)	3 (60.0)	3 (60.0)	0 (0.0)	0 (0.0)	2 (40.0)
L7 (2)	0 (0.0)	1 (50.0)	0 (0.0)	1 (50.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (100.0)

Note. Summary table of the autistic participants' context of acquisition and current use for each of their languages. Some percentages do not sum up to 100% due to cumulative rounding effects.
a. Acquisition context: Number and proportion of respondents who acquired their languages (L) 1 to 7 mostly at home, at school, in the community (Com.), or independently (Indep.), and total number (Tot.) of respondents who indicated a context of acquisition for the language.
b. Current context: Number and proportion of respondents who use their languages (L) 1 to 7 mostly at home, at school or at work (S/W), in the community (Com.), or independently (Indep.), and total number (Tot.) of respondents who indicated a current context of use for the language.

B. Visual perspective-taking, level 1

Full details of the task methodology and data pre-processing are given in Chapter 3 section II.B.2. Briefly, the level 1 visual perspective-taking (L1VPT) task included 4 conditions in a 2 x 2 design: Perspective (Avatar, Self) x Consistency (Consistent, Inconsistent). Each condition comprised 48 trials and the analysis focused on the response time to these trials. For each participant and each condition, the mean RT for correct trials was calculated and used in analysis (Table 4.5).

Table 4.5 - Mean response time per condition in the L1VPT task for autistic participants

	Avatar-Consistent	**Avatar-Inconsistent**	**Self-Consistent**	**Self-Inconsistent**
Number of participants	39	38	39	39
Mean (SD, range)	838.98 (178.67, 563.29 - 1243.47)	930.81 (191.88, 612.77 - 1290.19)	828.99 (166.08, 560.62 - 1203.29)	888.39 (194.11, 521.23 - 1224.57)
Normality of the distribution	W = 0.95, *p* = 0.071	W = 0.96, *p* = 0.12	W = 0.96, *p* = 0.23	W = 0.96, *p* = 0.15
Skewness	0.33	0.08	0.32	0.03

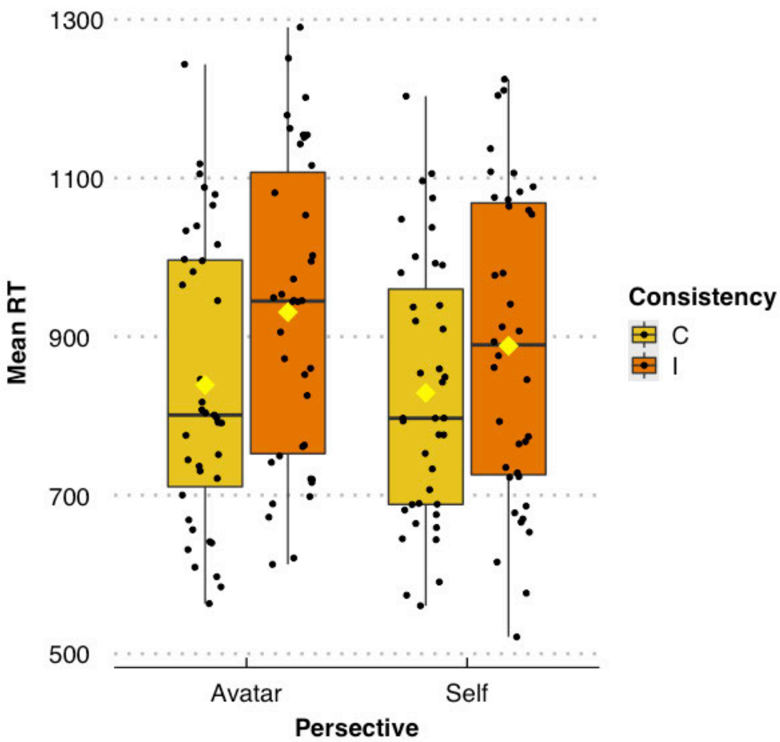
Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the 4 L1VPT conditions, in the autistic sample.

1. Effects of Perspective and Consistency on response time

Details of the data processing are reported in Chapter 3 section II.B.2 and Chapter 4 section II.B.1. Briefly, mean RT to each condition was compared using a 2x2 repeated measures ANOVA with Perspective (Avatar, Self) and Consistency (Consistent, Inconsistent) as within subject factors. To obtain a balanced design, the outlying participant excluded from the Avatar-Inconsistent condition was fully excluded from this analysis, which was carried out on the 38 remaining participants.

There was a main effect of Consistency with a large effect size ($F(1,37) = 93.56$, $p < 0.0001$, $\eta_p^2 = 0.72$; Consistent < Inconsistent), as well as a main effect of Perspective with a large effect size ($F(1,37) = 6.45$, $p = 0.015$, $\eta_p^2 = 0.15$; Self < Avatar). The interaction between Perspective and Consistency was significant (Figure 4.2) with a large effect size ($F(1,37) = 10.54$, $p = 0.0025$, $\eta_p^2 = 0.22$), further investigated using pairwise t-tests for repeated measures with Bonferroni correction: there was no significant difference between RT to Self and Avatar trials in the Consistent condition ($p = 1.00$), but in the Inconsistent condition mean RT were significantly higher in the Avatar trials compared to the Self trials ($p = 0.022$). Mean RT in Inconsistent trials were significantly higher than in Consistent trials, in both the Self ($p < 0.0001$) and Avatar ($p < 0.0001$) conditions.

Figure 4.2 - Mean response times in level 1 visual perspective-taking for autistic participants



Note. Box-plot diagram showing the mean response times (RT) in milliseconds (ms) in the autistic sample, in the four conditions of the level 1 visual perspective-taking task: Avatar (A), Self (S), Consistent (C), and Inconsistent (I).

2. *Bias scores*

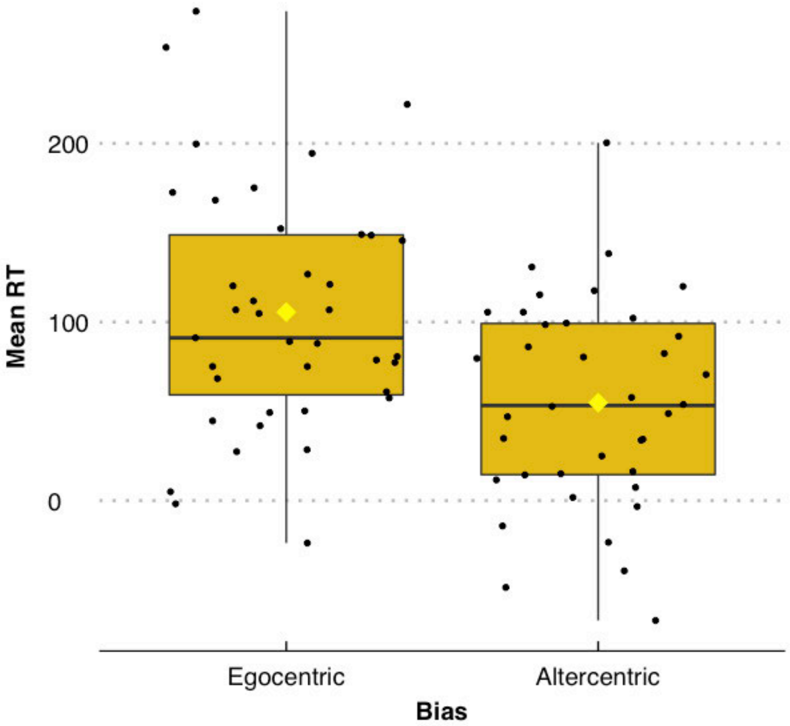
Having established a main effect of Consistency, bias scores were calculated in each Perspective condition, as the difference between the mean response times in the inconsistent and consistent conditions, as described in Chapter 4 section II.B.1. Normality and skewness of the distribution was assessed for each bias score (Table 4.6, Figure 4.3), and these scores were then used as outcome measures for the following regression models.

Table 4.6 - Mean response time per bias in the L1VPT task for autistic participants

	Egocentric bias	Altercentric bias
Number of participants	39	38
Mean (SD, range)	105.54 (68.3, -23.78 - 274.02)	54.8 (57.96, - 67.17 - 200.36)
Normality of the distribution	W = 0.98, *p* = 0.61	W = 0.99, *p* = 0.93
Skewness	0.47	0.03

Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the level 1 egocentric and altercentric bias, in the autistic sample.

Figure 4.3 - Level 1 egocentric and altercentric biases for autistic participants



Note. Box-plot and scatter-plot diagrams showing the mean response times (RT) in milliseconds in the two biases of the level 1 visual perspective-taking task. Each dot of the scatter-plot represents one participant, yellow lozenges represent the means of each condition.

3. *Regression models*

As described in Chapter 4 section II.C, first the optimal models obtained in the full sample of neurotypical bilinguals were applied to the sample of autistic participants for all the visual perspective-taking task and all the A-ToM-e outcome measures. Overall their performance was low, and a full account of these models is available in Appendix VI. Second, autism-specific models were created for each outcome measure using the method described in Chapter 3 section II.C.1. All the autism-specific models focusing on the visual perspective-taking task are presented in Table 4.7.

a. Egocentric bias

Autism-specific model

Model 1ERT_ASD (level 1, egocentric, response time, autistic sample) was applied to the full sample of autistic participants (n = 39) to investigate how specific features of the bilingual experience predicted the egocentric bias scores of autistic bi- or multilingual adults. Predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L3 age of acquisition; L3 proficiency; L3/L1 balance; Language switching.

The final model 1ERT_ASD included the following predictors: N language R-group, non-verbal IQ; TEA switching; and involved 34 participants (two participants had outlying or missing non-verbal IQ scores, one had outlying TEA switching, two had both outlying or missing non-verbal IQ and TEA switching). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Non-verbal IQ significantly predicted level 1 egocentric bias (β = -3.01, p = 0.0088), and so did TEA switching (β = 15.24, p = 0.0092). However, N language R-group did not (β = 48.77, p = 0.052). The results of the regression indicated that model 1ERT_ASD explained 24% of the variance and was a significant predictor of level 1 egocentric bias (R^2 = 0.31, R^2_{adj} = 0.24, F(3,30) = 4.44, p = 0.011), with a medium effect size f2 = 0.31. The post-hoc power was medium, at 73%.

b. Altercentric bias

Autism-specific model

Model 1ART_ASD (level 1, altercentric, response time, autistic sample) was applied to the full sample of autistic participants (n = 38) to investigate how specific features of the bilingual experience predicted the altercentric bias scores of autistic bi- or multilingual adults. Predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group;

L2 age of acquisition; L2 proficiency; L2/L1 balance; L3 age of acquisition; L3 proficiency; L3/L1 balance; Language switching.

The final model 1ART_ASD included only TEA attention as predictor; and involved 35 participants (three had missing or outlying TEA attention score). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA attention did not significantly predict level 1 altercentric bias (β = -33.96, *p* = 0.16), and the results of the regression indicated that model 1ART_ASD explained 3% of the variance and was not a significant predictor of level 1 altercentric bias (R^2 = 0.059, R^2_{adj} = 0.030, F(1,33) = 0.030, *p* = 0.16), with a small effect size f2 = 0.031. The post-hoc power was low, at 17%.

Table 4.7 - Regression models for level 1 and level 2 biases in the autistic sample

	1ERT_ASD					1ART_ASD					2ERT_ASD					2ART_ASD				
n, M (SD, range)	39, 105.54 (68.3, -23.78 – 274.02)					38, 54.8 (57.96, -67.17– 200.36)					37, 170.72 (98.47, -30.06 – 421.25)					39, 140.85 (79.51, -40.18 – 302.15)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
Int.	207.05	123.78	-45.75 – 459.84	1.67	0.105	282.83	162.92	-48.63 – 614.29	1.74	0.092	241.31	80.10	77.24 – 405.38	3.01	**0.005**	175.92	75.23	22.68 – 329.16	2.34	**0.026**
N lang. R-grp	48.77	24.06	-0.36 – 97.90	2.03	0.052															
nv IQ	-3.01	1.07	-5.21 – -0.82	-2.8	**0.009**															
TEA swi.	15.24	5.47	4.06 – 26.42	2.78	**0.009**											13.13	8.25	-3.68 – 29.94	1.59	0.121
TEA att.						-33.96	23.62	-82.02 – 14.10	-1.44	0.160										
L2 age											11.03	3.25	4.37 – 17.70	3.39	**0.002**					
TEA inh.											-15.20	8.47	-32.55 – 2.15	-1.79	0.084	-15.95	9.88	-36.07 – 4.18	-1.61	0.116
Obs.	34					35					31					35				
R^2 / R^2 adj.	0.31 / 0.24					0.059 / 0.030					0.34 / 0.30					0.092 / 0.035				
F	4.44					2.067					7.32					1.62				
p	**0.011**					0.16					**0.0028**					0.21				
f2	0.31					0.031					0.42					0.037				
pwr	73%					17%					87%					15%				

Note: Table summarising the regression models for visual perspective-taking scores. Coef. = coefficients. β = estimates of regression β coefficients. SE = standard errors. CI = confidence intervals at 95%. Stats. = t-statistics. p = p-value. Int. = intercept. N lang. R-grp = number of languages reported, by group. nv IQ = non-verbal IQ. L2 age = L2 age of acquisition. TEA att. = TEA attention. TEA inh. = TEA inhibition. TEA swi. = TEA switching. Obs. = observations. adj. = adjusted. F = F-statistic. f2 = effect size f2. pwr = post-hoc power. Number of participants (n) after removal of outliers in the outcome variable, means (M), standard deviation (SD) and range of the outcome variable are reported for the whole group. Observations (Obs.) indicate the number of participants with available data in the selected predictors.

C. Visual perspective-taking, level 2

Full details of the task methodology and data pre-processing are given in Chapter 3 section II.B.2. Briefly, the level 2 visual perspective-taking (L2VPT) task included 4 conditions in a 2 x 2 design: Perspective (Avatar, Self) x Consistency (Consistent, Inconsistent). Each condition comprised 48 trials and the analysis focused on response time to these trials. For each participant and each condition, the mean RT for correct trials was calculated and used in analysis (Table 4.8)

Table 4.8 - Mean response time per condition in the L2VPT task for autistic participants

	AC	**AI**	**SC**	**SI**
Number of participants	38	39	38	39
Mean (SD, range)	942.23 (177.06, 639.95 - 1306.09)	1105.45 (219.73, 739.38 - 1561.55)	859.34 (149.16, 582.88 - 1155.89)	1012.92 (172.81, 676.14 - 1437.11)
Normality of the distribution	W = 0.97, p = 0.45	W = 0.97, p = 0.27	W = 0.96, p = 0.26	W = 0.98, p = 0.85
Skewness	0.05	0.28	0.30	0.14

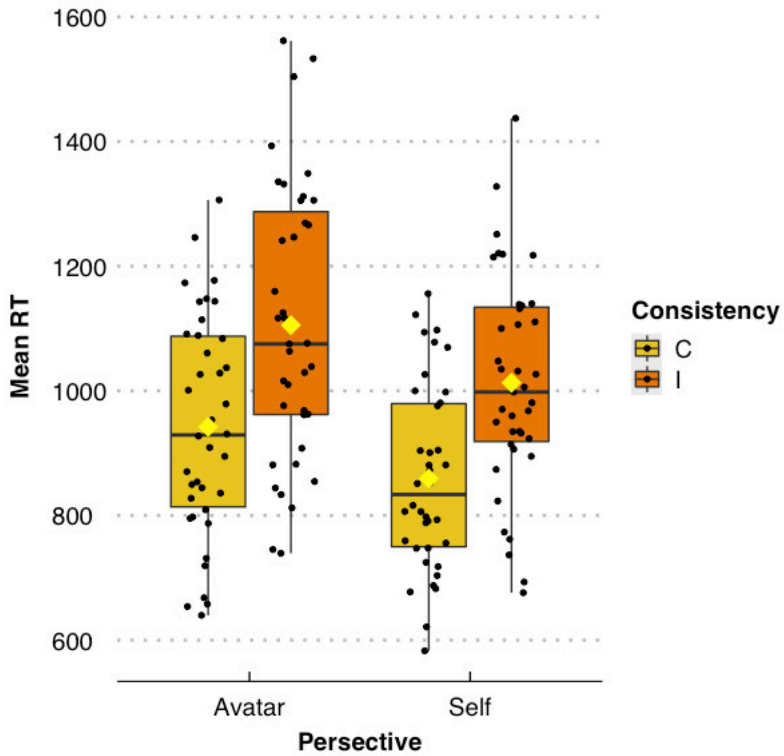
Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the 4 L2VPT conditions, in the autistic sample.

1. *Effect of Perspective and Consistency on response time*

As detailed in Chapter 3 section II.B.2 and Chapter 4 section II.B.1, the first step of the visual perspective-taking data analysis aimed at verifying the existence of the egocentric and altercentric biases described by Surtees, Samson & Apperly (2016). Mean response times between conditions were compared using a 2x2 repeated measures ANOVA with Perspective (Avatar, Self) and Consistency (Consistent, Inconsistent) as within-subject factors, with a balanced sample of 38 participants (Figure 4.4).

There was a main effect of Consistency with a large effect size ($F(1, 37) = 98.92$, $p < 0.0001$, ηp2 = 0.73; Consistent < Inconsistent), as well as a main effect of Perspective with a large effect size ($F(1, 37) = 44.35$, $p < 0.0001$, $\eta_p^2 = 0.55$; Self < Avatar). The interaction between Perspective and Consistency was not significant ($F(1, 37) = 0.162$, $p = 0.689$).

Figure 4.4 - Mean response times in level 2 visual perspective-taking for autistic participants



Note. Box-plot and scatter-plot diagrams showing the mean response times (RT) in milliseconds in the four conditions of the level 2 visual perspective-taking task. Each dot of the scatter-plot represents one participant, yellow lozenges represent the means of each condition.

2. *Bias scores*

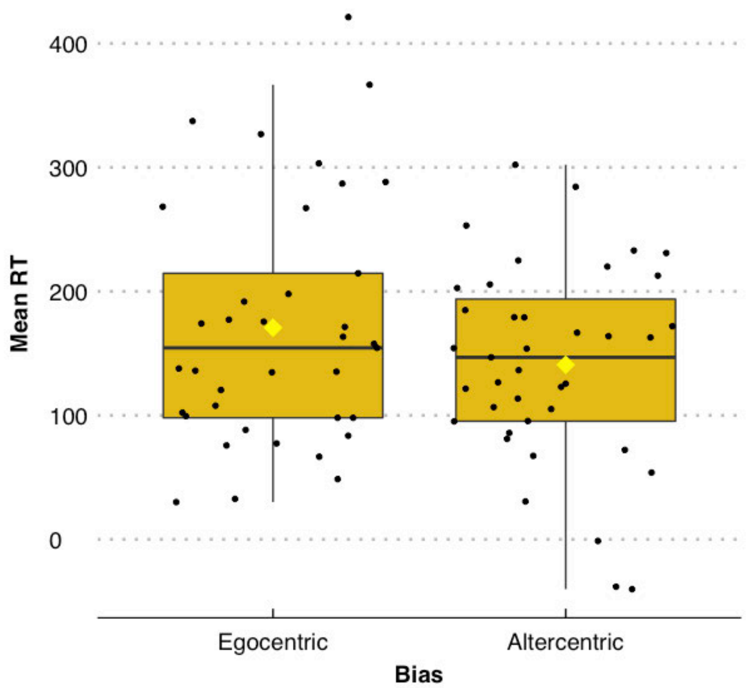
Having established a main effect of Consistency, bias scores were calculated within each Perspective condition, as the difference between the inconsistent mean RT and consistent mean RT. Higher RT in Inconsistent trials compared to Consistent trials produced a positive bias index. The altercentric bias was derived from response times in the Self condition, while the egocentric bias was derived from responses times in the Avatar condition. These bias scores (Table 4.9, Figure 4.5) were used as outcome measures in the multiple regression analysis.

Table 4.9 - Mean response time per bias in the L2VPT task for autistic participants

	Egocentric bias	Altercentric bias
Number of participants	37	39
Mean (SD, range)	170.72 (98.47, 30.06 – 421.25)	140.85 (79.51, -40.18 - 302.15)
Normality	W = 0.93, *p* = 0.027	W = 0.98, *p* = 0.83
Skewness	0.73	-0.29

Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the response time in the level 2 egocentric and altercentric bias, in the autistic sample.

Figure 4.5 - Level 2 egocentric and altercentric biases for autistic participants



Note. Box-plot and scatter-plot diagrams showing the mean response times (RT) in milliseconds in the two biases of the level 2 visual perspective-taking task. Each dot of the scatter-plot represents one participant, yellow lozenges represent the means of each condition.

3. *Regression models*

All the autism-specific models focusing on the visual perspective-taking task are presented in Table 4.7.

a. Egocentric bias

Autism-specific model

Model 2ERT_ASD (level 2, egocentric, response time, autistic sample) was applied to the full sample of autistic participants (n = 39) to investigate how specific features of the bilingual experience predicted the level 2 egocentric bias scores of autistic bi- or multilingual adults. Predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L3 age of acquisition; L3 proficiency; L3/L1 balance; Language switching.

The final model 2ERT_ASD included the following predictors: L2 age of acquisition; TEA inhibition; and involved 33 participants (one participant had outlying L2 age of acquisition, two participants had outlying or missing TEA attention score). Upon analysis of the regression assumptions, two data points were identified as highly influential values further than Cook's distance, and these points were excluded from the model, and the model then involved 31 participants. Following this, the data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. L2 age of acquisition significantly predicted level 2 egocentric bias (β = 11.03, p = 0.002), but after removal of the influential values, TEA inhibition did not (β = -15.20, p = 0.084). The results of the regression indicated that model 2ERT_ASD explained 30% of the variance and was a significant predictor of level 2 egocentric bias (R^2 = 0.34, R^2_{adj} = 0.30, F(2,28) = 7.32, p = 0.0028), with a large effect size f2 = 0.42. The post-hoc power was medium, at 87%.

b. Altercentric bias

Autism-specific model

Model 2ART_ASD (level 2, altercentric, response time, autistic sample) was applied to the full sample of autistic participants (n = 39) to assess how features of the bilingual experience predicted the level 2 altercentric bias scores of autistic participants. Relevant predictors were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance; L3 age of acquisition; L3 proficiency; L3/L1 balance; Language switching.

The final model 2ART_ASD included the following predictors: TEA inhibition; TEA switching; and involved 35 participants (one participant had TEA inhibition score, one participant had TEA switching score, two participants had missing both TEA inhibition and three scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Neither TEA inhibition (β = -15.95, *p* = 0.12) nor TEA switching (β = 13.13, *p* = 0.12) significantly predicted level 2 altercentric bias. The results of the regression indicated that model 2ART_ASD explained 4% of the variance and was not a significant predictor of level 2 altercentric bias ($R^2 = 0.092$, $R^2_{adj} = 0.035$, $F(2,32) = 1.62$, $p = 0.21$), with a small effect size f2 = 0.037. The post-hoc power was low, at 15%.

D. Cognitive perspective-taking, level 1 and level 2

Full details of the A-ToM-e task methodology and data pre-processing are given in Chapter 3 section II.B.3. The final scores used in the following analysis are reported in Table 4.10, Figure 4.6, and Figure 4.7.

1. Reliability of the A-ToM-e

Internal consistency was tested across all videos for each outcome variable to assess whether all video items measured the same core process. Internal consistency was mostly unacceptable to poor, except for the overall social score which was acceptable (α = 0.76). For the general score and both overall cognitive and affective scores internal consistency was poor (α = 0.54, α = 0.56, and α = 0.57, respectively). However, these overall social and overall affective scores were both obtained by excluding one level 1 affective question (from the "Crying man – sarcasm" video), and one level 2 affective question (from the "Bunnies - persuasion" video), as including these items led to a standard deviation of 0 in the correlation analysis required for the calculation of Cronbach's Alpha, and made the calculation impossible. Level sub-scores showed an even lower internal consistency, ranging from α = 0.47 (level 1 affective) to α = 0.48 (level 2 cognitive), with the exception of level 1 cognitive scoring particularly low (α = 0.29). The control physical score also showed unacceptable internal consistency, with α = 0.39.

In the cognitive modality, excluding one low-scoring video (Spaghetti – sarcasm) from level 1 and overall scores increased α to 0.45 and 0.60 respectively, and excluding a different low-scoring video (Bunnies – persuasion) from level 2 scores increased α to 0.51. For the affective modality, excluding one low-scoring video (Burglar – misunderstanding) from level 1 scores increased α to 0.55, and excluding a high-scoring video (Crying man –

sarcasm) from level 2 scores increased α to 0.52. Finally, regarding the original general score, eliminating one low-scoring item (Spaghetti, sarcasm) increased α to 0.55. Overall, no single video systematically lowered the internal consistency score, and elimination of one or two videos did not increase α to an acceptable range.

Inter-rater agreement for the full dataset, calculated across both the participants groups involved in the current study and the study reported in Chapter 3, was calculated for 37 participants (27% of the total sample), and is available in Appendix III.3. This subsample included 5 autistic participants (13% of the autistic sample). Inter-rater agreement was also calculated for each sub-score in this specific population. Overall, inter-rater agreement ranged from 87% to 93% across all outcome measures. Across all scores and videos, the lowest inter-rater agreement score was 60% (agreement on three out of five responses), and occurred twice: in the level 2 cognitive score (Burglar – misunderstanding), and level 1 affective score (Bunnies – persuasion).

As no video was consistently identified as lowering the internal consistency or inter-rater agreement of the sub-scores, they were all maintained in the final outcome measures.

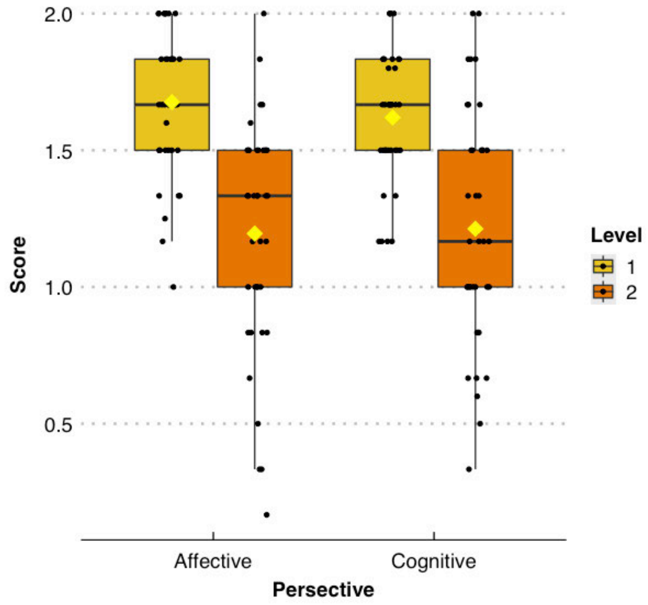
Table 4.10 - Scores of the A-ToM-e task for autistic participants

	L1C	**L2C**	**L1A**	**L2A**	
Number of participants	37	39	37	38	
Mean (SD, range)	1.62 (0.24, 1.17 - 2)	1.21 (0.43, 0.33 - 2)	1.68 (0.26, 1 - 2)	1.2 (0.42, 0.17 - 2)	
Normality of the distribution	W = 0.93, *p* = 0.021	W = 0.97, *p* = 0.43	W= 0.92, *p* = 0.014	W = 0.94, *p* = 0.055	
Skewness	-0.29	0.04	-0.55	-0.61	

	C	**A**	**G**	**S**	**P**
Number of participants	39	38	39	38	39
Mean (SD, range)	1.40 (0.29, 0.75 - 2)	1.42 (0.29, 0.67 - 2)	1.49 (0.37, 0.67 - 2)	1.43 (0.24, 0.93 - 1.87)	1.32 (0.40, 0.67 - 2)
Normality of the distribution	W = 0.97, *p* = 0.49	W = 0.90, *p* = 0.0033	W = 0.89, *p* = 0.0011	W = 0.96, *p* = 0.16	W = 0.93, *p* = 0.022
Skewness	-0.23	-0.88	-0.73	-0.46	-0.22

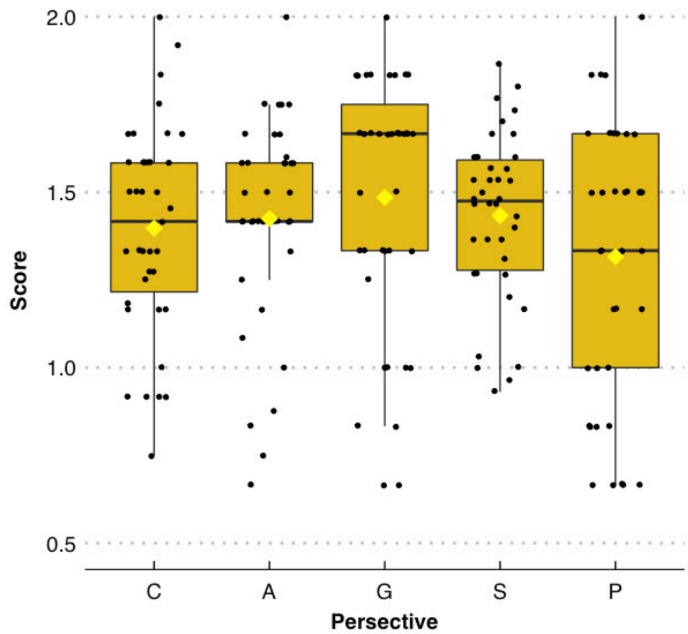
Note. Table summarising the total number of participants, mean, standard deviation (SD), minimum and maximum values (range), normality of the distribution and skewness of the outcome measures of the A-ToM-e task in the autistic sample. These outcome measures are level 1 (L1) and level 2 (L2) cognitive (C) and affective (A) perspective-taking, general (G) perspective-taking, overall social (S) score, and control physical score (P).

Figure 4.6 - Level 1 and level 2 cognitive and affective perspective-taking scores for autistic participants



Note. Box-plot diagram showing the level 1 and level 2 cognitive (C) and affective (A) perspective-taking scores in the autistic sample, without outliers.

Figure 4.7 - Cognitive, affective, general, and overall social perspective-taking scores and control physical scores for autistic participants



Note. Box-plot diagram showing the control physical (P) scores, cognitive (C), affective (A), general (G), and overall social (S) perspective-taking scores in the autistic sample, without outliers.

2. Regression models

The regression models were built following the same method as above (see Chapter 3 section II.C.1). All the models are presented in Table 4.11.

a. Level 1 cognitive perspective-taking

Autism-specific model

Model 1C_ASD (level 1, cognitive, autistic sample) was applied to the full sample of autistic participants (n = 37) to investigate how specific features of the bilingual experience predicted the level 1 cognitive scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model 1C_ASD included only age as predictor, and involved all 37 participants. The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Age significantly predicted L1C (β = 0.0078, p = 0.015). The results of the regression indicated that model 1C_ASD explained 13% of the variance and was a significant predictor of L1C ($R^2 = 0.16$, $R^2_{adj} = 0.13$, $F(1,35) = 6.53$, $p = 0.015$), with a medium effect size (f2 = 0.15), and the post-hoc power was medium, at 64%.

b. Level 2 cognitive perspective-taking

Autism-specific model

Model 2C_ASD (level 2, cognitive, autistic sample) was applied to the full sample of autistic participants (n = 39) to investigate how specific features of the bilingual experience predicted the level 2 cognitive scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model 2C_ASD included the following predictors: age, and L2 age of acquisition; and involved 38 participants (one participant had outlying L2 age of acquisition). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Both age (β = -0.013, p = 0.013) and L2 age of acquisition (β = -

0.033, *p* = 0.021) significantly predicted L2C. The results of the regression indicated that model 2C_ASD explained 24% of the variance and was a significant predictor of L2C (R^2 = 0.28, R^2_{adj} = 0.24, F(2,35) = 6.88, *p* = 0.0030), with a medium effect size (f2 = 0.32), and the post-hoc power was high, at 86%.

c. Overall cognitive perspective-taking

Autism-specific model

Model C_ASD (cognitive, autistic sample) was applied to the full sample of autistic participants (n = 39) to investigate how specific features of the bilingual experience predicted the overall cognitive scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model C_ASD included the following predictors: L2 age of acquisition; non-verbal IQ; and involved 34 participants (one participant had outlying L2 age of acquisition, four participants had missing or outlying non-verbal IQ). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. L2 age of acquisition significantly predicted C scores (β = -0.029, *p* = 0.010), but non-verbal IQ did not (β = 0.0030, *p* = 0.50). The results of the regression indicated that model C_ASD explained 17% of the variance and was a significant predictor of C scores (R^2 = 0.22, R^2_{adj} = 0.17, F(2,31) = 4.26, *p* = 0.023), with a medium effect size (f2 = 0.20), and the post-hoc power was medium, at 59%.

E. Affective perspective-taking, level 1 and level 2

1. Summary

Full details of the A-ToM-e task methodology and data pre-processing are given in Chapter 3 section II.B.3. The final scores used in the following analysis are reported in Table 4.10, Figure 4.6, and Figure 4.7.

2. *Regression models*

The regression models were built following the same method as above (see Chapter 3 section II.C.1). All the models are presented in Table 4.11.

a. Level 1 affective perspective-taking

Autism-specific model

Model 1A_ASD (level 1, affective, autistic sample) was applied to the full sample of autistic participants (n = 37) to investigate how specific features of the bilingual experience predicted the level 1 affective scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model 1A_ASD included the following predictors: L2 age of acquisition; and non-verbal IQ; and involved 32 participants (one participant had outlying L2 age of acquisition, four participants had outlying or missing non-verbal IQ). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. L2 age of acquisition significantly predicted L1A (β = -0.022, p = 0.023), but non-verbal IQ (β = 0.0029, p = 0.44) did not. The results of the regression indicated that model 1A_ASD explained 14% of the variance and was a significant predictor of L1A (R^2 = 0.20, R^2_{adj} = 0.14, $F(2,29)$ = 3.60, p = 0.040), with a medium effect size (f2 = 0.17), and the post-hoc power was low, at 49%.

b. Level 2 affective perspective-taking

Autism-specific model

Model 2A_ASD (level 2, affective, autistic sample) was applied to the full sample of autistic participants (n = 39) to investigate how specific features of the bilingual experience predicted the level 2 affective scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model 2A_ASD only included N language P-group as predictor, and involved 38 participants. The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. N language P-group significantly predicted L2A (β = -0.27016, *p* = 0.0067). The results of the regression indicated that model 2A_ASD explained 16% of the variance and was a significant predictor of L2A (R^2 = 0.19, R^2_{adj} = 0.16, F(1,36) = 8.28, *p* = 0.0067), with a medium effect size (f2 = 0.20), and the post-hoc power was medium, at 76%.

c. *Overall affective perspective-taking*

Autism-specific model

Model A_ASD (affective, autistic sample) was applied to the full sample of autistic participants (n = 38) to investigate how specific features of the bilingual experience predicted the overall affective scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model A_ASD only included the following TEA total as predictor; and involved 36 participants (two participants had outlying TEA total scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA total significantly predicted A scores (β = 0.025, *p* = 0.022). The results of the regression indicated that model A_ASD explained 12% of the variance and was a significant predictor of A scores (R^2 = 0.15, R^2_{adj} = 0.12, F(1,34) = 5.8, *p* = 0.022), with a medium effect size (f2 = 0.14), and the post-hoc power was medium, at 58%.

Table 4.11 - Regression models for cognitive and affective perspective-taking (level 1 and level 2) for autistic participants

	a. Cognitive perspective-taking														
	1C_ASD					**2C_ASD**					**C_ASD**				
n, M (SD, range)	37, 1.62 (0.24, 1.17 - 2)					39, 1.21 (0.43, 0.33- 2)					39, 1.4 (0.29, 0.75 - 2)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
Int.	1.36	0.11	1.14 – 1.58	12.55	**<0.001**	1.84	0.19	1.45 – 2.23	9.64	**<0.001**	1.21	0.55	0.09 – 2.32	2.2	**0.035**
Age	0.01	0	0.00 – 0.01	2.56	**0.015**	-0.01	0	-0.02 – -0.00	-2.62	**0.013**					
L2 age						-0.03	0.01	-0.06 – -0.01	-2.43	**0.021**	-0.03	0.01	-0.05 – -0.01	-2.73	**0.01**
nv IQ											0	0	-0.01 – 0.01	0.68	0.501
Obs	37					38					34				
R^2 / R^2adj	0.16 / 0.13					0.28 / 0.24					0.22 / 0.17				
F	6.53					6.88					4.26				
p	**0.015**					**0.0030**					**0.023**				
f2	0.15					0.32					0.20				
pwr	64%					86%					59%				

	b. Affective perspective-taking														
	1A_ASD					2A_ASD					A_ASD				
n, M (SD, range)	37, 1.68 (0.26, 1 - 2)					38, 1.2 (0.42, 0.17 - 2)					38, 1.42 (0.29, 0.67 - 2)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
Int.	1.50	0.46	0.55 – 2.45	3.23	**0.003**	1.78	0.21	1.35 – 2.21	8.38	**<0.001**	0.85	0.25	0.35 – 1.35	3.44	**0.002**
TEA att.	0.11	0.06	-0.01 – 0.23	1.85	0.075										
L2 age	-0.02	0.01	-0.04 – -0.00	-2.41	**0.023**										
nv IQ	0.00	0.00	-0.00 – 0.01	0.78	0.443										
N lang P-grp						-0.27	0.09	-0.46 – -0.08	-2.88	**0.007**					
TEA tot.											0.03	0.01	0.00 – 0.05	2.41	**0.022**
Obs	32					38					36				
R^2 / R^2adj	0.20 / 0.14					0.19 / 0.16					0.15 / 0.12				
F	3.60					8.28					5.8				
p	**0.040**					**0.0067**					**0.022**				
f2	0.17					0.20					0.14				
pwr	49%					76%					58%				

Note: Table summarising the regression models for cognitive (a) and affective (b) perspective-taking scores. Coef. = coefficients. *β* = estimates of regression β coefficients. SE = standard errors. CI = confidence intervals at 95%. Stats. = t-statistics. *p* = *p*-value. Int. = intercept. L2 age = L2 age of acquisition. nv IQ = non-verbal IQ. TEA att. = TEA attention. N lang. P-grp = number of languages known with a high proficiency, by group. TEA tot. = TEA total score. Obs. = observations. adj. = adjusted. F = F-statistic. f2 = effect size f2. pwr = post-hoc power. Number of participants (n) after removal of outliers in the outcome variable, means (M), standard deviation (SD) and range of the outcome variable are reported for the whole group. Observations (Obs.) indicate the number of participants with available data in the selected predictors.

F. Overall social perspective-taking

1. *Summary*

Full details of the A-ToM-e task methodology and data pre-processing are given in Chapter 3 section II.B.3. The final scores used in the following analysis are reported in Table 4.10, Figure 4.6, and Figure 4.7.

2. *Regression models*

The regression models were built following the same method as above (see Chapter 3 section II.C.1). Models are presented in Table 4.12.

a. General perspective-taking

Autism-specific model

Model G_ASD (general, autistic sample) was applied to the full sample of autistic participants (n = 39) to investigate how specific features of the bilingual experience predicted the overall general scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model G_ASD included the following predictors: N language R-group; L2 age of acquisition; TEA attention; non-verbal IQ; and involved 33 participants (one participant had outlying L2 age of acquisition, two participants had missing non-verbal IQ, three participant had both outlying or missing TEA attention and non-verbal IQ). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. All the predictors significantly predicted G scores (N language R-group: β = -0.31, p = 0.037; L2 age of acquisition: β = -0.029, p = 0.034; TEA attention: β = 0.28, p = 0.049; non-verbal IQ: β = 0.015, p = 0.0064). The results of the regression indicated that model G_ASD explained 28% of the variance and was a significant predictor of G scores (R^2 = 0.37, R^2_{adj} = 0.28, $F(4,28)$ = 4.09, p = 0.0099), with a large effect size (f2 = 0.39), and the post-hoc power was medium, at 75%.

b. *Overall social perspective-taking*

Autism-specific model

Model S_ASD (social, autistic sample) was applied to the full sample of autistic participants (n = 38) to investigate how specific features of the bilingual experience predicted the overall social scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model S_ASD included the following predictors: L2 age of acquisition; TEA switching; non-verbal IQ; and involved 32 participants. The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA switching significantly predicted S scores (β = 0.045, p = 0.033). However, L2 age of acquisition (β = -0.014, p = 0.097) and non-verbal IQ (β = 0.0022, p = 0.58) did not. The results of the regression indicated that model S_ASD explained 21% of the variance and was a significant predictor of S scores (R^2 = 0.28, R^2_{adj} = 0.21, F(3,28) = 3.67, p = 0.024), with a medium effect size (f2 = 0.26), and the post-hoc power was medium, at 60%.

G. Control items

1. *Summary*

Full details of the A-ToM-e task methodology and data pre-processing are given in Chapter 3 section II.B.3. The final scores used in the following analysis are reported in Table 4.10, Figure 4.6, and Figure 4.7.

2. *Regression models*

The regression model was built following the same method as above (see Chapter 3 section II.C.1). The model is presented in Table 4.12.

Autism-specific model

Model P_ASD (physical, autistic sample) was applied to the full sample of autistic participants (n = 39) to investigate how specific features of the bilingual experience predicted the overall physical scores of autistic bi- or multilingual adults. Relevant predictors available for these participants were entered: respondent age; non-verbal IQ; TEA scores (attention, inhibition, switching, and total); N language R-group; N language P-group; L2 age of acquisition; L2 proficiency; L2/L1 balance.

The final model P_ASD included only non-verbal IQ as predictor, and involved 35 participants. Upon analysis of the regression assumptions, it was observed that the model did not meet the assumption of linearity, which was addressed by applying a non-linear (logarithmic) transformation to the predictor. The data met the assumptions of homogeneity and the residuals were appropriately distributed. Non-verbal IQ significantly predicted P scores (β = 1.81, *p* = 0.019). The results of the regression indicated that model P_ASD explained 13% of the variance and was a significant predictor of P scores ($R^2 = 0.16$, $R^2_{adj} = 0.13$, F(1,33) = 6.06, *p* = 0.019), with a medium effect size (f2 = 0.15), and the post-hoc power was medium, at 60%.

H. Correlation between perspective-taking modalities

A correlation analysis using Pearson's correlation coefficient was used between the bias scores, the cognitive sub-score, and the affective sub-score (Figure 4.8).

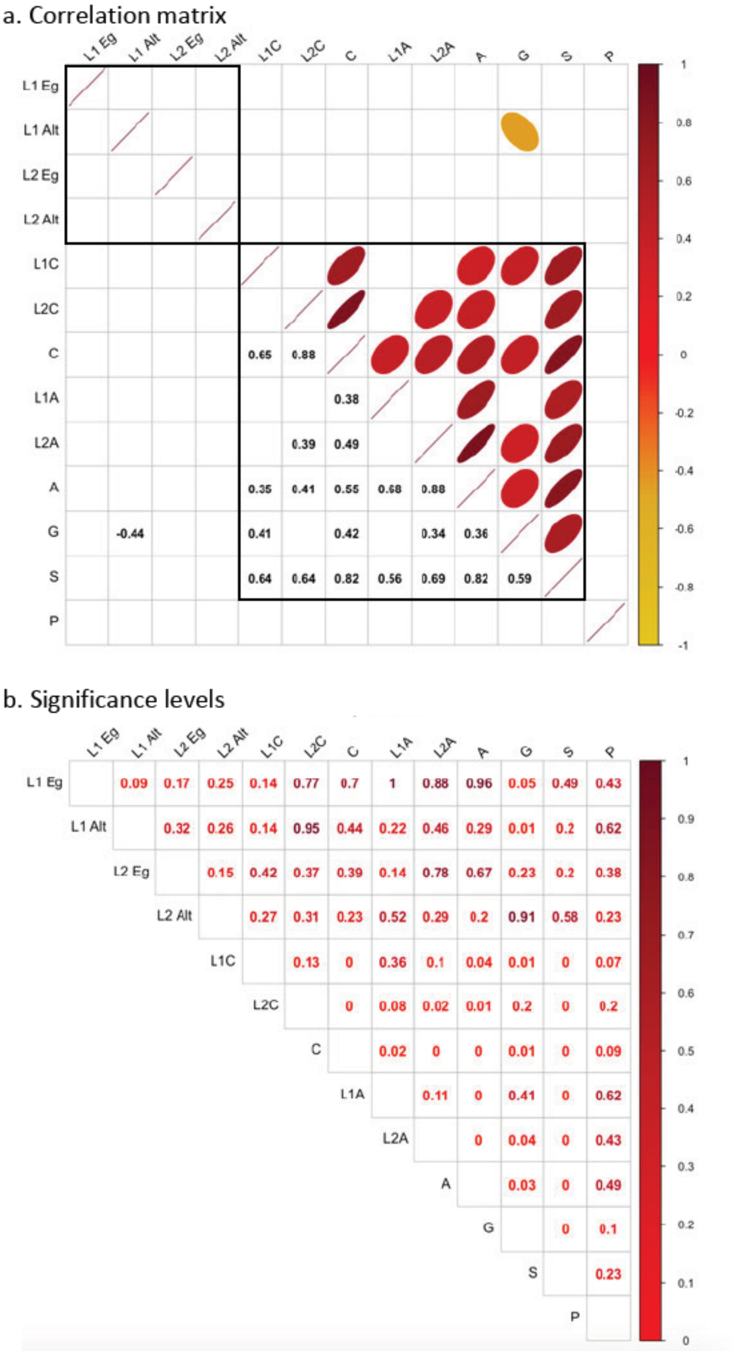
As described in Chapter 3 section II.C.2, a correlation analysis using Pearson's correlation coefficient was used between the bias scores, the cognitive sub-score, and the affective sub-score. The level 1 and level 2 egocentric biases and the level 2 altercentric bias were not significantly correlated with any other outcome variable, whether visual, cognitive, or affective. However, level 1 altercentric bias was significantly correlated with the general score (*p* = 0.0054, *r* = -0.44), and the negative correlation was moderate. However, the overall cognitive and affective scores were significantly correlated with each other, with a moderate strength (*p* = 0.00040, *r* = 0.55).

	G_ASD					S_ASD					P_ASD				
n, M (SD, range)	39, 1.49 (0.37, 0.67 - 2)					38, 1.43 (0.24, 0.93 - 1.87)					39 1.32 (0.4, 0.67 - 2)				
Coef.	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*	β	SE	CI	Stat.	*p*
Int.	-1.27	1.18	-3.69 – 1.15	-1.08	0.291	0.89	0.44	-0.00 – 1.79	2.04	0.051	-7.35	3.52	-14.50 – -0.20	-2.09	**0.044**
TEA att.	0.28	0.13	0.00 – 0.55	2.06	**0.049**										
L2 age	-0.03	0.01	-0.06 – -0.00	-2.23	**0.034**	-0.01	0.01	-0.03 – 0.00	-1.72	0.097					
nv IQ	0.02	0.01	0.00 – 0.03	2.95	**0.006**	0	0	-0.01 – 0.01	0.56	0.58	1.81	0.74	0.31 – 3.30	2.46	**0.019**
N lang R-group	-0.31	0.14	-0.59 – -0.02	-2.19	**0.037**										
TEA swi.						0.04	0.02	0.00 – 0.09	2.25	**0.033**					
Obs	33					32					35				
R^2 / R^2adj	0.37 / 0.28					0.28 / 0.21					0.16 / 0.13				
F	4.086					3.67					6.06				
p	**0.0099**					**0.024**					**0.019**				
f2	0.39					0.26					0.15				
pwr	75%					60%					60%				

Table 4.12 - Regression models for general perspective-taking, overall social perspective-taking, and Control scores for autistic participants

Note: Table summarising the regression models for general perspective-taking, social perspective-taking, and Control physical scores. In model P_ASD the predictor was adjusted with a non-linear transformation. Coef. = coefficients. β = estimates of regression β coefficients. SE = standard errors. CI = confidence intervals at 95%. Stats. = t-statistics. *p* = *p*-value. Int. = intercept. TEA att. = TEA attention. L2 age = L2 age of acquisition. nv IQ = non-verbal IQ. N lang. R-grp = number of languages reported, by group. TEA swi. = TEA switching. Obs. = observations. adj. = adjusted. F = F-statistic. f2 = effect size f2. pwr = post-hoc power. Number of participants (n) after removal of outliers in the outcome variable, means (M), standard deviation (SD) and range of the outcome variable are reported for the whole group. Observations (Obs.) indicate the number of participants with available data in the selected predictors.

Figure 4.8 - Correlation between perspective-taking outcome measures for autistic participants



Note. Correlation matrices between perspective-taking scores. L1 = level 1, L2 = level 2, Eg = egocentric, Alt = altercentric, C = cognitive, A = affective, G = general, S = social, P = physical.

a. Correlation matrix between all the perspective-taking and control (P) outcome measures. Pearson's correlation coefficient values r are reported numerically in the lower left corner and as ellipses in the upper right corner. Extreme r values are represented in dark blue narrow ellipses, while r values close to 0 are represented as white circles. Only the statistically significant correlation coefficients are reported. Black squares outline the visual perspective-taking scores and the cognitive and affective perspective-taking scores.

b. Significance levels of each Pearson's correlation test, with p-values close to 0 coloured from light blue and p-values close to 1 coloured from dark blue.

I. Results summary

This study included 39 neurotypical bilingual adults with a wide range of language profiles (Chapter 4 section II.A).

The Visual Perspective-Taking task results showed an effect of Consistency in both level 1 (Chapter 4 section III.B.1) and level 2 (Chapter 4 section III.C.1) processes, when the participants were asked to take either their own or the avatar's perspective, which allowed the creation of egocentric and altercentric biases (Chapter 4 section III.B.2 and Chapter 4 section III.C.2). The influence of different bilingualism variables upon these biases was investigated in the sample of autistic participants (Chapter 4 section III.B.3 and Chapter 4 section III.C.3) revealing that inhibition and attention switching were most influential on bias scores.

The validity of the new A-ToM-e task was verified (Chapter 4 section III.D.1), and the influence of the bilingualism variables on the different outcome measures of the A-ToM-e was investigated in the sample of autistic participants (Chapter 4 section III.D.3 to section III.G.2). The results of all the regression models on the sample of autistic participants are summarised in Table 4.13. These show that A-ToM-e scores are related to the age of acquisition of the second language and non-verbal IQ.

A correlation analysis was conducted to analyse the relationship between the three modalities of perspective-taking at the centre of this study, which reported no link between the visual and social modalities, but multiple significant correlations between variables from the cognitive and affective modalities (Chapter 4 section III.H).

Table 4.13 - Summary of the regression models in the sample of autistic participants

	Predictors	**L1Ego**	**L2Ego**	**L1Alter**	**L2Alter**	**L1C**	**L2C**	**C**	**L1A**	**L2A**	**A**	**G**	**S**	**P**
Bilingualism	N lang. R-grp	+										-		
	N lang. P-grp									-				
	L2 age		+				-	-	-			-	-	
	L2 pro.													
	L2/L1 bal..													
	L switch													
Controls	Age					+	-							
	nv IQ	-						+	+			+	+	+
	TEA att.			-					+			+		
	TEA inh.		-		-									
	TEA swi.	+			+								+	
	TEA tot.										+			
Indicators	R^2 adj.	24%	23%	3%	4%	13%	24%	17%	14%	16%	12%	28%	21%	13%
	p													
	f2	0.31	0.28	0.03	0.04	0.15	0.32	0.20	0.17	0.20	0.14	0.39	0.26	0.15
	pwr	73%	76%	17%	15%	64%	86%	59%	49%	76%	58%	75%	60%	60%

Note. Summary of the regression models applied to the sample of autistic participants. Each column represents an outcome measure and its associated final model, and each row represents a candidate predictor (grouped in bilingualism or control variables, the later in grey text), or a performance indicator of the models. For each outcome measure, predictors selected in the final model are coloured in yellow (selected but not significant) or green (selected and significant), and the direction of their relationship with the outcome variable are represented with a + (positive relationship) or a – (negative relationship) sign. The significance level of each model is coloured in yellow when $p > 0.05$, and green when $p \leq 0.05$. The observed power of each model was coloured in grey when < 50%, in blue when ≥ 50% and < 80%, and in green when ≥ 80%. For outcome measures: L1 = level 1; L2 = level 2; Ego = egocentric bias; Alter = altercentric bias; C = cognitive; A = affective; G = general; S = social; P = physical. For predictors: N lang. R-grp = number of languages reported, by group; N lang. P-grp = number of languages known with a high proficiency, by group; L2 age = age of acquisition of the second language; L2 pro. = second language proficiency; L2/L1 bal. = proficiency balance between the first and second languages; L switch = language switching score; nv IQ = non-verbal IQ; TEA att. = TEA attention; TEA inh. = TEA inhibition; TEA swi. = TEA switching. TEA tot. = TEA total score. For the model performance indicators: R^2 adj. = adjusted R^2; p = p-value; f2 = effect size f2; pwr = post-hoc power.

IV. Discussion

A. Bilingualism and perspective-taking in autism

1. Overall pattern of interaction

Building upon the findings that bilingualism impacted the social experiences of autistic adults (Chapter 2), the primary goal of this study was to investigate whether the positive influence of early bilingualism on social perspective-taking skills that seems to exist in neurotypical adults (Chapter 3) also occurs in autism. To do so, the innovative approach described in Chapter 3 was replicated, relying on a multidimensional definition of both bilingualism and perspective-taking. Importantly, the goal of this study was not to assess potential impairments in perspective-taking skills in autistic adults compared to their neurotypical peers, but to investigate how this particular social cognitive process was shaped by bilingualism in each specific population, when controlling for confounds.

The main findings of this study are that, just as in the neurotypical mind, in the autistic mind not all forms of perspective-taking have the potential to be influenced by the bilingual experience, and that not all bilingual experiences shape perspective-taking processes. The pattern in the autistic sample is not as striking as in the neurotypical sample, and the neurotypical models did not provide a good description of the data. Nonetheless, the results indeed showed again that cognitive and affective perspective-taking processes are susceptible to the positive influence of bilingualism, while visual perspective-taking is not, and that the main driver of this effect is the age of acquisition of the second language. In this sense, without making a direct statistical comparison, the results from this chapter and those from neurotypical data (Chapter 3) are strikingly similar.

Visual measures were predominantly predicted by executive skills, notably inhibition and switching skills, but there was no consistent pattern across bilingualism predictors. In contrast, the cognitive and affective perspective-taking measures were in majority linked with the age of acquisition of the second language and non-verbal IQ. Previous studies also reported the prominent role of IQ in cognitive perspective-taking, especially when measured with the Strange Stories Task, which inspired the development of the A-ToM-e used here (Adler et al. (2010), Dziobek et al. (2006), and see Hamilton et al. (2016) for a review) and overall social skills (Sasson et al., 2020), though the latter contradicts previous findings by Morrison et al. (2017).

The relationship between early bilingualism and social processes in autism has numerous implications, especially regarding the interplay between language and perspective-taking processes, and regarding the benefits of enriched over simplified environments on the development of social skills in autistic children. A review by Garfield et al. (2001) highlighted the stimulating role of social interactions, parent-child conversations and verbal input on the development of social cognition, and my results support this theory. In particular, Hamilton et al. (2016) suggested that language might play an even greater role in the development of perspective-taking in autism than in typical development, as a compensatory mechanism. Admittedly extremely few studies are currently available on the topic of the link between bilingualism and social skills in autism, and all focus on toddlers or young children under the age of 6, showing no differences in overall social abilities between bilingual children with autism and their monolingual peers (Valicenti-McDermott et al., 2019; Zhou et al., 2019). Both the studies by Valicenti-McDermott et al. (2019) and Zhou et al. (2019) focused on overall social functioning, and as the development of perspective-taking is at least delayed in autism (Baron-Cohen et al., 1985; Pino et al., 2017; Zhou et al., 2019), the children included were still developing their social cognitive skills. By following the developing skills of monolingual and bilingual children with autism over time, we could understand whether bilingualism anticipates the onset of perspective-taking development, or only enhances the process once development has started.

2. *Specific interaction patterns*

Although the goal of this study is to reduce the interplay between bilingualism and perspective-taking to its most prevalent relationship, a closer look at each model also illustrates how this relationship varies between the various forms of perspective-taking.

In the visual modality, there was a striking difference between the egocentric and altercentric bias models in their success in explaining the outcome measures. The models explaining egocentric bias performed much better, suggesting that in autism altercentric bias might rely more on other skills not measured here, such as mental rotation abilities (Pearson et al., 2016).

The models explaining social perspective-taking abilities were also successful, although all but one were underpowered. While there was an overall consistent pattern across the models, there were some contrasting results between the cognitive and affective modalities. The cognitive models frequently showed an influence of the age of acquisition of the second language and of the chronological age of the participant. As described above and in the neurotypical population, early bilingualism was linked with higher cognitive perspective-taking skills. Surprisingly, the influence of age showed opposite directions between level 1 and level 2 processes: age increased level 1 cognitive performance, but decreased level 2 ones. However, previous findings reporting a link between age and cognitive perspective-taking in autism described an age-related decline, which would support my findings in level 2 processes (Stewart et al., 2019).

The affective models showed a more inconsistent pattern, with distinct predictors selected in each model, and overall average performance. For level 1 scores, second-language age of acquisition effects indicated that early bilinguals perform better than late bilinguals. On the contrary, level 2 scores were only predicted by the number of languages known with high proficiency, indicating that proficient multilinguals performed worse than participants proficient in only one language. The high performance of this model suggests that this relationship is worth investigating further, though the failure of this relationship to generalise to other affective scores or the level 1 cognitive scores challenges it. Finally, overall affective scores were only predicted by overall executive function, with higher overall executive skills leading to higher overall affective perspective-taking skills. A relationship between executive function and affective perspective-taking has been described in the literature, but the lack of a distinct pattern between inhibition and switching skills, as seen in the neurotypical sample, is surprising. This would support previous findings reporting that in autistic children, social cognition seems associated with initiation and planning skills, not accounted for in this study (Miranda et al., 2017). However, lack of generalisation of this effect across other affective models, and the poor performance of the model overall, cast some doubt on the robustness of this relationship.

B. Visual and social perspective-taking

The second goal of this study was to examine the existence of a general perspective-taking process, uniting all three modalities. As described in Chapter 3, the modalities were directly compared with a correlation analysis. Again, validating the hypothesis, I did not identify a relationship between the visual modality and the cognitive and affective modalities in any of the analyses performed. These results do not exclude shared underlying mechanisms in autism, but they indicate that there is a connection between the cognitive and affective perspective-taking processes that is not present with visual processes.

1. *Biases in visual perspective-taking*

Before discussing the significance of the key findings, the intermediate results have to be examined. Interestingly, in level 1 processes, the exact same pattern as in the neurotypical sample was observed. Furthermore, the egocentric and altercentric interferences described in the previous chapter, theoretically reflecting the fast and unintentional processing of non-target perspectives, were also found in this sample, as shown by the significant differences between consistent and inconsistent conditions, in both level 1 and level 2 processes. Although samples were not directly compared, the biases present in the autistic group seem of the same nature as those described in the neurotypical group.

These results only partly align with previous findings on perspective interferences. Several studies have reported intact level 1 egocentric bias in autistic adults (Doi et al., 2020; Schwarzkopf et al., 2014), but while Schwarzkopf et al. (2014) also found, as did I, intact level 1 altercentric bias, Doi et al. (2020) did not. These contrasting findings may be due to methodological differences. Specifically, the orientation of the avatar is different between the original dot-perspective task (sideways) and the task used here (facing forward). Considering the body of literature discussed in Chapter 3, arguing that the avatar is merely a directional cue guiding the participant's attention, this detail could be crucial, in that its social value could be reduced when not facing the participant.

The dearth of research in the field of explicit and implicit visual processes in autistic adults thus currently shows highly inconsistent findings, potentially linked with the diversity in paradigm used, and a direct comparison of experimental stimuli would reveal the influence of the target position in this mechanism.

2. *Comparisons between modalities*

There was no significant correlation between the visual measures and the cognitive and affective measures, except one correlation between the general A-ToM-e score and the level 1 altercentric bias score. Surprisingly, there was no significant inter-correlation between any of the visual scores. This absence of correlation could be due to a lack of power in this sample, or it could reflect that, unlike in typical development, in autism these different biases rely on distinct supporting mechanisms. To the best of my knowledge no previous research has directly addressed this question, neither in adults nor children with autism, and my results call for a dedicated investigation into these mechanisms.

In the cognitive and affective modalities, skills generally correlated with each other, and across modalities. However, when considering the different levels of difficulty, the pattern was less clear, and level 1 and 2 scores did not correlate with each other in any modality, although both level 2 scores were linked. Again, these results could be due to a lack of power, or could mean that in autism, cognitive and affective level 1 processes are modality-specific, while level 2 processes rely on common higher-order mechanisms.

Finally, the lone correlation between the general score and the level 1 altercentric bias could suggest that in autism the distinction between modalities might not be as pronounced as in the neurotypical population. This result also suggests that the distinctive patterns found across modalities are not only due to their implicit versus explicit differences. While these questions are worth investigating further, it is important to consider that this result is distinct from any cluster or pattern of correlation, and therefore could be an artefact. In such a case, my results in autism would still support the distinction between visual and social modalities described in the neurotypical population.

C. The Adult-Theory of Mind-extended test

The third goal of this study was to assess the validity of the A-ToM-e as a reliable tool to measure the different forms of social perspective-taking in autistic adults, and by extension, its validity in addressing the first two research questions. I uncovered mostly low internal consistency across videos for levels and modality sub-scores, though the overall social score had acceptable internal consistency. On the other hand, I did find high inter-rater agreement, suggesting good reliability.

As discussed in the neurotypical sample (Chapter 3 section IV.C), the low internal consistency could be due to the range of social interactions portrayed in the videos (i.e. white lie, persuasion), and that some types of interactions might be more complex to process. Regardless of the types of interaction, some scenarios including only a short exchange and few cues might also have been more difficult than others to understand. However, as discussed in Chapter 3, the original Adult-Theory of Mind task (Brewer et al., 2017) was rigorously designed, and therefore likely to be of high quality. Also, the range of difficulty in the task limits potential floor or ceiling effects and allowed me to account for the diversity of perspective-taking abilities suspected in autistic adults. As a result, I would still suggest the A-ToM-e as a suitable naturalistic tool to measure the various forms of perspective-taking.

D. Implications of the findings

1. Theoretical implications

My results are the first to experimentally support the theoretical overlap between bilingualism and social processes in autism, and more specifically to demonstrate the influence of bilingualism on perspective-taking skills in autistic adults, above and beyond the role of well-established predictors of perspective-taking skills in autism, such as executive skills, age, and general intelligence.

The most compelling result in this study is the relationship between early bilingualism and social processes in autism, suggesting that an enriched and diverse linguistic environment has the potential to nurture the social abilities of people with autism. As discussed above in section IV.A.1, this has considerable theoretical implications, most notably with regards to the developmental trajectory of perspective-taking in autism. As discussed above in section I.A.2.d, based on the existing literature it could have been expected that an influence of bilingualism on perspective-taking skills would only occur through explicit learning, during later childhood, adolescence or adulthood. However, my findings show the opposite pattern, with an influence of bilingualism via implicit and unintentional learning during early childhood. The finding that in autism developing perspective-taking skills are susceptible to the implicit influence of environmental factors and experiences calls into question the hypothesis that autistic people can only develop perspective-taking explicitly and deliberately. Together, my findings suggest that, as for neurotypical children, in autism the development of social processes is linked with language, and might follow a more automatic developmental path than currently thought, at least in a context of a rich linguistic environment.

My results also support the theory reported in Chapter 3, which argues that visual perspective-taking and cognitive and affective perspective-taking are distinct processes, although these results suggest that in autism these processes might be less contrasted than in typical development. Indeed, the results highlighted that in autism, the influence of executive skills on perspective-taking seems more prevalent in the visual modality than in the social (cognitive and affective) modalities, suggesting that these modalities rely on partially distinct cognitive substrates. However, the significant correlation between some visual and social scores, as well as the influence of some predictors across all types of perspective-taking processes, also suggest that these modalities may have more overlap than in the neurotypical population.

Examining the impact of bilingualism and the other control measures across modalities would support the hypothesis of distinct mechanisms. Specifically, visual models systematically included executive skills, while social models did not. The predictors considered enabled the creation of efficient models in the social modalities, but not in the context of altercentric interferences, suggesting that these do not share largely common underlying mechanisms. Finally, early bilingualism appears to stimulate the development of social perspective-taking skills, while no aspect of bilingualism seems to have any influence on the visual modality.

2. *Practical implications*

My findings are directly relevant to parents, clinicians, and policy makers alike. When focusing on perspective-taking skills, bilingualism appears to be beneficial primarily from a developmental point of view: it is therefore essential to counter the current practices of favouring a monolingual environment around bilingual autistic children. As discussed in Chapter 1 sections III.A and III.B, bilingual parents of autistic children regularly refrain from using their home language, out of their own decision or after being advised to do so by clinicians and practitioners. However, my results do not show any negative effects of bilingualism on perspective-taking skills, which supports the body of literature arguing that the concerns around the use of multiple languages with autistic children are unfounded. Furthermore, given the stimulating developmental influence of bilingualism, an enriched linguistic environment should be promoted earlier rather than later, benefitting from parental input. Therefore, clinicians should encourage parents to maintain the minority language, and any support received by the child should be, ideally, promoting this multilingual setting as well. Beyond the family and clinical environments, my results also suggests that the teaching of foreign languages should be encouraged at school, as it is possible that the critical period of sensitivity to the early exposure of bilingualism is extended in autism, as social processes follow a delayed timeline compared to their monolingual peers. In conclusion, when it comes to social processes, autistic people can only benefit from early exposure to an enriched linguistic environment, and bilingual families and bilingual children should be supported in their bilingual education.

E. Limitations

It is essential to consider these results in the light of the limitations of the study. This study was the first of its kind to rely on an innovative and multidimensional definition of bilingualism, with measurements of multiple forms of perspective, and the first of its kind to assess this relationship in the context of autism in general, and in autistic adults in particular.

First, and as discussed in Chapter 3, grounding this study in this multidimensional framework meant investigating this relationship with a highly exploratory approach, which had an impact on the analysis strategy. As with the neurotypical sample, the interpretation of the regression results not only considered the significance threshold associated with each predictor, but also the selection of these predictors in the models. This procedure, which actively limits over-interpretation of single results, was adopted due to the highly exploratory nature of this study, and was even more judicious with regards to the present study due to its low sample size and the resulting likely underpowered analysis. Therefore, I am confident in the findings and overall patterns discussed here, but I recognise that some effects may have been under-estimated.

Second, as discussed in Chapter 3, my conclusions regarding the distinction between the visual and social modalities could be a result not of the modality, but rather of the nature of the tasks, since the visual measures rely on implicit mechanisms while the social measures were exclusively explicit. This possibility needs to be ruled out via the use of comparable implicit and explicit measures before a firm conclusion can be drawn on the differences between modalities.

Third, it must be acknowledged that the bilingualism variables – all self-reported – may be subject to reporting bias, in turn affecting the results. In particular, participants may have had different interpretations of proficiency ratings, which is key in my results, as this variable, often used to select bilingual participants, was not selected in a single model. Still, studies showed that self-ratings were an accurate proxy for language abilities (Brantmeier et al., 2012; Edele et al., 2015), which further supports my confidence in these findings.

Fourth, as discussed in Chapter 3, multiple factors have not been included in this analysis, which only focused on the most critical potential confounds: inhibition, attention switching, age, and non-verbal IQ. Future studies should therefore build upon these findings and consider other potential confounds specific to autism, such as working memory (Hamilton et al., 2016), processing speed (Sasson et al., 2020), and social synchrony (Fitzpatrick et al., 2018).

Finally, and specifically to this sample of autistic participants, a major limitation is the sample size involved, drastically smaller than the neurotypical sample included in Chapter 3. The large diversity of bilingualism profiles was undeniably a strength when the goal was to understand the influence of the naturalistic bilingualism experience, but a larger sample size would have increased the robustness of the results.

F. Future directions

As discussed in Chapter 3, these results raise questions regarding the underlying mechanisms of perspective-taking and the relationship between these mechanisms and bilingualism. First of all, seeing as the methods used here allowed me to contrast modalities and levels of perspective-taking but not to address the implicit versus explicit distinction, future research should also disentangle these two routes. A better understanding of these mechanisms and their distinct developmental pathways, in the specific context of autism, will allow us to make clearer predictions regarding the potential impact of environmental experiences such as bilingualism. This is particularly relevant, given the developmental timeline of these mechanisms in regard to the developmental effect of bilingualism, and for assessing whether bilingualism can advance the onset of the development of these skills, boost said development once started, or both.

Second, as discussed in Chapter 3, it would be critical to also consider potential interactions between aspects of bilingualism and other cognitive skills underlying perspective-taking processes. Furthermore, building upon these findings, it would be relevant to adopt a more fine-grained approach to some of the measures used here, such as age of acquisition or language proficiency.

Third, and especially in the context of autism, it will be essential to address the topic of language-development delay. Several of the participants disclosed having been non-verbal during a certain period of their childhood, and considering bilingualism seems to be particularly impactful during development, it will be necessary to assess how a bilingual upbringing affects the development of social skills of non-verbal autistic children.

Finally, it is now essential to identify the mechanisms by which early bilingualism stimulates the development of perspective-taking, especially form a neurological perspective. Considering the distinct neurological profile of autism regarding social processes, it is necessary to assess whether early bilingualism has the potential to influence the developing autistic brain in promoting the social neural network.

Chapter 5: Influence of early bilingualism upon the neural basis of perspective-taking in autistic adults and their neurotypical peers

I. Introduction

The findings reported in Chapter 3 and Chapter 4 describe a long-lasting developmental influence of bilingualism upon cognitive and affective perspective-taking which is similar between neurotypical and autistic participants. What are the mechanisms supporting this effect? One hypothesis is that exposure to bilingualism during early development influences the neural networks supporting perspective-taking, in terms of volume, density, connectivity, or activity. The following exploratory study sets out to address this hypothesis, focusing on neural activity.

A. Neural correlates of perspective-taking

The neural basis of perspective-taking has been extensively described in the neurotypical population. In their review, Gallagher & Frith (2003) described the specific involvement of the anterior paracingulate cortex, the superior temporal sulci, and the bilateral temporal poles in the various steps of perspective-taking. In a meta-analysis gathering 200 functional imaging studies, Van Overwalle (2009) concluded that the inference of other’s mental states strongly engaged the temporo-parietal junction, and the medial prefrontal cortex. This mirrored findings by Gallagher et al. (2000) and Carrington & Bailey (2009) that these regions were activated during perspective-taking regardless of the nature of the task – comparing text-based and single-frame cartoon-based tasks in the case of Gallagher et al. (2000), but also comparing instruction types, mental states investigated, or verbal demand in the case of Carrington & Bailey (2009). These results were reproduced by numerous experimental studies, such as D’Argembeau et al. (2007), which specifically addressed the role of the posterior dorsal medial prefrontal cortex. Several studies also highlighted the role of other key regions for perspective-taking, such as the fusiform gyrus, the occipital gyrus (Castelli et al., 2000), the middle temporal gyrus, the insula, the amygdala and the precuneus (Deuse et al., 2016).

Previous research has also highlighted that cognitive and affective perspective-taking rely on both shared and modality-specific neural correlates (Abu-Akel & Shamay-Tsoory, 2011). Both modalities have been shown to engage key regions such as the temporo-parietal junction, the precuneus, and the temporal poles (Healey & Grossman, 2018). However, affective perspective-taking has been linked with a specific enrolment of the ventromedial prefrontal cortex (Healey & Grossman, 2018; Sebastian et al., 2012; Westby, 2014), the medial orbitofrontal lobe (Hynes et al., 2006; Westby, 2014), the limbic system (Healey & Grossman, 2018), the inferior lateral frontal gyrus, and the ventral anterior cingulate cortex (Hynes et al., 2006). On the contrary, cognitive perspective-taking has been linked with the dorsomedial and dorsolateral prefrontal cortex (Healey & Grossman, 2018; Westby, 2014) and the dorsal anterior cingulate cortex (Westby, 2014).

B. Neurological features of bilingualism

1. Neuroanatomical characteristics of the bilingual brain

While few studies have investigated the influence of bilingualism on the neural activity supporting social cognition specifically, previous findings have described neuroanatomical changes due to bilingualism, but also differences between bilingual experiences.

Comparing 15 Spanish-English unimodal bilingual (with two spoken languages) and 15 English-speaking monolingual adults, Olulade et al. (2016) found that bilingualism was associated with greater grey matter volume in the dorsolateral prefrontal cortex and the parietal cortex, and reduced grey matter volume in the cerebellum, the occipital lobe, the temporal lobe, the hippocampus, and the amygdala. However, when comparing this same monolingual group with 15 bimodal American Sign Language-English bilinguals, no anatomical differences were found.

Anatomical characteristics of the unimodal bilingual brain also depend on the age of acquisition of the second language. For instance, Berken et al. (2016) found that simultaneous bilingual adults (n = 16) showed greater grey matter density in the left putamen, left insula, right prefrontal cortex, and bilateral occipital cortex, as well as reduced grey matter density in the bilateral premotor cortex, compared to late bilingual adults who had acquired their second language after the age of 5 (n = 18). With this same sample of bilinguals, Berken et al. (2016) reported in a subsequent study focusing on the inferior frontal gyrus that early bilinguals showed stronger functional connectivity between the left and right inferior frontal gyri, and between these regions and other areas such as the dorsolateral prefrontal cortex, the inferior parietal lobule and the cerebellum, compared to late bilinguals.

Recently, Archila-Suerte et al. (2018) showed that even within early bilingual children who had acquired their second language before age 5, proficiency in the second language also shaped the neuroanatomical changes linked with bilingualism. Authors compared 27 balanced and 22 unbalanced Spanish-English children aged 6 to 13 with similar age of acquisition of the second language, and found that compared to unbalanced bilinguals, balanced bilinguals showed reduced grey matter volume in the left superior temporal gyrus, the left inferior and medial frontal gyrus and the putamen bilaterally.

Taken together, these results support the hypotheses that the need to inhibit and select languages leads to neuroanatomical changes, and that not all bilingual experiences lead to similar neural modifications, with factors such as age of acquisition and proficiency being key in this bilingualism effect.

2. *Bilingualism and the neural correlates of perspective-taking*

Little is currently known about the way in which the neurological features of bilingualism influence the neural networks supporting perspective-taking. Comparing 16 Japanese-English late bilingual adults to 16 English-speaking monolingual adults performing a text-based level 2 cognitive perspective-taking task, Kobayashi et al. (2006) found that both groups shared common neural correlates for perspective-taking, such as the medial prefrontal cortex and the anterior cingulate gyrus. However, other regions were more activated in monolinguals, such as the medial prefrontal cortex, the inferior and middle frontal gyrus, the insula, the temporal pole, or the temporo-parietal junction, or were more activated in bilinguals, such as the right inferior frontal gyrus. Furthermore, authors showed that in bilinguals neural activity varied between the language used: completing the task in their first, compared to second language, was associated with increased activity in the bilateral middle frontal gyrus and the dorsolateral prefrontal gyrus, as well as reduced activity in the precentral gyrus and the caudate nucleus.

Building upon these findings, Kobayashi et al. (2008) found the neural correlates of cognitive perspective-taking differed between early bilingual children and late bilingual adults, with children showing a stronger perspective-taking-specific activity than adults, for example in the medial prefrontal cortex. These differences could be due to the chronological age of the participants, suggesting that the neural basis of perspective-taking mature in the bilingual brain from childhood to adulthood. These results could also be due to the age of acquisition of the second language, suggesting that early and late bilinguals recruit different neural networks during perspective-taking. Together, these findings suggest that bilingual and monolingual adults may rely on partly shared and partly distinct neural networks during cognitive perspective-taking, and that the neural basis of perspective-taking may vary based on the age of acquisition of the second language. However, no study to date has addressed this question in regard with the affective modality.

C. Neural correlates of perspective-taking in autism

Numerous studies have attempted to identify the neural network changes at the root of the social cognitive differences that are characteristic of autism. A recent large scale study by Moessnang et al. (2020) involving 205 autistic and 289 neurotypical participants aged between 6 and 30 performing a single animated-shapes social cognitive task found no differences between the neural activity of autistic and neurotypical participants. However, this result could be due to the simplistic nature of the task, or to the large age range included. Indeed, numerous studies have highlighted that autism shapes the neural networks of perspective-taking. For example, in children, an increase in the degree of social and communication difficulties has been linked with reduced activation in the medial prefrontal cortex, the temporoparietal junction, and the anterior cingulate cortex during perspective-taking (Kim et al., 2016; O'Nions et al., 2014). In adults as well activity patterns typical of perspective-taking have been described as reduced or absent in autism, particularly in the right temporoparietal junction and the anterior middle temporal pole (Nijhof et al., 2018).

These results mirror the overall conclusion of large-scale activation likelihood estimation meta-analyses. Combining 24 functional imaging studies focusing on social processes, drawing on a total of 276 autistic participants and 291 neurotypical participants, Di Martino et al. (2009) reported in autism a reduced activation of the middle and inferior fontal gyri, the anterior cingulate cortex, the superior temporal gyrus, the anterior insula, and the middle and inferior occipital gyrus. Identifying 15 studies covering complex social cognitive abilities (such as irony comprehension), Philip et al. (2012) also reported that compared to their neurotypical peers, autistic people showed both under- and overactivation in the left superior temporal gyrus, and under-activation in the right superior temporal gyrus. More recently, Patriquin et al. (2016) conducted a large-scale meta-analysis gathering 50 imaging studies measuring social cognition in a total of 675 autistic and 695 neurotypical children, adolescent and adults (mean age = 21.7 years). Authors reported that compared to their neurotypical peers, autistic participants showed reduced activation in the inferior frontal gyrus, the cingulate cortex, the superior temporal gyrus, the fusiform face area, and the amygdala, as well as increased activity in the superior temporal gyrus, the inferior frontal gyrus, the amygdala (in a different cluster than above, for all these three regions), the middle frontal gyrus, the precentral and postcentral gyri, and the insula.

However, fewer functional imaging studies of autism have addressed the differences between modalities of perspective-taking using a single task, thus allowing for a direct comparison of the modalities. Recently, Kim et al. (2016) did report neuroactivity differences between autistic (n = 15) and neurotypical (n = 14) children and adolescents (age range: 7 – 18) in both cognitive and affective perspective-taking. Using a non-verbal task measuring both modalities, authors found a greater cognitive-specific activation in autistic participants compared to their neurotypical peers in the medial frontal gyrus, the superior temporal gyrus and anterior cingulate gyrus, and a greater affective-specific activation in the medial and superior frontal gyrus. These findings suggest that both the affective and cognitive perspective-taking networks are shaped by autism. However, as the over-activation reported goes against a large body of research highlighting under-activation of these key areas in autism, these findings should be considered carefully.

In a nutshell, most studies do find clear neuroactivity differences between autistic people and their neurotypical peers during perspective-taking. There are discrepancies between studies in terms of the precise location of the regions influenced by autism, but the most regularly highlighted brain areas are those that are key for perspective-taking (such as the temporoparietal junction, the prefrontal cortex or the anterior cingulate gyrus), and these are regularly hypo-activated in autism.

D. Aim of the study and hypotheses

As discussed above, bilingualism is associated with neuroanatomical changes, and seems to shape the neural networks activity underlying cognitive perspective-taking. However, it is unknown whether this influence extends to affective perspective-taking, and whether the age of acquisition of the second language is a key determinant of any bilingual effect (as was found in the previous two chapters at the behavioural level). Furthermore, as autism modifies the neural correlates of perspective-taking, it is unknown whether the autistic brain presents the same susceptibility to the influence of early bilingualism as does the neurotypical brain.

These questions were addressed, building upon the findings presented in Chapter 3 and Chapter 4 showing a similar influence of early bilingualism across neurotypical and bilingual adults. I identified a non-verbal task adapted to the unique nature of my population of interest, and that also finely measures both affective and cognitive perspective-taking. I deployed the task in this exploratory study, that aimed to describe the neural network supporting cognitive and affective perspective-taking in bilingual adults, and to investigate whether age of acquisition would shape the activity of the adult brain during cognitive and affective perspective-taking. Finally, this study explored whether the effect of early bilingualism on these activity patterns was influenced by autism. Based on my previous findings and the research currently available, I hypothesised that in bilingual adults just as in monolingual adults, cognitive and affective perspective-taking rely on both shared and specific neural networks, and that the age of acquisition of the second language impacts the activity of these networks, but that this effect does not differ between autistic and neurotypical adults.

II. Methods

A. Participants

Participants were a subsample of the participants introduced in Chapter 3 and Chapter 4. Neurotypical participants (Chapter 3 section III.A) who had reported an age of acquisition of their second language under or equal to 1 (early bilinguals) or over or equal to 9 (late bilinguals) were invited via email to take part in the study. The threshold of 1 for early bilinguals was chosen to ensure simultaneous acquisition of the languages while allowing for the possibility that participants reported an age of 1 as a rounding up of acquisition during the first year of life. The original threshold for late bilinguals was set at 10 years to ensure acquisition after late childhood, but was lowered to 9 years due to recruitment difficulties.

For autistic participants the same stringent recruitment strategy could not be used due to the small size of the original sample (Chapter 4 section III.A). Therefore, all participants were invited to take part to this study, and participants who had reported an age of acquisition of their second language equal to or under 5 were assigned to the early bilinguals group, while participants who had reported an age of acquisition over 5 were assigned to the late bilinguals group. The final sample included 17 autistic (9 early bilinguals and 8 late bilinguals) and 15 neurotypical participants (8 early bilinguals and 7 late bilinguals). A detailed account of the participants' demographics and language profiles can be found in Table 6.1. In both cases a significant mean difference in age of acquisition was achieved between the early and late bilingual subgroups. In the neurotypical sample the mean difference in age of acquisition of the second language was 9.6 years. In the autistic sample the mean difference in age of acquisition of the second language was 7.9 years.

Participants were provided with the details of the study and gave informed consent. Participants received a £20 gift voucher for their participation, and their travel expenses to and from the appointment were covered.

Table 6.1 - Demographic and language profiles of the participants (n = 32)

	NT			ASD		
	All (n = 15)	Early (n = 8)	Late (n = 7)	All (n = 17)	Early (n = 9)	Late (n = 8)
a. Demographic profile						
Age in years, M (SD, range)	29.1 (7.2, 20 - 45)	26.5 (3.2, 22 - 32)	32.1 (9.4, 20 - 45)	32.4 (11.2, 20 - 56)	27.9 (6.3, 20 - 37)	37.5 (13.5, 26 - 56)
Gender, N (%)						
Female	10 (66.7)	5 (62.5)	5 (71.4)	9 (52.9)	3 (33.3)	6 (75.0)
Male	5 (33.3)	3 (37.5)	2 (28.6)	4 (23.5)	4 (44.4)	0 (0.0)
Other / Not disclosed	0 (0.0)	0 (0.0)	0 (0.0)	4 (23.5)	2 (22.2)	2 (25.0)
Non-verbal IQ,	114.0 (12.1,	109.6 (7.0,	119.0 (15.2,	119.7 (9.2,	122.6 (8.6,	116.5 (9.3,
Autism quotient, M (SD, range)	14.3 (5.2, 5 - 27)	13.3 (4.4, 5- 18)	15.4 (6.1, 8 - 27)	36.8 (6.4, 23 - 46)	36.6 (7.0, 23 - 45)	37.0 (6.1, 26 - 46)
Highest Education, N (%)						
Less than an undergraduate degree	1 (6.7)	0 (0.0)	1 (14.3)	4 (23.5)	2 (22.2)	2 (25.0)
Undergraduate degree or higher	14 (93.3)	8 (100.0)	6 (85.7)	13 (76.5)	7 (77.8)	6 (75.0)
Country of birth, N (%)						
UK	3 (20.0)	3 (37.5)	0 (0.0)	8 (47.1)	5 (55.6)	3 (37.5)
Non-UK, English-speaking [a]	1 (6.7)	1 (12.5)	0 (0.0)	2 (11.8)	2 (22.2)	0 (0.0)
Europe, non-English speaking [b]	10 (66.7)	4 (50.0)	6 (85.7)	4 (23.5)	1 (11.1)	3 (37.5)
Non-Europe, non-English speaking [c]	1 (6.7)	0 (0.0)	1 (14.3)	3 (17.6)	1 (11.1)	2 (25.0)

	NT			ASD		
	All (n = 15)	Early (n = 8)	Late (n = 7)	All (n = 17)	Early (n = 9)	Late (n = 8)
b. Language profile						
Number of languages reported,	3.5 (1.5,	3.5 (1.6,	3.6 (1.5,	3.4 (1.2,	3.3 (1.4,	3.4 (1.1,
Number of languages mastered,	2.5 (0.7,	2.8 (0.9,	2.3 (0.5,	2.2 (0.8,	2.1 (1.0,	2.4 (0.5,
Age of acquisition of the 2nd	5 (5.0,	0.5 (0.5,	10.1 (0.9,	5.4 (4.9,	1.7 (1.9,	9.6 (3.4,
Overall proficiency in the 2nd	6.9 (1.4,	6.6 (1.7,	7.4 (0.7,	6.0 (2.4,	6.2 (2.2,	5.7 (2.7,

Note: Table summarising the demographic and language characteristics of the participants, by diagnosis and bilingualism group. Participants attended the data collection appointment at the imaging facility 1 day to 1 year after their first appointment for the cognitive assessment detailed in Chapter 3 and Chapter 4. NT = neurotypical group, ASD = autistic group, Early = early bilinguals, Late = late bilinguals.
a = Canada (1), India (1), USA (1).
b = Bulgaria (1), France (5), Germany (3), Greece (1), Italy (1), The Netherlands (2), Ukraine (1).
c = China (1), Macau (1), Madagascar (1), Russia (1).
d = Proficiency rated on a scale from 0 (= "no proficiency) to 8 (= "excellent proficiency").

B. Materials and data processing

1. *Task battery*

a. Demographic and language characteristics

For each participant, data from the Demographic and Language questionnaires (Chapter 3 section II.B.1) and the WASI-II (Chapter 3 section II.B.5) were extracted to characterise the sample.

b. Autism-Spectrum Quotient

Because of the small sample size in this study the Autism-Spectrum Quotient (AQ, Baron-Cohen et al. (2001)) was used to verify autism profiles. The AQ is a self-administered questionnaire that participants completed independently prior to the brain imaging appointment via an personal anonymised link to the online questionnaire platform Qualtrics.

The AQ is composed of five sections, each including 10 items: social skills, communication, imagination, attention to detail, and attention-switching. Each item is phrased as a statement associated with a 4-points Likert scale allowing the participant to indicate how much they agree with the statement ("strongly disagree", "disagree", "agree", "strongly agree").

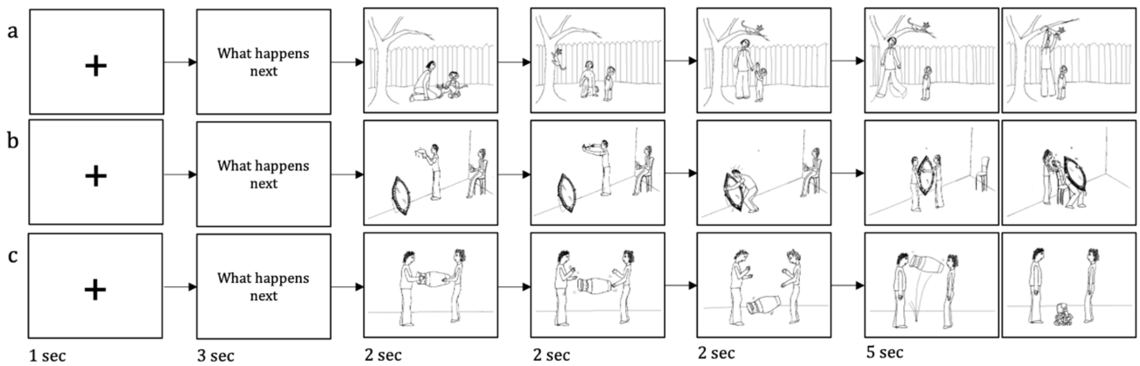
Half the items are worded to elicit an "agree" or "strongly agree" response from participants with autism, and such answers are scored 1 for these items, while other answers are scored 0. The other items are worded to elicit a "disagree" or "strongly disagree" response, and such responses are scored 1 for these items, while other responses are scored 0. As such, each item receives a score of 0 or 1. The final AQ score was calculated for each participant as the sum of all the items' scores, with a maximum score of 50.

c. Cognitive and affective perspective-taking task

Stimuli

The cognitive and affective perspective-taking task was taken from Sebastian et al. (2012). It included a total of 30 cartoons stories, evenly split across three experimental conditions: affective perspective-taking, cognitive perspective-taking, and physical causality (the control condition). Each story presented two characters interacting with each other over the course of three frames, with the participants having to infer the ending of the story by choosing between two possible ending frames. In the affective condition (Figure 6.1a), participants had to indicate how one character would react to the other character's emotional state. In the cognitive condition (Figure 6.1b), participants had to infer the ending based on the beliefs or intentions of the characters. In the physical control condition (Figure 6.1c), the inference of the ending only depended on the understanding of cause and effects on physical, non-social events (for example, a balloon pierced with a needle will pop, and a vase dropped on the floor will not bounce but break).

Figure 6.1 - Perspective-taking task



Note. Examples of the social stories for the affective (a), cognitive (b) and control physical causality (c) conditions, and duration of each frame.

Procedure

Practice trials and experimental trials were both completed in the scanner (see section II.B.2 below for magnetic resonance imaging (MRI) data acquisition details). Practice trials included one story from each condition, and experimental trials included ten stories from each condition. During the experimental trials, cartoon stories were presented in blocks of two trials from each condition, randomised so that there was a maximum distance of three blocks between two repetitions of a same condition. The order of the conditions was randomised across participants.

Each trial started with a fixation cross displayed for 1 second, followed by the instruction "What happens next" displayed for 3 seconds, followed by the cartoon stories. During the cartoon stories, each story frame was presented for 2 seconds, for a total of story build-up of 6 seconds, before presentation of the response option frames for 5 seconds. Response frames were presented side by side, with the correct answer randomly located across trials and participants on the right- or left-hand side of the screen. Participants, equipped with key press handles before entering the scanner, selected their response by pressing the key on the side of their chosen frame (i.e. to select the frame on the right they pressed the key on the handle in their right hand). The selected picture was outlined in blue around the edge until the end of the 5 seconds answer period. Each trial lasted a total of 15 seconds (Figure 6.1), with a 15 seconds rest period following each block of two trials.

Data processing

For each participant, accuracy was calculated for each condition as the number of correct trials out of the 10 experimental trials, and converted into percentages. Response time was extracted for each correct trial, and mean response time was calculated across trials for each condition.

2. *Functional MRI data*

a. *Data acquisition*

The study was carried out at the Edinburgh Imaging Facility QMRI, University of Edinburgh (registration number E181898). A 3 Teslas Siemens Magnetom Skyra fit MRI was used to obtain a 10-minute 3D T1-weighted structural scan (192 sagittal 1mm slices), and 489 multislice T2-weighted (192 sagittal 1mm slices) echo planar volumes with blood oxygenation level-dependent contrast taken during the 10-minute-long perspective-taking task. The acquisition parameters for the fMRI task were as follow: 57 axial 3mm slices; echo-time = 30ms; repetition time = 1400ms; flip angle = 68°; field of view = 210 mm; matrix size = 70 x 70. Fieldmaps were also acquired and used during pre-processing to correct deformations due to magnetic field in-homogeneities in the functional images.

b. *Data analysis*

Imaging data were analysed with SPM12 (www.fil.ion.ucl.ac.uk/spm) in MATLAB R2019b. After removing the first four volumes from each time series, the functional imaging data were slice time corrected, then rigid body realigned to the mean echo-plannar imaging (EPI) image, with application of a field map distortion correction. T1-weighted and T2-weighted images were co-registered to the mean EPI image, and entered into a multispectral segmentation from which normalisation parameters to the Montreal Neurological Institute (MNI) space were obtained. These non-linear wrapping parameters were applied to EPI time series for normalisation into MNI-defined standard space with a voxel size of 2mm isotropic, and spatial smoothing was applied with an 8mm isotropic Gaussian kernel.

Initially, first-level whole-brain analysis was conducted to identify the neural activity associated with each condition. A block analysis was conducted for each block of two trials, replicating the analysis of Sebastian et al. (2012). The design matrix partitioned the time series into sections corresponding to the fixation periods, instructions, frames presentation (6 seconds), which were then modelled as functions of 1- or 30-seconds duration, convolved by the standard hemodynamic response function. This led to a total of 5 task regressors: 1 for each task condition (affective blocks, cognitive blocks, physical blocks), 1 for all fixation crosses, and 1 for all instruction frames. The 6 motion parameters were also entered as additional regressors to account for head-movement-related variance, for a total of 12 regressors, after inclusion of the model constant as the final regressor. The activation and deactivation associated with each task condition was thus calculated against the model constant.

The second-level analysis explored the effects of bilingualism and of the experimental conditions on brain activity. A repeated measures ANOVA was conducted with Conditions (affective, cognitive, physical) as within-subject variables, and Bilingualism group (early versus late bilinguals) as the between-subject variable. The interaction between both variables was also assessed. The threshold for main effects and interactions were set to $p < 0.001$ uncorrected for peak-level significance and regions were identified with cluster-level significance $p < 0.05$, with FWE (family-wise error) correction.

Finally, the influence of autism was assessed only on the regions showing a significant interaction between Bilingualism group and Conditions. Parameters estimates averaged across voxels in a 6 mm sphere centred on the coordinate with the interaction effect peak were extracted for each participant and each condition. The post-hoc analysis on these extracted activity measures was conducted in R 3.5.3 run in RStudio 1.2.1335. For the conditions involved in the significant interaction, the difference in activity between these two conditions was calculated for each participant. In order to assess whether autism influenced the activity of the regions susceptible to the age of acquisition of the second language, and whether autism shaped the effect of early versus late bilingualism in these regions (further details below in section III.D), activation differences were entered in a 2x2 ANOVA;

Bilingualism group (early versus late bilinguals) and Diagnosis group (autistic versus neurotypical participants) were included as between-subject factors.

III. Results

A. Demographic and language profiles of the participants

After verification of the normal distribution of the data, chronological age, IQ scores, AQ scores, gender, number of languages reported, number of languages mastered, age of acquisition of the second language, and proficiency in the second language were compared between autistic and neurotypical participants. Wilcoxon signed-ranks tests indicated that the autistic and neurotypical groups did not significantly differ in chronological age (W = 146.5, p = 0.48), IQ scores (W = 178.0, p = 0.059), age of acquisition of their second language (W = 135.5, p = 0.77), or average proficiency in their second language (W = 102.5, p = 0.34). Chi-squared tests indicated that the autistic and neurotypical groups did not differ in their distribution of gender ($\chi^2(2, n = 32) = 4.05$, p = 0.13), number of languages reported ($\chi^2(4, n = 32) = 2.33$, p = 0.68), or number of languages mastered ($\chi^2(4, n = 32) = 2.33$, p = 0.68) either. A t-test verified that autistic participants had significantly higher AQ scores than their neurotypical peers ($t(29.8) = 11.0$, $p < 0.0001$).

B. Behavioural scores

Accuracy scores and mean response times are presented in Table 6.2 and Figure 6.2. First, to compare autistic and neurotypical participants, accuracy and mean response time between groups and conditions were compared using a 2x3 repeated measures ANOVA with Condition (affective, cognitive, physical) as within subject-factor and Diagnosis group (autistic, neurotypical) as between-subject factor.

For accuracy scores, there was a main effect of Diagnosis group with a large effect size ($F(1,30) = 7.30$, p = 0.011, ηp2 = 0.20; autistic < neurotypical), as well as a main effect of Condition with a medium effect size ($F(2,60) = 4.382$, p = 0.017, η_p^2 = 0.13). The interaction between Diagnosis group and Condition was not significant ($F(2,60) = 2.40$, p = 0.10, ηp2 = 0.074). The main effect of Condition was further investigated with pairwise t-tests with Bonferroni correction. Accuracy during the affective condition was significantly lower than during the cognitive condition (p = 0.011), but there was no significant difference in accuracy between the affective and physical conditions (*p* = 1), nor between the cognitive and physical conditions (*p* = 0.15).

For mean response time, there was a main effect of Condition with a large effect size (F(2,60) = 7.582, p = 0.001, η_p^2 = 0.20), but no main effect of Diagnosis group (F(1,30) = 0.784, p = 0.38, η_p^2 = 0.03). The interaction between Diagnosis group and Condition was significant with a large effect size (F(2,60) = 7.078, p = 0.002, η_p^2 = 0.19). The Diagnostic x Condition interaction was further investigated with pairwise t-tests with Bonferroni correction within each Diagnosis group. While in the neurotypical group there were no significant differences between conditions, in the autistic group the mean response time during the affective condition was significantly higher than during the cognitive (*p* = 0.00032) and physical (*p* = 0.015) conditions, but there was no significant difference between the cognitive and physical conditions (*p* = 0.9). T-tests with Bonferroni correction were also used to compare the Diagnosis groups within each condition, and showed that while there was no significant difference in the mean response time of neurotypical and autistic participants in the cognitive (*p* = 0.85) and physical (*p* = 0.81) conditions, in the affective condition autistic participants had a significantly higher mean response time than neurotypical participants (*p* = 0.047).

Second, to mirror the design used in Chapter 3 and Chapter 4, which investigated the influence of bilingualism within each population independently, accuracy and mean response time between bilingual group and conditions were compared independently within each diagnosis group using a 2x3 repeated measures ANOVA with Condition (affective, cognitive, physical) as within-subject factor and Bilingualism group (early bilingual, late bilingual) as between-subject factor.

For accuracy scores, in the neurotypical group, Greenhouse-Geisser correction was applied to the within-subject factor Condition and its interaction with Bilingualism group as the data violated sphericity assumptions. In this group there was no main effect of Bilingualism (F(1,13) = 2.69, p = 0.13, ηp2 = 0.17) or Condition (F(1.26, 16.4) = 2.73, p = 0.11, ηp2 = 0.17), and the interaction was not significant (F(1.26, 16.4) = 0.22, p = 0.71, ηp2 = 0.02). In the autistic group however, there was a main effect of Condition with a large effect size (F(2,30) = 3.57, p = 0.041, ηp2 = 0.19), but again no main effect of Bilingualism (F(1,15) = 0.235, p = 0.64, ηp2 = 0.02) and the interaction was not significant (F(2,30) = 0.289, p = 0.75, ηp2 = 0.02). The main effect of Condition on accuracy scores in the autistic group was further investigated with pairwise t-tests. Without corrections for multiple testing the same pattern as in the whole sample was observed (accuracy during the affective condition was significantly lower than during the cognitive condition (p = 0.024)), but once Bonferroni corrections were applied no significant differences between conditions were found.

For mean response time, in the neurotypical group there was no main effect of Bilingualism ($F(1,13) = 0.065$, $p = 0.80$, ηp2 = 0.005) or Condition ($F(2, 26) = 0.028$, $p = 0.97$, ηp2 = 0.002), and the interaction was not significant ($F(2, 26) = 0.052$, $p = 0.95$, ηp2 = 0.004). In the autistic group, as for accuracy scores, there was a main effect of Condition with a large effect size ($F(2,30) = 13.6$, $p < 0.0001$, ηp2 = 0.48), but no main effect of Bilingualism ($F(1,15) = 0.041$, $p = 0.84$, ηp2 = 0.003) and the interaction was not significant ($F(2,30) = 0.168$, $p = 0.17$, ηp2 = 0.11). The main effect of Condition on the response times of autistic participants was the same as described in the first analysis above.

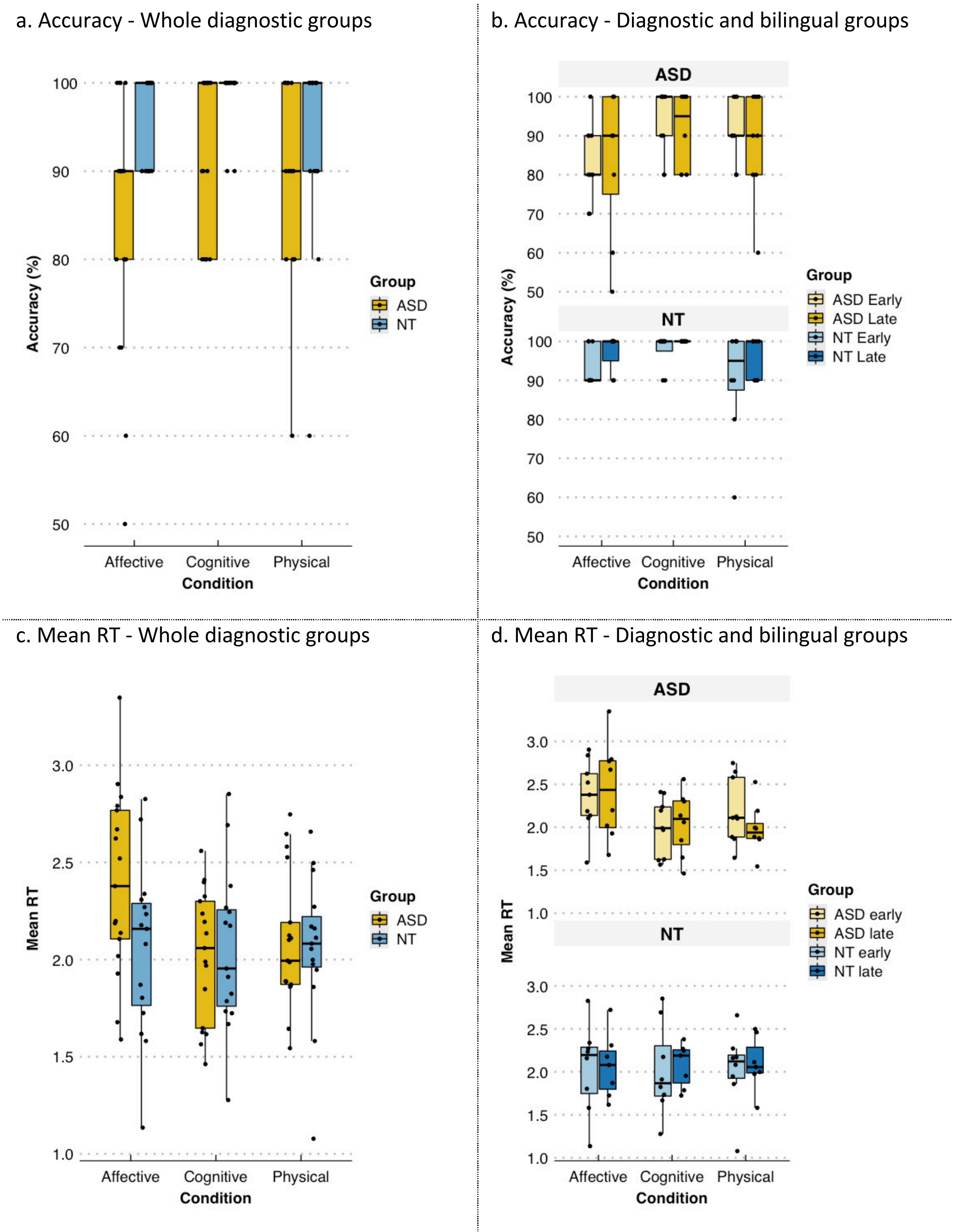
Overall, the results show that autistic participants were less accurate than their neurotypical peers across the board, but slower than them only in the affective condition. Unlike neurotypical participants who did not show a main effect of Condition on their mean response times, autistic participants were slower in the affective conditions compared to other conditions. Finally, neither Diagnosis group showed an influence of Bilingualism on accuracy or response times.

Table 6.2 - Behavioural scores

Outcome measures	Neurotypical			Autistic		
	All	Early	Late	All	Early	Late
Accuracy, % (SD)						
Affective condition	95.3 (5.2)	93.8 (5.2)	97.1 (4.9)	83.5 (14.6)	83.3 (10.0)	83.8 (19.2)
Cognitive condition	98.7 (3.5)	97.5 (4.6)	100 (0.0)	92.4 (9.0)	93.3 (8.7)	91.2 (9.9)
Physical condition	92.7 (11.0)	90.0 (14.1)	95.7 (5.3)	90.0 (11.2)	92.2 (8.3)	87.5 (13.9)
Mean RT (sec), M (SD)						
Affective condition	2.06 (0.44)	2.04 (0.52)	2.07 (0.38)	2.39 (0.47)	2.36 (0.41)	2.42 (0.56)
Cognitive condition	2.04 (0.41)	2.02 (0.53)	2.08 (0.26)	2.02 (0.34)	2.00 (0.34)	2.04 (0.37)
Physical condition	2.06 (0.38)	2.03 (0.45)	2.10 (0.31)	2.09 (0.35)	2.19 (0.39)	1.98 (0.29)

Note. Table summarising the accuracy (proportion and standard deviation) and mean response time in second (mean and standard deviation) for each condition of the perspective-taking task, presented by diagnosis and bilingualism group.

Figure 6.2 - Accuracy and mean response time



Note. Boxplot and scatter-plot diagrams showing the accuracy proportion (a and b) and mean response times (mean RT, c and d) in second for each condition of the perspective-taking task, presented by diagnosis group (a and c), and by diagnosis and bilingualism group (b and d).

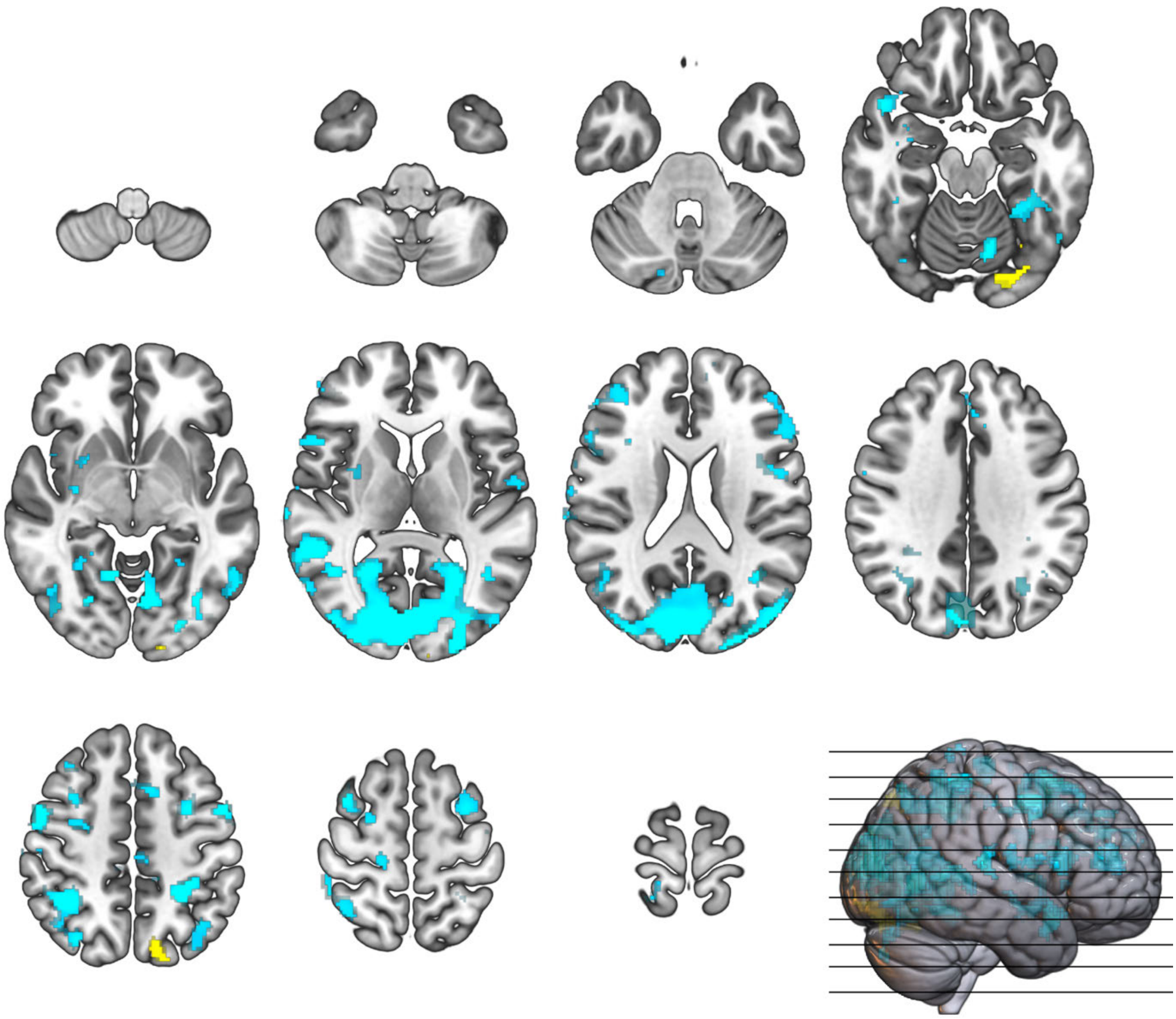
C. Whole brain analysis: Bilingualism and task effects

1. Main effect of early versus late bilingualism

Overall activation pattern differences were observed between the early and late bilingual participants (Figure 6.3) in several regions (cluster-level significance at $p < 0.05$ with FWE correction). The early bilingual group showed more activation than the late bilingual group in the left superior parietal lobule (Brodmann area (BA) 7) and in the left lingual gyrus / left occipital fusiform gyrus (BA 18) (coloured in yellow in Figure 6.3).

The late bilingual group showed more activation than the early bilingual group in the bilateral opercular part of the inferior frontal gyrus (BA 44), the bilateral middle frontal gyrus (BA 6/8), the right superior frontal gyrus (BA 9), the left supplementary motor cortex (BA 6), the right temporal pole (BA 38), the left superior parietal lobule (BA 5), and in the right cuneus (BA 18) (coloured in light blue in Figure 6.3).

Figure 6.3 - Activation differences between early and late bilinguals



Note. Multislice axial representation of the regions showing a main effect of bilingualism (radiological orientation). Areas more activated in the early bilingual group compared to the late bilingual group are coloured in yellow, areas more activated in the late bilingual group compared to the early bilingual group are coloured in light blue.

2. *Main effect of the task*

a. *Activity patterns within conditions*

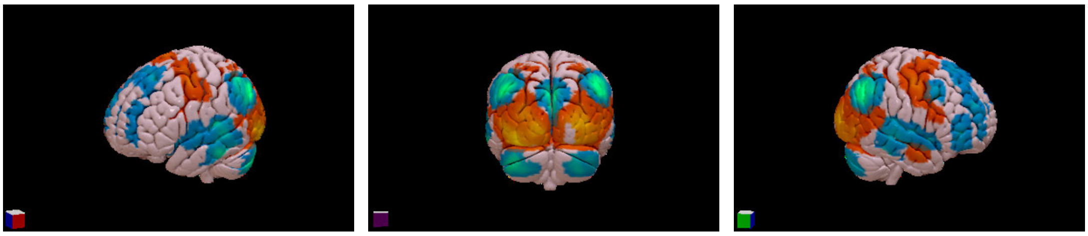
Regions with cluster-level significance at $p < 0.05$ with FWE correction were identified for each condition. The affective condition (Figure 6.4a) showed activations in the bilateral middle occipital gyri (BA 18), the bilateral superior and middle frontal gyri (BA 6), and the right middle temporal gyrus (BA 22), and deactivations in the bilateral middle frontal gyrus (BA 8), the bilateral superior and transverse temporal gyri (BA 40/41), the bilateral anterior and medial cingulate gyri (BA 24), the bilateral angular gyri (BA 39), the bilateral cuneus (Ba 19), and the bilateral cerebellar lobule VIIa.

The cognitive condition (Figure 6.4b) showed activations in the right middle temporal gyrus (BA 21) and the bilateral inferior occipital gyri (BA 18), and deactivations in the right orbital gyrus (BA 10), the right superior frontal gyrus (BA 9), the bilateral superior and middle temporal gyrus (BA 21), the bilateral angular gyri (BA 39), the bilateral cuneus (BA 19), and the left cerebellar lobule VIIa.

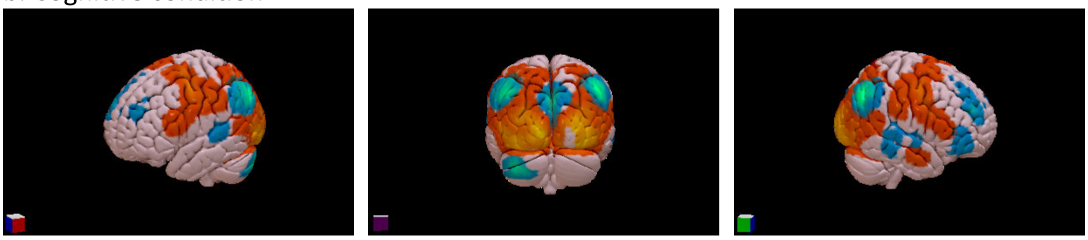
The physical condition (Figure 6.4c) showed activations in the bilateral inferior occipital gyri / lingual gyri (BA 18) and, and deactivation in the bilateral superior and middle frontal gyri (BA 8/9/10), the bilateral anterior cingulate gyrus (BA 24), the bilateral angular gyri (BA 39), the bilateral superior temporal gyri (BA 41), and the bilateral cuneus (BA 18).

Figure 6.4 - Effect of the task

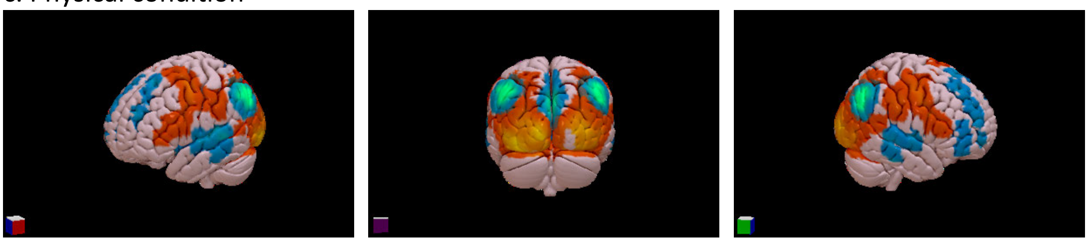
a. Affective condition



b. Cognitive condition



c. Physical condition



Note. Three-dimensional visualisation of the brain activity during the affective (a), cognitive (b) and physical (c) conditions of the perspective-taking task, across the whole sample. Activations are shown in a yellow-red gradient (with yellow for the highest T values), and deactivations are in a green-blue gradient (with green for the highest T values).

b. Activity differences between conditions

The activity patterns between the conditions of interest were analysed by comparing the affective and cognitive conditions with each other and with the control physical condition. Significant regions were found by first setting a peak-level threshold at $p < 0.001$ uncorrected, and then by identifying clusters with a significance at $p < 0.05$ with FWE correction (Table 6.3a, Figure 6.5).

Compared to the control physical condition, the affective condition showed less activation in the lingual gyrus bilaterally (Figure 6.5, coloured in green), while the cognitive condition showed more activation in the lingual gyrus bilaterally and in the left precuneus (Figure 6.5, coloured in red). Compared to the affective condition, the cognitive condition also showed more activation in the left cuneus, the left lingual gyrus, and the right fusiform gyrus (Figure 6.5, coloured in dark blue).

3. *Interaction between bilingualism and perspective-taking*

The group differences in these specific Affective (AT versus PC and CT) and Cognitive (CT versus PC and AT) responses (Table 6.3a) were further investigated by identifying regions showing an interaction between the bilingualism group (early versus late bilinguals) and condition effects (Table 6.3b) following the same thresholds.

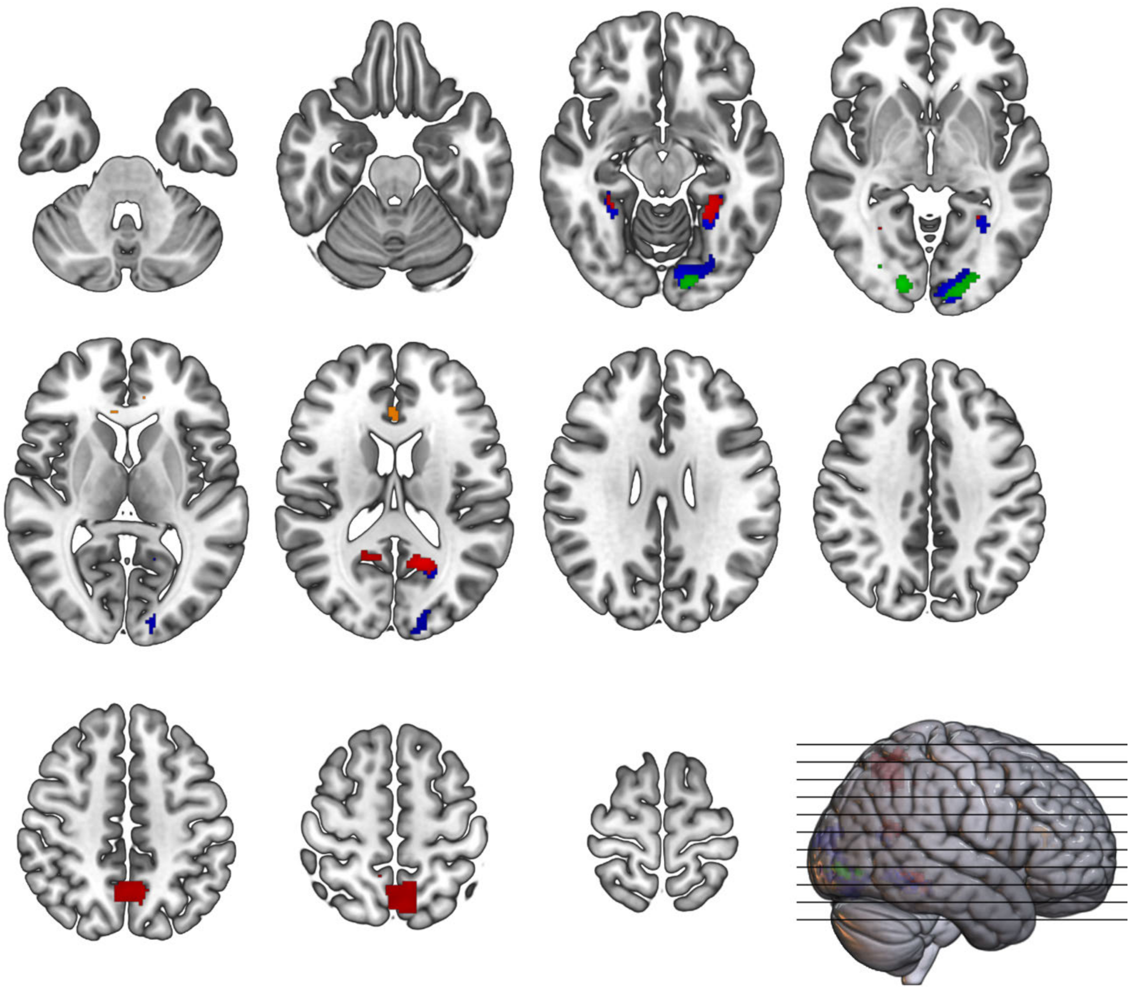
Table 6.3 - Regions showing main effects of contrasts between conditions and interactions between bilingual groups and contrasts

Region (BA)	Hemisphere	Peak voxel coordinates			*k*	*z*-value	Cluster level *p*-value
		x	y	z			
a. Condition contrasts							
Affective > Physical - none							
Affective < Physical							
Lingual gyrus (BA 18)	Left	-14	-88	-8	386	4.60	0.002
Lingual gyrus (BA 18)	Right	16	-86	-4	204	4.43	0.040
Cognitive > Physical							
Lingual gyrus (BA 19)	Left	-28	-46	-8	402	5.62	0.002
Lingual gyrus (BA 37)	Right	26	-42	-10	213	4.73	0.034
Precuneus (BA 23)	Left	-14	-56	20	507	5.02	0.000
Precuneus (BA 7)	Left	-6	-62	50	963	4.21	0.000
Cognitive < Physical - none							
Affective > Cognitive - none							
Affective < Cognitive							
Cuneus (BA 18)	Left	-20	-62	16	216	4.66	0.033
Lingual gyrus (BA 19)	Left	-28	-50	-8	1882	5.78	0.000
Fusiform gyrus (BA 37)	Right	28	-46	-12	271	4.85	0.013
b. Bilingualism x Conditions							
Bilingualism – Cognitive (Cognitive < Physical)							
Anterior cingulate gyrus (BA 24)	Right	6	30	10	184	3.75	0.057[a]

Note. Table summarising the regions showing a main effect of conditions (a) or an interaction between the conditions and bilingualism (b), and the BOLD response for the contrasts of interest. BA = Brodmann area, *k* = cluster size, *p*-values are FWE corrected. [a]: Uncorrected *p*-value = 0.006.

No voxel survived the defined peak-level threshold in the interaction between bilingualism and the contrasts affective > physical, affective < physical, cognitive > physical, and affective > cognitive. In the interaction between bilingualism and the contrast cognitive > affective, none of the surviving voxels showed a cluster-level significance of $p < 0.05$ with or without FWE correction. In the interaction between bilingualism and the contrast cognitive < physical, there was no significant findings after the FWE correction was applied, however a cluster showed a strong trend towards significance ($p = 0.057$) in the right anterior cingulate gyrus (Figure 6.5, coloured in orange, and Figure 6.6a), and was further investigated with an exploratory analysis.

Figure 6.5 - Condition-specific activations and interaction with bilingualism



Note: Multislice axial representation of the regions showing a main effect of conditions or an interaction between the conditions and bilingualism (radiological orientation). Areas more activated the cognitive condition compared to the physical condition are coloured in red. Areas more activated the physical condition compared to the affective condition are coloured in green. Areas more activated the cognitive condition compared to the affective condition are coloured in dark blue. Areas with an interaction between bilingualism and the cognitive-specific activity are coloured in orange.

D. Influence of autism

To explore whether differences in neural responses for the regions showing a significant Bilingualism (early versus late bilinguals) x Condition (CT versus PC) interaction (Table 6.3b) were influenced by autism, for each participant activity estimates were extracted (as described in Chapter 5 section II.B.2.b above). For each participant, the mean activity during the control physical condition was subtracted from the mean activity during the cognitive condition to obtain the cognitive-specific activity. This cognitive-specific activity was entered in a 2x2 ANOVA with Bilingualism (early versus late bilinguals) and Diagnosis (autistic versus neurotypical participants) as between-subject factors.

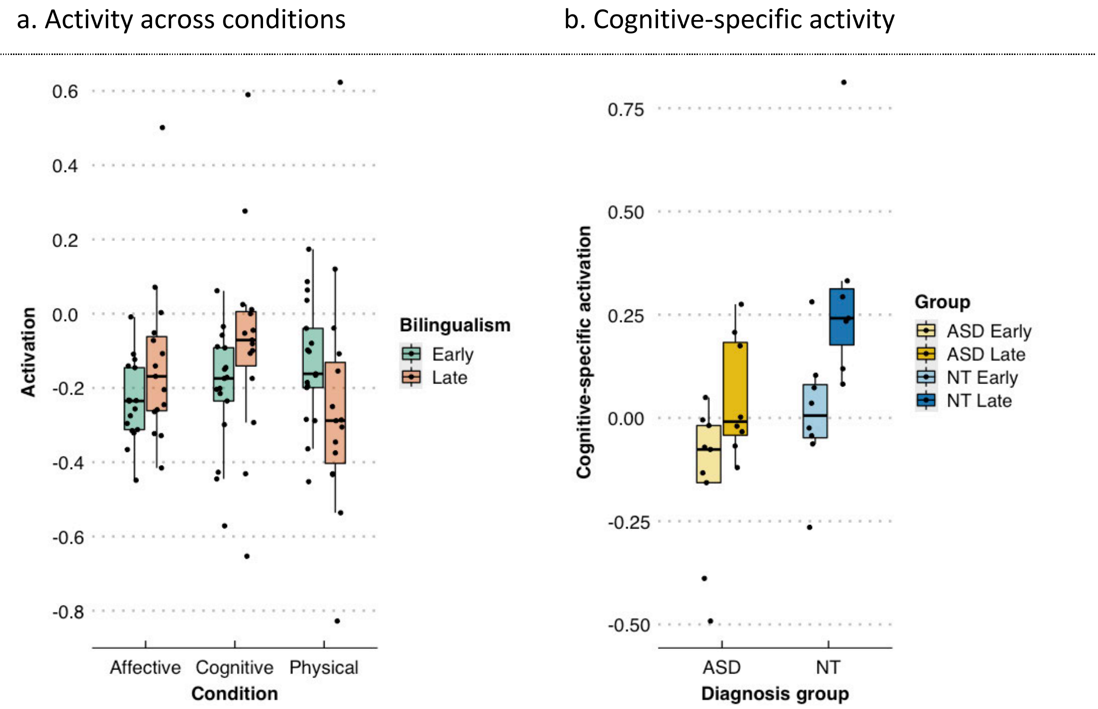
In the right anterior cingulate gyrus (Table 6.4, Figure 6.6), there was as expected a main effect of Bilingualism with a large effect size ($F(1,28) = 14.0$, $p = 0.0008$, $\eta_p^2 = 0.33$, Early < Late bilinguals), with early bilinguals showing a significantly smaller BOLD signal difference between the cognitive and physical condition (M = -0.07, SD = 0.18) than late bilinguals (M = 0.17, SD = 0.23). There was also a main effect of Diagnosis with a large effect size ($F(1,28) = 9.8$, $p = 0.004$, $\eta_p^2 = 0.26$; Autistic < Neurotypical participants), with autistic participants showing a significantly smaller BOLD signal difference between the cognitive and physical condition (M = -0.05, SD = 0.19) than neurotypical participants (M = 0.15, SD = 0.25). However, the interaction between Bilingualism and Diagnosis was not significant ($F(1,28) = 0.5$, $p = 0.47$, $\eta_p^2 = 0.02$).

Table 6.4 - Post-hoc analysis: Influence of autism and bilingualism

Region (hemisphere)	**Peak voxel coordinates**			***k***	**Main effect of Bilingualism**	**Main effect of Diagnosis**	**Interaction Bilingualism x Diagnosis**
	x	**y**	**z**				
Group – Cognitive (Cognitive < Physical)							
Anterior cingulate gyrus (right)	6	30	10	184	Early < Late, *p* = 0.0008	ASD < NT, *p* = 0.004	No interaction, *p* = 0.47

Note. Table summarising the influence of Bilingualism (early versus late bilinguals) and Diagnosis (autistic and neurotypical participants) on the BOLD signal difference between the cognitive and physical conditions of the perspective-taking task in the right anterior cingulate gyrus [6 30 10]. *k* = cluster size, Early = early bilinguals, Late = late bilinguals, ASD = autistic group, NT = neurotypical group.

Figure 6.6 - Activity patterns in the right anterior cingulate gyrus



Note. Boxplot and scatter-plot diagrams showing: a. the BOLD response in the right anterior cingulate gyrus [6 30 10] for each condition of the perspective-taking task, by bilingualism group; b. the difference in BOLD response in the right anterior cingulate gyrus [6 30 10] between the cognitive and physical conditions of the perspective-taking task, by diagnosis and bilingualism group. Early = early bilinguals, Late = late bilinguals, ASD = autistic participants, NT = neurotypical participants.

E. Results summary

Autistic and neurotypical participants were similar on most key demographic and language variables, and, as expected, differed in their AQ score (Chapter 5 section III.A). Looking across all conditions, autistic participants were overall less accurate than neurotypical participants, and all participants were less accurate in the affective condition compared to other conditions. These accuracy results aligned with results from the analysis of response times, with autistic participants, but not neurotypical, being slower during the affective condition compared to other conditions. Bilingualism did not influence accuracy or response time, neither in autistic nor in neurotypical participants.

Overall neural activity was influenced by the age of acquisition of the second language in several regions: compared to late bilinguals, early bilinguals showed more activation in the left superior parietal lobule, the occipital lobe, and less activation in multiple regions of the frontal lobes, the right superior temporal gyrus, the left superior parietal lobule, and in the right cuneus (Chapter 5 section III.C.1).

There were condition-specific activity patterns, with the affective condition showing decreased activity in the lingual gyrus compared to the control condition, and the cognitive condition showing increased activity in the lingual gyrus and the left precuneus compared to the control condition, as well as increased activity in the left lingual gyrus, the left cuneus, and the right fusiform gyrus compared to the affective condition (Chapter 5 section III.C.2).

There was little overlap of areas that showed an influence of bilingualism and that responded differently between perspective-taking conditions. There was a tendency for an interaction between perspective-taking condition and bilingual grouping in the right anterior cingulate gyrus, where the age of acquisition of the second language mediated the activation differences between the cognitive and physical conditions (Chapter 5 section III.C.3). Post-hoc analysis showed that early bilinguals exhibited a smaller difference between the cognitive and physical conditions than late bilinguals. This effect of early bilingualism was not influenced by autism. However, autistic participants also showed a smaller cognitive-specific activity than neurotypical participants (Chapter 5 section III.D).

IV. Discussion

Following the findings in Chapter 3 and Chapter 4 that early bilingualism predicted higher cognitive and affective perspective-taking skills in both autistic and neurotypical adults, this neuroimaging study investigated whether the influence of age of onset of bilingualism could be observed at the neural level. In addition, I asked whether any such influence would be apparent in both autistic and neurotypical participants.

This study is the first to examine the social cognitive neural network of autistic bilinguals, and accordingly, it is highly exploratory. Building upon the finding that the developmental influence of bilingualism followed a similar pathway in autistic and neurotypical adults, this study adopted an innovative approach relying first on comparing early and late bilinguals across both population before investigating autism-specific patterns. This approach allowed for the investigation of the bilingual effect on the neural basis of perspective-taking in autistic bilingual adults while unveiling how this relationship may be similar to or different from the case of neurotypical adults.

Taken together, the findings suggest that in autistic and neurotypical bilingual adults alike, the age of acquisition of the second language has a marked effect on brain function, with some evidence for a specific effect on the neural basis of cognitive perspective-taking, but no evidence for an impact on the neural correlates of affective perspective-taking.

Overall, these findings indicate that the developmental influence of bilingualism on cognitive and affective perspective-taking seen at the behavioural level in adulthood (Chapter 3 and Chapter 4) is only partially supported by similar strong and long-lasting changes in activity in social cognitive neural networks.

A. Neural bases of cognitive and affective perspective-taking

My findings support the hypothesis that the neural bases of cognitive and affective perspective-taking are at least partly distinct in bilingual adults, as has already been described in monolinguals. Compared to the control condition, affective perspective-taking was only linked with reduced activity in the lingual gyrus bilaterally. This was unexpected, as when using the same paradigms with 30 neurotypical monolingual adults and adolescents, Sebastian et al. (2012) did not find a significant difference between the affective and control conditions in this region. Instead, and unlike the present study, authors reported affective-specific activity in the precuneus, the temporo-parietal junction, the temporal pole, and the prefrontal cortex, bilaterally. The same discrepancy between findings appeared in cognitive perspective-taking. The present study found increased activity in the lingual gyrus bilaterally and the left precuneus during the cognitive condition compared to the control. Sebastian et al. (2012) reported activation in the precuneus as well, but also in the temporal pole bilaterally and in the right temporo-parietal junction.

Although the results of my study did not mirror those by Sebastian et al. (2012), the regions specifically activated or deactivated during perspective-taking in the present study have previously been linked with social cognition. In an activation likelihood estimation meta-analysis that compiled 50 functional imaging studies measuring social cognition in both autistic and neurotypical children, adults and adolescents (for a total of 675 autistic participants and 695 neurotypical participants), Patriquin et al. (2016) indeed found an increase in activity in the lingual gyrus and the precuneus during social cognition, alongside other frequently reported regions such as the temporo-parietal junction, the prefrontal cortex, and the insula.

That being said, the present results did not highlight a number of other regions frequently reported as key for cognitive perspective-taking and theory of mind, such as the temporo-parietal junction and the prefrontal cortex. For example, in a recent review focusing on typical development Healey & Grossman (2018) described the involvement of the temporo-parietal junction, the precuneus and the temporal poles in both affective and cognitive perspective-taking, as well as a specific activation of the limbic system and the ventromedial prefrontal cortex in affective perspective-taking, and a specific activation of dorsomedial and dorsolateral prefrontal cortex during cognitive perspective-taking. The overall absence of findings regarding the prefrontal cortex is particularly unexpected considering the extensive body of research linking this region to social cognitive processes (D'Argembeau et al., 2007; Frith, 2007; Van Overwalle, 2009), particularly in both in affective and cognitive perspective-taking (Westby, 2014). The differences in findings between the present study and previous research could be due to the very small sample size, but also the unique nature of the population researched here. In the next section I will consider what these results tell us about the influence of bilingualism.

B. Developmental influence of bilingualism

As mentioned above, there is a dearth of research on the neural correlates of social cognition in bilinguals compared to monolinguals, but also between the many forms of bilingualism. The whole-brain analysis revealed neuroactivity differences between early and late bilinguals during the overall task, with extensive overactivation of multiple regions in late compared to early bilinguals. These overactivations were observed in regions that Kobayashi et al. (2006) also found to be more activated in monolinguals compared to late bilinguals during cognitive perspective-taking, such as the inferior and middle frontal gyri or the temporal pole, thus following the pattern observed in the present data. Moreover, over-activation was observed in regions previously linked with perspective-taking, such as the temporal poles (Carrington & Bailey, 2009; Healey & Grossman, 2018). Together, these preliminary findings suggest that the neural basis of cognitive perspective-taking differ between bilinguals and monolinguals, with an increased processing efficacy in the neural networks of early bilinguals to compute social cognitive tasks.

This whole-brain analysis also provided some, albeit relatively weak, evidence that early bilingualism had long lasting effects on the neural basis specific to cognitive perspective-taking, thus only partially validating my hypothesis. The absence of interaction between early bilingualism and the activity specific to affective perspective-taking is highly informative in that it mirrors the findings at the behavioural level (Chapter 3 and Chapter 4). Indeed, both in the neurotypical and autistic adults, the role of early bilingualism visible in overall social perspective-taking, general perspective-taking, and cognitive perspective-taking was fainter in the affective modality. Taken together, these findings suggest that while affective perspective-taking appears to be susceptible to early bilingualism, this effect seems more subtle than in the cognitive modality. Furthermore, this effect only seems faintly related to a long-lasting alteration of neural activation patterns, suggesting a need to investigate the neural basis of affective perspective-taking also in terms of anatomy and connectivity.

Contrary to the affective modality, the neural networks supporting cognitive perspective-taking may be influenced by the age of acquisition of the second language, specifically in the right anterior cingulate gyrus. At the whole-brain level with statistical correction, there was only a trend for an interaction, but when extracting the activity in this region, it showed reduced cognitive-specific activation in early bilinguals compared to late bilinguals. This region has previously been linked with perspective-taking and social cognition (Kobayashi et al., 2006; Patriquin et al., 2016; Westby, 2014), with Apps et al. (2016) suggesting a specific role in estimating others' social motivations, which would be in line with the nature of the task used here. Previous research by Kobayashi et al. (2006) has also highlighted that the anterior cingulate gyrus appeared to be sensitive to bilingualism. Indeed, authors reported that both monolingual and late bilingual adults activated the right anterior cingulate gyrus during cognitive perspective-taking, but also that clusters within this region showed different activation between monolinguals and late bilinguals performing in their second language (with some clusters more activated in monolinguals and other clusters more activated in bilinguals).

These findings converge with the results of the present research, and support the hypotheses that the activity linked with cognitive perspective-taking within the anterior cingulate gyrus is influenced by bilingualism, and that this influence of bilingualism is linked with the age of acquisition of the second language. To conclude, this study suggests that early-exposed bilinguals under-activate multiple brain regions during a social cognitive task, though there were only few differences between bilinguals in the activity linked to a specific condition. The general under-activation and the reduced recruitment of the anterior cingulate gyrus in early bilinguals may result from increased processing efficiency of the bilingual brain to compute perspective-taking.

C. In the context of autism

As described in Chapter 4, the developmental influence of bilingualism on perspective-taking followed a similar pattern in autism as in typical development. However, is there also a similar relationship between bilingualism and perspective-taking for both populations at the neural level? As discussed above (Chapter 5 section IV.B), this study found a limited influence of the age of acquisition of the second language on the neural activity underlying perspective-taking in adulthood, with only one region showing a sensitivity to early bilingualism. The activity in this region, the anterior cingulate gyrus, was significantly smaller in autistic compared to neurotypical participants. This finding dovetails with previous research summarised above describing hypoactivation in the anterior cingulate gyrus in autism during social cognition, with the hypothesis that this hypoactivation translates into the social processing difficulties experienced by people with autism (Di Martino et al., 2009; Kim et al., 2016; O'Nions et al., 2014; Patriquin et al., 2016). Together, these results suggest that the anterior cingulate gyrus may play a role in the expected overall lower accuracy observed in the present sample of autistic adults compared to their neurotypical peers. It is important to note however, that the effect of autism across the whole brain was not tested in this study and that other differences may be present that are not revealed here. Also, beyond the effect of autism on the anterior cingulate gyrus activity, there was no interaction between autism and bilingualism, indicating that this relationship did not operate differently for the autistic group, and that early bilingualism influenced the neural activity supporting cognitive perspective-taking regardless of the presence of autism.

D. Implications of the findings

1. Theoretical implications

First, my findings support the theory that the different modalities of perspective-taking rely on both shared and specific neural correlates (Schlaffke et al., 2015), and further this theory by showing that this pattern extensively reported in monolingual adults is also present in a bilingual population. This suggests that bilingualism does not preclude the development of an organisation into joint and specialised networks for perspective-taking. However, the present study was not able to precisely highlight these networks in the bilingual brain, possibly due to the nature of the task and the subtlety between the cognitive and affective conditions, and because no monolingual control groups were involved in the study. However, while it seems that bilingualism does not prevent this organisation in joint and specialised networks, the findings presented above suggest that early bilingualism does influence the networks specifically supporting the cognitive modality.

Furthermore, these findings highlight that the influence of bilingualism on the brain is not binary, but shaped by the various features of the bilingualism experience, such as the age of acquisition of the second language. The neurological repercussions of bilingualism are still highly under-researched and poorly understood, and taken together, my findings emphasise a need for a clearer appreciation of the way each feature of the bilingual experience can shape the brain.

The results of this study also hint that the developing autistic brain is susceptible to the neurological influence of early bilingualism as much as the typically developing brain is, at least regarding social neural networks. Following this conclusion, this study raises numerous questions regarding the sensitivity of the developing brain to enriched environments, and particular enriched linguistic environments. While these questions are beyond the scope of this exploratory study, the finding that autistic early bilingual adults differ in their neural activity from their late bilingual peers supports the hypothesis that early experiences have long-lasting consequences on the neural activity patterns of the autistic brain, which needs to be further investigated.

2. *Practical implications*

These preliminary findings support several of the practical implications discussed in Chapter 3 and Chapter 4. First, they reinforce the need for a multidimensional approach of bilingualism, not only at the behavioural and cognitive level, but also when assessing its neurological impact. Second, these findings again support the conclusion discussed in Chapter 4 that autism does not prevent the developing brain from being shaped by bilingualism. While these neurological results are not alone sufficient to propose recommendations for parents and practitioners, taken together with the behavioural results described in Chapter 4, they support the advice to encourage and maintain a bilingual upbringing for autistic children in bilingual environments.

E. Limitations

This preliminary study was highly exploratory, and accordingly suffered a number of weaknesses. First, there were undeniable limitations related to the sample of participants involved in the study. Indeed, the overall sample size was small, with the four subgroups (early versus late, autistic versus neurotypical) counting only 7 to 9 participants, resulting in very limited power in the analyses. Furthermore, even though age of acquisition of the second language did not significantly differ between autistic and neurotypical participants, recruitment difficulties led to different distributions of the data on this variable. Indeed, neurotypical early and late bilingual participants had widely differing ages of acquisition of their second language (with an age of 1 or under for early bilinguals, and an age of 9 or over for late bilinguals). In contrast, the age of acquisition of the second language for autistic participants was continuously distributed between 0 and 16 years, thus weakening the comparison between early and late bilinguals in this sample. Moreover, some characteristics of the autistic sample, such as the high non-verbal IQ, the high education level, and the high rate of females, may hinder the generalisability of the findings to the larger bilingual population with autism.

Second, as discussed by Deuse et al. (2016) the nature of the task might have limited the findings. As discussed by Sebastian et al. (2012) who used the same task, the nature of the task implied the use of visually complex stimuli, which could explain the extensive recruitment of the occipital lobe in both my results and those reported by Sebastian et al. (2012). Similarly, the lack of significant activation of key perspective-taking regions such as the prefrontal cortex could also be due to the task used. Indeed, Sebastian et al. (2012) found no perspective-taking-specific activity in the prefrontal cortex either in their adult sample ($n = 15$). Crucially, this task was highly complex conceptually, and the differences between conditions were extremely subtle. All conditions involved two protagonists interacting with each other, thus carrying a comparable social load, and the difference between the cognitive and affective conditions focused exclusively on a character's reaction to the inferred emotion or intention / belief of the other, without verbal or overt facial cues. The subtlety of this task reduces the chances of exposing a stark distinction in neural activation between conditions in an adult sample. However, the complex nature of this task also reinforces the practical significance of the neural activity patterns observed in my results.

Finally, it is necessary to address the limitations due to the analysis strategy used here. Due to the exploratory nature of this study and the paucity of available findings in neurotypical and autistic bilinguals, I adopted a data-driven whole-brain analysis approach. Undeniably, this means that activity patterns in specific brain regions may not have survived statistical correction. Therefore, it is essential to note that the absence of findings regarding the involvement of certain regions does not exclude that these regions are indeed involved in perspective-taking in autistic and neurotypical bilingual adults. As a consequence, it will be relevant to reproduce this analysis focusing on regions of interests defined by the literature, even though they concern in majority monolingual populations. Furthermore, modelling this analysis in blocks may have led to a reduced temporal definition of activation patterns. Therefore, it would be relevant to reproduce this analysis while distinguishing the activity occurring while participants are presented with the story and the activity occurring while participants actually perform the perspective-taking decision.

F. Future directions

As repeated above, this study was highly exploratory, but nonetheless the results highlight that bilingualism can indeed shape neural activity in neurotypical and autistic adults alike, thus raising numerous questions ripe for further investigation.

This study involving autistic and neurotypical participants did not rely on the usual approach of first comparing these groups, before exploring bilingualism in a post-hoc analysis. Indeed, this study did not aim to identify autism-specific activity differences in the brain and whether early bilingualism could moderate them. Instead, building upon the findings discussed in Chapter 3 and Chapter 4, this exploratory analysis aimed to investigate whether early bilingualism could shape the activity of the adult neural networks involved in social processes, and if so, whether the autistic brain differed from the typical brain in its sensitivity to early bilingualism. These two approaches are drastically different, and the results of the present study only address the latter. Therefore, future research should also focus on the former, and investigate whether bilingualism reduces or increases the differences between the autistic and the neurotypical brain.

This study highlights that different experiences of bilingualism are associated with different activity patterns, in both neurotypical and autistic adults, but only address the long-lasting impact of the age of acquisition of the second language. Following these findings and those by Kobayashi et al. (2006) showing distinct activity patterns within bilinguals using their first or second language, future research should investigate the neurological impact of other features of the bilingualism experience. Indeed, as discussed by DeLuca (2019), the field of research on the neurological specificities of bilingualism should follow the direction of its behavioural and psychological counterparts, and consider the individual contribution of each language experience factor, instead of adopting a binary definition of bilingualism.

Finally, this research only addresses discrete brain activity, but the influence of bilingualism on the brain has been shown at the structural level in grey and white matter volume (Del Maschio et al., 2019; Deluca et al., 2019; Olulade et al., 2016), and at the connectivity level (Berken et al., 2016), though only in neurotypical populations. For example, Berken et al. (2016) reported that the increased functional connectivity between certain brain regions observed in simultaneous compared to late bilingual adults was also associated with reduced neural activation in these same regions during language production, suggesting that early bilingualism may shape the connections between brain regions and enhance neural efficiency, translating into a reduced activation of certain brain regions in bilinguals. Therefore, it is highly likely that the influence of early bilingualism on the developing autistic brain also shapes the neuroanatomy and connectivity in a longer-lasting way than it does in terms of neuroactivity. As such, it is essential that future research investigates the impact of bilingualism on the autistic brain from multiple angles, combining neuroactivity, neuroanatomy and connectivity.

Chapter 6: Conclusion

I. Summary of the findings

This research provides a first portrayal of many facets of the bilingual experience in autism, and investigates specifically how these can shape the social abilities of autistic people. The studies previously available focusing on autistic bilinguals only highlight two extremes of the bilingual experience: simultaneous or early bilinguals from bilingual families, or highly proficient polyglots, which does not mirror the diversity of language profiles described in typical development. Are these the only two ways for autistic people to be bilingual? As expected, this is not the case (Chapter 2), and in this sense my findings are both remarkable and mundane. Mundane, in that apart from presumptions and prejudices, there was no evidence to suggest that autistic people could not be bilingual. Remarkable, in that my study is the very first to provide a description of the diversity of language profiles in autism. This study showed that autistic people can experience bilingualism in as many ways as neurotypical people can.

Having described the population of interest in some details, the over-arching question of this research was to determine whether, and if so, how, bilingualism influences social processes in autism. I found that bilingualism shapes social cognition in autism, from the level of lived experiences down to the neural correlates of social processes. When asked how satisfied they were with their social life, multilinguals were overall happier with their social life habits than bilinguals, who were in turn happier than monolinguals (Chapter 2). This was the first hint that in autism, bilingualism and social skills were somehow linked. Could this link also appear at a deeper cognitive level? I assessed whether bilingualism could influence a key social cognitive skill, perspective-taking. I found that in autistic (Chapter 4) as in neurotypical adults (Chapter 3), bilingualism indeed influenced cognitive and affective perspective-taking abilities. Crucially, I found that this bilingual effect was likely to be developmental: the earlier the acquisition of the second language, the higher the perspective-taking abilities. Important, too, was the finding that this effect was still visible in adulthood, and occurred above and beyond the influence of other factors known to influence perspective-taking, such as executive skills, non-verbal IQ, or age. Another compelling point in my findings, as mentioned above, was that this relationship between early bilingualism and perspective-taking was similar in autism and typical development.

Following these findings, another question arose: if bilingualism has a stimulating influence on the development of perspective-taking, could this effect be observed at the neurological level? I contrasted neural responses during a perspective-taking task in early and late autistic and neurotypical bilinguals, and found distinct activity patterns between early and late bilinguals (Chapter 5). The results highlighted that compared to late bilinguals, early bilinguals under-activated multiple brain regions during social cognition, and in particular they showed in the anterior cingulate gyrus a reduction of the activity specifically related to cognitive perspective-taking. As bilinguals did not differ in terms of perspective-taking skills at the behavioural level, the findings suggest an increased processing efficiency of the early bilingual brain to compute perspective-taking. Importantly, this relationship did not operate differently for the autistic group, suggesting that the influence of early bilingualism upon the perspective-taking neural network is similar between autistic and neurotypical populations.

This study also allowed me to address a critical debate in the field of social cognition: the relationship between the various modalities of perspective-taking. I found that in both neurotypical (Chapter 3) and autistic adults (Chapter 4), visual perspective-taking did not follow the same path as the cognitive and affective modalities. As a result, my findings support the theory that visual perspective-taking is distinct from social-cognitive processes, as applied in cognitive and affective perspective-taking tasks.

II. Limitations

A number of limitations have to be considered when examining these findings. First, the results are limited by some characteristics of my study design. The studies are all cross-sectional, which limits my ability to robustly estimate the developmental effect of bilingualism, or demonstrate a causal relationship between bilingualism and social cognitive skills. While it is possible to make a developmental inference from the relationship between age of acquisition and perspective-taking, longitudinal data would provide the most robust test of this hypothesis.

The nature of the samples included in this research also has to be considered. Indeed, it is possible, and likely, that the distribution of demographic and bilingual profiles in my samples is not representative of the wider autistic and neurotypical bilingual populations. Therefore, the influence of early bilingualism reported in this research should also be verified in other specific demographic and linguistic sub-samples.

The bilingualism variables in these studies were self-reported, and therefore were susceptible to the participants' bias and interpretation, in particular when it comes to language proficiency. As mentioned previously, it is possible that participants had a heterogenous understanding of what qualifies as an "average" or a "good" proficiency, possibly under- or over-estimating their own language abilities. This potential mismatch could in turn be the reason why language proficiency did not seem to influence social cognitive abilities (which were measured objectively). Self-ratings have been validated as accurate measures of proficiency when the use of standardised language tests was not possible (Brantmeier et al., 2012; Edele et al., 2015) as was the case here, but this has not been verified in autism. Even though a standardised language assessment would have provided a more comparable proficiency measure, the strategy used in this research allowed me to recruit more participants, which reinforces my confidence in the findings.

Another methodological limitation of my results is that, due to its exploratory nature, some potential confounds were not controlled for in my study. In order to limit the number of candidate predictors, only the most prominent confounds were measured, but the role of some potential secondary confounds – such as mental health conditions for social life quality (Mason et al., 2018), or working memory (Hamilton et al., 2016; Laillier et al., 2019; Maylor et al., 2002) for perspective-taking skills – should be addressed to produce a more robust estimate of the bilingualism effect.

Finally, and specifically regarding my conclusion that visual perspective-taking did not belong to the same type of processes as cognitive and affective perspective-taking, it must be noted that in the visual modality I measured implicit processes, while in the cognitive and affective modalities I measured explicit processes. Therefore, my results might reflect not a difference between modalities, but between implicit versus explicit routes. The theoretical and methodological implications of this possibility are discussed below in sections III.A.3 and III.B.3 respectively.

A second source of limitation comes from the analytical framework used in this group of studies. This research is highly innovative in that it was grounded in a multidimensional approach to both bilingualism and perspective-taking. This had the benefit of allowing for a more naturalistic portrayal of the relationship between both elements, but it did lead to the inclusion of numerous candidate predictors and outcome variables, and therefore, a large number of statistical tests, some of which might have produced false positives or negatives. To counter this shortcoming, I adopted a standardised two-step analysis method, which reduced the number of candidate predictors for each outcome measure. To further address the issue of multiple testing, I structured my discussion around, not single results, but overall patterns of effects. This strategy reduced the risk of over-interpretation of single results, though it may also have led to the under-estimation of some effects. As such, my results highlight only the most prominent effect of bilingualism on perspective-taking, but I acknowledge that other effects might also exist.

III. Implications

A. Theoretical implications

1. *Theories about autism*

The most compelling result of this research is the influence of early bilingualism on social processes in autism. Reporting on lived experiences, it is clear that bilingual and multilingual autistic people experience better social quality of life. While the causal direction here is unclear, my investigation at the behavioural level exposes more mechanistic clarity. Chapters 3 and 4 indicate that bilingualism shapes social cognition in autism, and apparently operates similarly to typical development. As discussed in Chapter 4, these findings support the hypothesis that language and social cognitive development are indeed intertwined in autism. My findings suggest that an enriched and diverse linguistic environment, over a simplified one, may act as a scaffolding, or a helping hand, in the development of social processes. This idea mirrors previous theories proposing that the role of language was even more essential in autism than in typical development (Hamilton et al., 2016), in that language could act as a compensator for poorer innate social cognitive potentialities. Importantly, my results show that whether or not autistic children fall behind their neurotypical peers in terms of perspective-taking abilities, both groups of children show the same susceptibility to the influence of bilingualism. This suggests that the dissimilarities in the substrates of perspective-taking in autism compared to typical development, while clearly present, may not be as pronounced as previously thought. This is also seen in the mutual distinction between modalities observed between the autistic and neurotypical participants. Indeed, it appears that as in typical development, in autism visual perspective-taking does not share the same underlying mechanisms as cognitive and affective perspective-taking.

It is also interesting to note that while bilingualism seems to have a developmental influence on social cognitive processes, that specific influence is not the case for broader, lived social abilities. Social life quality seems to be shaped by the number of languages known, showing a drastically distinct relationship with bilingualism. This suggests that the bilingual autistic people with the highest perspective-taking skills (linked to early bilingualism) are not necessarily the bilingual autistic people with the highest social life quality. This influence of the number of languages could be a proxy, masking other personality traits, such as educational success or social drive, and future studies should address the interplay between these individual differences. However, my results do suggest that there is not a direct causal influence of perspective-taking skills on social life quality, which is doubtlessly the result of the interaction between numerous cognitive skills and lived experiences.

Finally, my results urge the academic community as well as practitioners and educators to recognise the remarkably varied, enriched, and complex linguistic lives of autistic people, beyond the linguist savants or the people with social communication difficulties. The findings highlighted a wide diversity of language profiles, mirroring how some autistic people also embrace communication and international communities. This research showed that autistic people could learn languages at home, at school, in the community, or on their own, based on their individual set of strengths and difficulties, and on their lived experiences. Participants reported that language learning had brought them more than simply languages, but had also helped them to better understand themselves *("Each language I know allows me to better express specific thoughts, emotions"*[1]) and others *("It is useful to understand others and to perceive reality through different perspectives"*, *"There is more than one way of thinking, speaking, and experiencing things"*). They reported that being able to understand and use multiple languages had brought them closer to the worldwide autistic community (*"It is great to be able to communicate online with people about ourselves and our autism. It makes you feel less alone"*). In other words, bilingualism can open up the world to autistic people, just as it does to non-autistic people (*"Foreign languages bring freedom and adventure"*).

[1] These citations were taken from the responses to the open-ended questions at the end of the ABC online questionnaire described in Chapter 2. Analysing and reporting the sheer volume of qualitative responses, entirely unprecedented in the field, was beyond the scope of this thesis, and these quotes are provided here to illustrate further the lived experiences of autistic bilinguals.

2. *Relationship between language and social cognition*

My findings support the theoretical link between language and social cognitive development, with impacts persisting into adulthood, above and beyond the role of executive skills and general intelligence. This supports existing theories that language is a key factor for perspective-taking during development, though this influence diminishes in adulthood. Indeed, the key role of the age of onset of bilingualism shows that the enriched linguistic experience of bilingualism only shapes perspective-taking processes when it starts in early childhood, but not when it starts in later in life, by which time perhaps perspective-taking abilities are set. As no differences were found between level 1 and level 2 measures, it seems that bilingualism influences cognitive and affective perspective-taking processes regardless of the difficulty of the task. These results raise new questions regarding the specific way in which bilingualism influences perspective-taking. Is this effect indeed linked to language, and the diversity and richness of language inputs? In this case, are the child’s receptive bilingual language skills the main driver of the effect, or on the contrary does the child need to be active in this early bilingual experience? Alternatively, could this effect be purely due to metacognition, and the early understanding that, as different people speak different languages, different people have access to different knowledge? In short, early bilingualism illustrate how poorly understood the theoretical overlap between language and social cognition still is, and highlights different potential routes for this effect. These multiple hypotheses might not be mutually exclusive, and answering these question will advance our comprehension of the developmental path followed by social cognition.

Furthermore, my results show that the influence of bilingualism on social cognitive processes does not mirror its influence on executive functioning. Indeed, in the field of executive skills, the Adaptive Control Hypothesis (Green & Abutalebi, 2013) proposes that it is how bilinguals use their languages that shapes executive abilities. My research thus showed that bilingualism can influence different cognitive processes, but understanding these patterns will require specific theoretical models for each cognitive domain.

3. *Perspective-taking theories*

An expanding body of research is now questioning the inclusion of visual perspective-taking as a modality of perspective-taking, alongside the cognitive and affective modalities (Cole & Millett, 2019). My results support this theory showing that in both the autistic and neurotypical populations, visual perspective-taking abilities do not correlate with cognitive or affective modalities, and do not show the same susceptibility to the bilingualism effect. As such, the visual modality does seem to rely on distinct cognitive components compared to the other perspective-taking modalities. These differences appear to be large enough to set aside the concept of visual perspective-taking as a social perspective-taking process. Based on my findings, the visual modality seems to be closely related to executive functioning, both in autism and in typical development, though both populations did not show exactly the same pattern of interaction between visual perspective-taking and executive skills. As suggested by Pearson et al. (2016) who compared the underlying mechanisms of visual perspective-taking in autistic and neurotypical children, these distinct patterns could be due to the use of different executive strategies to perform such a task. This question could be addressed by comparing autistic and neurotypical adults on a battery of visual perspective-taking and executive tests.

Still, as mentioned above, the discrepancy between modalities observed in the present study could be due to a difference between implicit and explicit mechanisms. In this case, the results would suggest that implicit processes (instead of visual processes) are highly distinct from explicit ones (instead of cognitive and affective ones) in terms of their susceptibility to bilingualism and their relationship with perspective-taking. However, the existence of implicit mechanisms, regardless of the modality, is now being questioned, and if not their existence, at least their categorisation as genuine, domain-specific, mentalising processes (Cole & Millett, 2019; Heyes, 2014; Kulke et al., 2018). The present research cannot, ultimately, rule out this possibility, and a design involving comparable measures of explicit and implicit processes in each modality will be needed to fully answer this question.

B. Methodological implications

1. Bilingualism research

My findings highlight the need to reconsider methodological approaches in research at the crossroad between bilingualism and cognitive psychology. Indeed, my results showed the bilingualism effect on cognitive skills is not a “one size fits all”, and different aspects of bilingualism are crucial for different aspects of cognition. I recommend that the most rigorous approach is to abandon the binary or categorical vision of bilingualism, and instead assume a multidimensional definition, acknowledging the many factors shaping the bilingual experience. When this approach is not possible, I recommend researchers refrain from too hastily using proficiency as a selection criterion when recruiting bilingual participants, especially when no previous research or theories suggest that this particular factor is the most relevant for the cognitive process studied.

Relying on this multidimensional definition of bilingualism does raise a number of methodological issues as well. Indeed, amidst the many variables shaping the bilingual experience, which should be measured? If no reliable tool to calculate a single bilingualism index encompassing multiple aspects of bilingualism exists in the population of interest, then this variable selection should be made based on the theoretical framework around the cognitive process at hand. For example, while this study did not distinguish between the different components of language proficiency, it might be relevant for other studies to separate written and oral competences, or to separate comprehension and expression skills, just as studies in children distinguish between receptive and expressive vocabulary when relevant. The matter of proficiency also raises another issue, that of self-report versus standardised assessment. This decision should also be made based on the specificities of the study. When possible, the use of standardised assessments in all the participant's languages removes possible issues of over- and under-estimations of their proficiency. However, when targeting specific language combinations would drastically interfere with recruitment, as in the present study, then the use of a clearly-worded self-reported questionnaire may be the most appropriate strategy.

2. *Measuring cognitive and affective perspective-taking*

Tasks measuring Theory of Mind often focus only on cognitive perspective-taking, or merge cognitive and affective processing in a single output measure. However, since these modalities did not show exactly the same pattern of relationships with bilingualism and the other control variables, I recommend that both modalities should be distinguished, and measured with a single tool to allow for comparison. Furthermore, cognitive perspective-taking is often measured by simple false-belief paradigms, but instead I recommend the use, especially in adulthood, of naturalistic, ecologically valid tasks. Such tasks will better capture real life social processing, and produce more translatable findings. Such video-based or virtual-reality-based tasks will also be able to capture the wide range of social abilities existing in adulthood. However, this may have to be achieved at the expense of the distinction between implicit and explicit mechanisms.

3. *Measuring implicit and explicit perspective-taking*

The existence of implicit mechanisms has been debated in both the visual and cognitive modalities, and has not been addressed in the affective modality. Implicit processes in the cognitive and sometimes also visual domains are measured using eye tracking. In cognitive perspective-taking tasks, this is usually paired with a false-belief paradigm, with pre-verbal toddlers as well as adults. Eye-tracking is an effective method to track rapid attentional changes, and is therefore a suitable tool to measure implicit processes. However, as mentioned above, the use of more ecologically valid tasks to measure cognitive and affective perspective-taking will mean setting aside simple false-belief scenarios, and therefore the use of eye-tracking will have to be adapted to these new procedures. Indeed, the use of naturalistic videos without a fixed frame, or of virtual reality, will create new challenges for the use of eye-tracking. However, this strategy still does not allow for the precise measurement of implicit affective mechanisms. One potential method to measure them could be the use autonomic physiological measures, that can also be coupled with the naturalistic tasks used to measure explicit perspective-taking. Indeed, regarding the measure explicit processes I concur with Livingston et al. (2019), and recommend the use of ecologically-valid tasks that will allow for a more accurate presentation of the nuanced perspective-taking abilities of adults, neurotypical or autistic alike.

C. Implications for practice

1. *Speaking languages at home: Advice for parents and practitioners*

The belief that bilingualism would confuse children and delay their development used to refer to all developmental types, even typical development. This misconception has long been abandoned by the general public and clinicians alike, at least for typically-developing children. However, parents of autistic children have regularly reported that they had been advised by practitioners to abandon bilingualism with their child, as it was expected to, again, delay their development (Hampton et al., 2017). Admittedly, few studies have researched the interplay between bilingualism and autism, but to date research does not find evidence for a bilingualism-related developmental delay in autism, and my study adds to the body of evidence that, as in typical developmental, early bilingualism might actually be beneficial for children with autism.

Based on these findings, I encourage bilingual parents of both autistic and neurotypical children to maintain a bilingual upbringing. Parents of autistic children are often worried that bilingualism will be a burden for their child (Hampton et al., 2017). However, I did not find evidence supporting this concern. Instead my findings show that the learning of a second language in early childhood is not only possible for autistic people, but carries significant social cognitive benefits into adulthood. Therefore, I urge practitioners to comfort, and support parents in their decision to maintain the home language with their children, neurotypical and autistic alike. Especially in the case of autism, this rich and diverse linguistic environment provided by the parents seems to stimulate the social development of the child, which is particularly crucial in autism. Therefore, I recommend that, when possible, therapists also promote this enriched language environment, which could reinforce the positive influence of bilingualism. This beneficial relationship might also exist for children with intellectual disabilities and non-verbal children, though research involving direct assessment of these children is lacking. In the absence of clear results regarding the cognitive outcomes of bilingualism in these children, I still recommend that parents should, as much as possible, maintain the use of the home language with their child. Indeed, beyond any cognitive effect, the home language will allow the child to bond with their family and community (Jegatheesan, 2011), but will also offer the child more empowering opportunities to learn and interact with the wider autistic community (see the quotes reported above in section III.A.1, from the participants described in Chapter 2).

2. *Learning languages at school: Advice for education*

My findings present a developmental influence of bilingualism, with early bilingualism carrying greater benefits than late bilingualism, when focusing on social abilities. However, this does not mean that learning a second language later in life is worthless. Rather, I recommend that a rich language diversity should also be encouraged at school, in the context of autism just as in typical development. Indeed, it appears that when it comes to social processes, language is only key during the sensitive period of development. While it could be assumed that in autism this sensitive period is absent, my findings regarding the stimulating role of bilingualism invalidate this hypothesis. On the contrary, this sensitive period might have a delayed onset, or be slowed down, with cognitive mechanisms crystallised before having reached their full potential. As such, in autism, school education could benefit from this potentially delayed sensitivity, and provide rich and diverse linguistic inputs to encourage the child's social cognitive development.

Furthermore, I found that in autism, the effect of bilingualism on social abilities goes beyond the cognitive benefits related to early acquisition. Indeed, social life quality benefitted from the entire bilingualism experience, not only early acquisition. Autistic people can experience broader benefits of bilingualism by learning languages outwith the family and the home. School can therefore foster an environment propitious to language learning, and provide an opportunity for autistic pupils from monolingual families to also benefit from the multiple other positives of bilingualism. Indeed, being able to understand and communicate in several languages has undeniable benefits beyond cognition, in terms of access to information and leisure, educational and professional opportunities, and autistic people should not be refused the right to this learning experience and its long-term benefits. Importantly, it is necessary to point out that this cross-sectional data did not allow me to address the situation of people, autistic or neurotypical, who rejected their second language, which can occur in either population (Hampton et al., 2017). Therefore, neither parents nor practitioners or teachers should force bilingualism upon autistic children, or neurotypical children, solely for sake of potential social cognitive benefits, if the child rejects the language.

IV. Future directions

My findings unveil numerous new directions for multidisciplinary research in the fields of autism, social functioning, neurocognitive development, and psycholinguistics.

I have established that in autism and in typical development, bilingualism can enhance the development of perspective-taking abilities. The next step is to identify the ways in which bilingualism operates its influence. In terms of developmental timeline, it is possible that bilingualism increases the efficiency in acquiring perspective-taking, which leads to higher abilities by the end of the developmental phase. However, it is also possible that bilingualism advances the onset of the developmental phase, and therefore increases its duration. Addressing this question is particularly crucial in the context of autism, characterised by atypical social cognitive development. Indeed, this developmental impact of bilingualism could benefit the development of social cognition in autism, potentially by increasing the efficiency or the duration of the acquisition phase. The precise timeline of this bilingualism effect could be understood via a longitudinal study design following carefully selected children throughout their childhood. Furthermore, as discussed above (Chapter 6 section III.A.2), now that this research has highlighted that bilingualism carries its strongest effect on social cognition during childhood, the mystery remains as to what it is about bilingualism that stimulates the development of perspective-taking. Specifically addressing this relationship will allow us to better understand the developmental trajectory of social cognition and its close link with language, but this will also allow us to provide better support for parents, practitioners and educators wishing to assist children, autistic and neurotypical alike, in their language journey. This will be especially revealing in the case of autism, as many people, including some of my participants – though this factor was not addressed in the present study – have experienced delayed language development and were non-verbal in childhood. A better understanding of the developmental effect of bilingualism will also allow us to provide better support for non-verbal children living in a bilingual environment.

This research was highly exploratory, and did not investigate any interaction between the candidate predictors. The links between bilingualism and executive skills, and between executive skills and perspective-taking, lead me to include these skills in the list of candidate predictors to ensure that the effect of bilingualism was visible above and beyond the influence of executive functioning. However, it is probable that the influence of specific bilingualism factors mediates each other, or that the influence of bilingualism mediates, or is mediated by the control variables, in particular executive abilities. Therefore, future studies should aim to have sufficient power to also include key interactions between bilingualism predictors, such as age of acquisition and proficiency, and between bilingualism and control variables, such as bilingualism and executive skills. This will produce a clearer picture of the specific bilingualism effect when considering the naturalistic interplay between bilingualism and a person's cognitive abilities.

Another key aspect of the bilingualism – perspective-taking relationship that requires further investigation is the distinction between implicit and explicit processes in cognitive and affective perspective-taking – assuming that such distinction does exist. As no task currently available allowed me to directly compare both affective and cognitive perspective-taking, each at both level 1 and level 2 processes, all while measuring both implicit and explicit mechanisms, I made the decision to prioritise the comparison between modalities and levels, and only address explicit mechanisms. As such, the effect of bilingualism upon implicit perspective-taking processes is still unknown. As my research highlighted a developmental effect of bilingualism, this is a crucial question. Indeed, it has been suggested that these two routes follow distinct developmental timelines in typical developmental (Apperly & Butterfill, 2009), and might show specific impairment patterns in autism – though these exact patterns are still debated, as discussed in Chapter 4. As such, it is also plausible that these routes are differently susceptible to the influence of early bilingualism.

The findings of this research support the large body of evidence arguing for a clear distinction between the visual modality and the cognitive and affective modalities of perspective-taking, enough so that I would suggest that future studies focus instead on better understanding the similarities and differences between cognitive and affective processes. Indeed, these modalities are often merged into one mentalising ability – when affective processes are not ignored – and are rarely measured with comparable tools. However, the results showed that these two processes, though highly related, are truly distinct, especially in autism. Identifying clearly how distinct these processes are might help us to better understand the lived social difficulties of autistic people, and better support them to navigate their social world.

V. Conclusion

Autism is a lifelong developmental condition, clinically characterised by difficulties in social interactions and processes. However, this research went beyond notions of social and communication impairments, and uncovered for the first time an aspect of the autistic social and communication experience unrelated to pathology: benefits of, and joy in, language learning. Challenging presumptions and misconceptions, this thesis describes language learning in autism as neither an area of deficit, nor a savant-like curiosity. Instead, we see autistic people acquiring languages, using them, learning from them, and being shaped by them, in their life as well as in their mind, experiencing languages in as rich a way as neurotypical people do.

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Appendices

I. Appendix I. Supplementary materials of Chapter 2

1. *Supplementary materials s1: Development of the Autism & Bilingualism Census*

The Autism & Bilingualism Census (ABC) was a new online survey designed by the authors. It consists of 4 sections: Section A, General demographic information; Section B, General life satisfaction and social life quality; Section C, Language history; Section D: Open-ended questions. Section B included 4 sub-sections: Social life quality, General life satisfaction, Current mood, and Personality. Only the subsection The SLQ score used as outcome variable in the study is derived from the Social life quality sub-section only. Content for section B Social life quality and section C were inspired by existing, open-access and free-to-use measures of relevant domains. Questions were created drawing on the wording of these measures but adapted to provide a consistent response-format across items, and to be more specifically relevant to the target population (i.e. autistic adults) and research question. For example, items designed to measure language use and exposure in our adult sample were partially inspired by the BiLEC, which was designed to capture these phenomena in children. The table below provides a detailed mapping of ABC survey items against the original measures that inspired the survey. The table covers all items contained within ABC survey sections that are analysed in the current report. We do not claim to replicate the reliability or validity of the original measures in our novel survey, but merely to illustrate how our survey design was grounded in the relevant literature.

1. Social life quality

As detailed above, the Social life quality sub-section of the ABC comprised 12 items within Section B of the survey (General life satisfaction and social life quality). Item scores from this section were used to build the Social Life Quality score used as outcome measure in the present study. Supplementary Table 1 presents a direct comparison between the phrasing of the previously published questionnaires and the ABC Social life quality items. The questionnaires reviewed during design of this section were: the ESS = European Social Survey (ESS Round 8: European Social Survey Round 8 Data, 2016); the WHODAS 2.0 = World Health Organization Disability Assessment Schedule 2.0 (Üstün et al., 2010); and the WHOQOL = World Health Organization Quality of Life assessment (The Whoqol Group, 1995).

2. Language history

The Language History section of the ABC comprised 13 questions characterising language history, encompassing acquisition, proficiency, exposure, use and anything else. Each of the respondent's languages (first to seventh language) were addressed in a separate page, that included all these items. Supplementary Table 1 presents the example question set for the 2nd language. As each ABC item was inspired by multiple questionnaires, this table does not present a direct comparison of the phrasings used. The questionnaires reviewed during design of this section were: the BEQ = Bilingualism and Emotions Questionnaire (Dewaele & Pavlenko, 2001); the BiLEC = Bilingual Language Experience Calculator (Unsworth, 2013); the LEAP-Q = Language Experience and Proficiency Questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007); the LHQ = Language History Questionnaire (Li et al., 2006)

Table s1 - Construction of the Autism & Bilingualism Census – Social life quality scale and Language History

		A. Social life quality	
ABC section	ABC item wording	Source	Source Questionnaire item wording
Social life quality	I am satisfied with my personal relationships.	WHOQOL	How satisfied are you with your personal relationships?
	I find it easy to work with other people.	*n/a, new item*	
	I often meet socially with friends, family members or colleagues.	ESS	How often do you meet socially with friends, relatives and work colleagues?
	I have several friends and/or family members with whom I can discuss intimate and personal matters.	ESS	Do you have a friend or relative with whom you can discuss intimate and personal matters?
	I engage online in social activities and/or organisations related to my interests.	*n/a, new item*	
	I participate in person in group activities and/or organisations related to my interests.	ESS	Compared to other people your age, how often would you say you take part in social activities?
	I like to get involved in activities with people I know.	WHODAS 2.0	In the past 30 days, how much of a problem did you have in joining in community activities (for example festivities, religious or other activities) in the same way as anyone else can?
	I like to get involved in activities with people I don't know.		
	I can easily make new friends.	WHODAS 2.0	In the past 30 days, how much difficulty did you have in making new friends?
	I can easily maintain a friendship.	WHODAS 2.0	In the past 30 days, how much difficulty did you have in maintaining a friendship?
	I get along with people who are close to me.	WHODAS 2.0	In the past 30 days, how much difficulty did you have in dealing with people who are close to you?
	I can easily deal with people I do not know.	WHODAS 2.0	In the past 30 days, how much difficulty did you have in dealing with people you do not know?

B. Language history		
ABC section	ABC item	Questionnaires
2nd Language	What is your second language (L2)?	
	How old were you when you first encountered L2?	BEQ, BiLEC, LHQ
	How did you first encounter L2?	BEQ, BiLEC, LHQ
Current proficiency	How well do you speak L2?	BEQ, BiLEC, LHQ, LEAP-Q
	How well do you understand spoken L2?	BEQ, BiLEC, LHQ, LEAP-Q
	How well do you write L2?	BEQ, LHQ, LEAP-Q
	How well do you understand written L2?	BEQ, LHQ
Past exposure	Past exposure: While learning L2, how much did you speak it with ...? - your mother / guardian 1 - your father / guardian 2 - your brothers and sisters - other adults in the household - other members of your family - your friends - people at school / work - people in the community	BiLEC, LHQ, LEAP-Q,
Current use	Current use: With people, do you use L2 ...? - with your mother / guardian 1 - with your father / guardian 2 - with your brothers and sisters - with your partner - other members of your family - your friends - at school / work - with your flatmates - people in the community	BEQ, BiLEC, LHQ, LEAP-Q
	Current use: In your mind, do you use L2 to ...? - express emotions - swear - remember some information - do maths - think	BEQ, LHQ
	Current use: Do you use L2 when ...? - reading - watching TV / listening to the radio - using computers - tablets - doing other activities outside of home	LHQ, LEAP-Q
Open-ended	Is there anything else you wish to tell us about your L2 past exposure / past or current use?	
Next language	Do you know any other languages?	

2. *Supplementary materials s2: Language history of the respondents*

Table s2 - Respondents' Acquisition and Current Contexts of Use

L	A. Acquisition context, N (%)					B. Current context, N (%)				
	Home	School	Com.	Indep.	Tot.	Home	S/W	Com.	Indep.	Tot.
L2	202 (97.6)	2 (1.0)	2 (1.0)	1 (0.5)	207	201 (96.6)	3 (1.4)	3 (1.4)	1 (0.5)	208
L2	50 (24.0)	86 (41.3)	19 (9.1)	53 (25.5)	208	73 (35.3)	46 (22.2)	13 (6.3)	75 (36.2)	207
L3	13 (11.8)	29 (26.4)	17 (15.5)	51 (46.4)	110	15 (13.6)	24 (21.8)	7 (6.4)	64 (58.2)	110
L4	5 (9.3)	16 (29.6)	5 (9.3)	28 (51.9)	54	6 (11.1)	6 (11.1)	4 (7.4)	38 (78.4)	54
L5	1 (3.6)	10 (35.7)	1 (3.6)	16 (57.1)	28	5 (17.9)	5 (17.9)	0 (0.0)	18 (64.3)	28
L6	2 (14.3)	3 (21.4)	0 (0.0)	9 (64.3)	14	2 (14.3)	1 (7.1)	0 (0.0)	11 (78.6)	14
L7	1 (20.0)	0 (0.0)	0 (0.0)	4 (80.0)	5	1 (20)	0 (0.0)	0 (0.0)	4 (80.0)	5

Note. Some percentages do not sum up to 100% due to cumulative rounding effects.
A. Acquisition context: Number and proportion of respondents who acquired their languages (L) 1 to 7 mostly at home, at school, in the community (Com.), or independently (Indep.), and total number (Tot.) of respondents who indicated a context of acquisition for the language.
B. Current context: Number and proportion of respondents who use their languages (L) 1 to 7 mostly at home, at school or at work (S/W), in the community (Com.), or independently (Indep.), and total number (Tot.) of respondents who indicated a current context of use for the language.

II. Appendix II. Power calculations and statistical thresholds

1. *Sample size calculation script*

The sample size needed to carry out multiple regression analyses was calculated prior to recruitment using appropriate function of the *pwr* R package. For example:

```
pwr.f2.test(u = 4, v = NULL, f2 = 0.15, sig.level = 0.05, power = 0.8)
```

calculated the sample size needed to carry out a multiple regression analysis with 5 predictors (u = 4), with a medium effect size (f2 = 0.15), a significance level (sig.level) α of 0.05, and a 80% power.

The sample size n needed is calculated as follow based on the round up v result:

```
n = v + u + 1.
```

2. *Statistical thresholds*

Throughout this research, the following statistical thresholds will be used:

Table II.1 - Statistical thresholds

Measures		Interpretation			Reference
		Small / Low	Medium / Moderate	Large / High	
Pearson's correlation coefficient	r	≤ |0.5|	|0.5| to |0.7|	≥ |0.7|	(Mukaka, 2012)
Effect size	f2	≥ 0.02	≥ 0.15	≥ 0.35	(Selya et al., 2012)
Post-hoc power		≤ 50%	50 to 80%	≥ 80%	

		Poor	Questionable	Acceptable	High
Cronbach's Alpha	α	0.5 to 0.6	0.6 to 0.7	0.7 to 0.8	≤ 0.8

III. Appendix III. Adult - Theory of Mind - extended

1. *Script from the Adult-Theory of Mind test videos*

The A-ToM videos were based on the Strange Stories test (Happé, 1994a), and each social video focused on different types of social interactions (i.e. sarcasm, misunderstanding). The script of each video is provided below (Table III.1), with the corresponding Strange Stories item and social interaction type. Some characters' names were altered for clarity of the newly created social questions.

Table III.1 - Script of the Adult-Theory of Mind task

A-ToM item	**Strange Stories item**	**Social interaction type**
Bunnies	Kittens	Persuasion
Two women sit in their living room discussing their bunnies. LILA: "So you know there is a lady coming over today to take a look at the rabbits." MRS SMITH: "That's good, because you know we can't keep them all." LILA: "I know." She looks sad as she picks up one of the bunnies and cuddles it. LILA: "I just love them so much. I can't bear the thought of anything bad happening to them. They're just so beautiful and cuddly." A girl approaches the house and knocks on the front door. The door opens to reveal Lila and Mrs Smith. JESS: "Hi I'm here to look at the bunnies." LILA: "Of course, come inside." Mrs Smith, Lila and Jess are sitting in the living room. Jess is cuddling one of the bunnies. JESS: "Oh they are all so cute. It's a shame they're all have males though, I was really looking for a female bunny." LILA: "Oh that is a shame. You know if I can't find a good home for them, I'm going to have to drown them." Jess looks shocked and cuddles the bunny closer.		
Burglar	Burglar	Misunderstanding
A burglar is robbing a suburban house, and is seen taking valuables and money. He climbs out of the window of the house, and runs down the street. He runs past a policeman on his beat, and drops his glove. The policeman sees the burglar drop his glove, and picks it up and begins to run after the burglar. POLICEMAN: "Stop, you dropped your- -" Before the policeman can even finish his sentence, the burglar stops running, puts his hands up and interrupts him. BURGLAR: "Okay. You got me. I broke into the house."		

Crying man	(unnamed)	Sarcasm
A man is seen sobbing in on the couch. Anna and Bob are chatting across the room. BOB: “What’s the matter with him?” ANNA: “His wife just left him for a younger man.” BOB: “Oh no, is he doing okay?” The man bursts into tears dramatically, as Anna and Bob are watching him ANNA: “Yeah, he’s doing just fine.”		
Hat	Hat	White Lie
Two girls are sitting at a table drinking coffee. JESS: “Have you seen Aunty Jane in that silly hat?” EMILY: “I thought you loved Aunty Jane.” JESS: “I do. It’s just that hat is ridiculous.” Aunty Jane approaches the girls. She is wearing the hat. EMILY & JESS: “Oh hi Aunty Jane!” AUNTY JANE: “Hi. How do you like my new hat?” JESS: “It’s really nice, I love it!”		
Party	(unnamed)	Faux pas
Simon and Finn are standing in the corner of a party. SIMON: “So my brother knows the guy who owns this place.” FINN: “That’s funny, my brother is the guy who owns this place.” They laugh together. SIMON: “Nice. I know this might be a bit forward, but I was wondering if I could grab your number?” FINN: “Sure, but if you don’t mind, can you not tell anyone about it, as my father doesn’t know I’m gay. Only my brother knows.” SIMON: “Yeah that’s cool, I know it’s hard. My family knows but they seem pretty chill with it.” On the other side of the room Rob and Peter, are chatting to John, Finn’s dad. PETER: “So, Mr Jones it looks like my brother and your son are really hitting it off. They make a cute couple.” ROB (trying to cover it up): “Ah... Did you watch that footy game last night?” John ignores what Rob says. JOHN (To Peter): “Sorry, hitting it off’? What are you implying?” PETER (Realising what he has said) “Uh, nothing.” He turns and faces Rob. PETER: “Yeah, I saw the game! It was epic.”		

Spaghetti	(unnamed)	Sarcasm
A child and his mother are sitting at a table eating spaghetti. The boy is sitting with a full plate of food in front of him, pushing it around with his fork. His mother stands up after finishing her meal. She goes to take his plate. ANNA: “Okay, have you finished that meal there Isaac?” ISAAC: “Yes.” A close up of the bowl reveals it is full of food. ANNA: “Well. That meal must have really filled you up.”		
Car	Car	Control item
A man is at a car dealership looking at a new car for sale. He is wearing an expensive suit, suggesting he is well off. DEALER: “So have you decided?” MAN: “I’ll take the car, I really like it. I’ve got enough money, so I’ll go down to the bank and get it.” DEALER: “You can pay the car off over a 12-month period with monthly instalments.” The man completely disregards the offer, knowing it will just end up costing him more. MAN: “Oh no that’s fine, I’ll pay in full. I’m sure you guys charge interest.” DEALER: “Well we do charge interested, but it’s only 5%.” MAN: “Oh good. I get 8% in the bank, so in that case, I’ll pay in monthly instalments.” DEALER: “Does this mean you’ll take the car? MAN: I’ll take the car.” DEALER: “Congratulations.” MAN: “Thank you very much.” DEALER: “It is a very beautiful car.”		
Leg injury	Leg	Control item
An older lady steps into the doctor’s office. DOCTOR “Hi, hello, how are you?” LADY: “Hi.” DOCTOR: “Have a seat. What can I do for you today?” LADY: “Well yesterday I fell over on my icy doorstep. I did get up straight away, although I did feel quite shaken and bruised. And when I woke up this morning I could scarcely walk. And my leg feels really stiff.” DOCTOR: “Hmm, let me take a look, and let me know if you feel any pain.” She analyses the swollen leg, looking quite concerned. DOCTOR: “It looks quite swollen. I’m going to have to send you to the casualty department at the hospital, and they’re going to need to take an x-ray.”		

Librarian	Mrs Simpson	Control item

Mrs Simpson, a librarian sits at her desk, using the computer. A boy approaches her holding a book.
BOY: “Hi Mrs. Simpson, I have a book here you may want to put in your library. Which section would you like to put it in?”
MRS SIMSPON: “Well our library has a lot of different sections, what’s the book about?”
BOY: “It’s about plants and their medical uses. It’s heavily illustrated.”
MRS SIMPSON: “Ah I know the perfect place for it.”
BOY: “Are you going to put it with the rest of the books on botany or medicine?”
MRS SIMPSON: “No, I have a special room for this book, where all the books are kept in special cases at a constant temperature. I think I’ll put it in that room.”

Light bulbs	Light bulbs	Control item

John is looking at light bulbs, a sales assistant approaches him.
ASSISTANT: “Excuse me sir, can I help you there?”
JOHN: “Yes, I’ve just bought a new for my desk, and I need a new light bulb for it.”
ASSISTANT: “Oh right, okay, well you can buy the Litebrite here, which comes in a single, or you can pay just a little bit more and get the Everbright, which comes in a pack of ten.
JOHN: Well I only need the one, but I think I will take the pack of ten. Thank you.”
ASSISTANT: “Have a good day”

Lost glasses	Glasses	Control item

Sarah is looking around for her glasses. Ted is sitting on the couch watching television
SARAH: “Ted, have you seen my reading glasses?”
TED: “When did you last have them?”
SARAH: “I had them yesterday evening when I was looking at the TV programs. Can you help me find them please?”
Ted picks up a piece of paper next to him, looks underneath, sees nothing, then looks straight back at the TV.
TED: “Can’t find them.”
SARAH: “Seriously Ted. I need them.”
Ted gives in, switches off the TV and stands up.
TED: “Fine. Try retracing your steps. What did you do today?”
Sarah thinks for a moment.
SARAH: “Well I went to my early morning fitness class, then the post office, and the flower shop.”
Ted grabs his car keys and heads for the door, without wasting a second.
TED: “Come on then, we’ll try the post office first.”

Swimming competition	Armies	Control item

A boy and girl sit on the beach looking at the ocean.
BOY: “Oi, wanna have a swimming race?”
GIRL: “Uh, yeah, sure.”
BOY: “I’m definitely going to win.”
GIRL: “Uh no you’re not, I’m a much better swimmer.”
BOY: “You’re a better than me in the pool, but I always win in the ocean.”
GIRL: “Okay then, I’ll race you to the jetty and back.”
BOY: “Ready, set, go!”
They jump up off the sand and run out into the ocean.
Fade to black.
Both children are running out of the water, with the boy in front. The boy throws his arms into the air.
BOY: “And Harry wins! See? I told you I could beat you.”

2. A-ToM-e questions and scoring criteria

The scoring criteria of the A-ToM-e is provided below (Table III.2). The scoring criteria of the Control physical question and the general question followed those of the original A-ToM task. For the newly-designed social questions the scoring followed similar criteria to those described by Mckinnon & Moscovitch (2007) for the Social Scenarios Task, a text-based level 1 and level 2 cognitive and affective theory of mind task.

Table III.2 - Marking scheme of the Adult-Theory of Mind-extended task

	Bunnies	
General	***"Why does Lila say she will have to drown the rabbits?"***	
Score	Definition	Examples
2	Reference to persuasion, manipulating feelings, and MUST include reference to trying to induce pity/guilt/make her feel bad, encourage to buy etc. "Convince" or "encourage" alone are not enough.	*"To make the girl feel guilty and take a rabbit"* *"She is lying to try to guilt her into taking a rabbit"* *"Trying to pressure her"*
1	Reference to outcome (to sell them), or simple motivation (to make Jane sad), or make clear that the statement was not true.	*"To get rid of them"* *"She couldn't keep them"*
0	Reference to general knowledge or dilemma, without realisation that statement was not true, or no answer, or incorrect facts.	*"She can't keep them, it's kinder to kill them"* *"She's evil, and the authorities should be called"*
Level 2 cognitive	***"What does Jess think Lila thinks when she says she will have to drown the bunnies?"***	
2	Reference to Jess believing Lila, or Jess correctly perceiving the manipulation.	*"Jess thinks that Lila thinks that Jess won't take any of the bunnies"*
1	Reference to understanding she cannot keep them, or factually correct information which may include comments about thoughts, but no specific reference to the manipulation.	*"Jess thinks that Lila thinks it'll be unfortunate to have to drown the bunnies, but it'll have to be done"*
0	No answer, or incorrect facts, or no information about Lila's internal states.	*"She thinks that she is a bad person"*
Level 2 affective	***"How does Jess think Lila feels about the rabbits when she says she will have to drown them?"***	
2	Reference to negative feelings, or reference to loving the bunnies, and awareness of manipulation.	*"Jess thinks Lila doesn't like the rabbits"*
1	Reference to Lila's mixed feelings, or partial understanding that Jess thinks Lila has negative thoughts.	*"Jess thinks that Lila is sorry that she has to drown them, but that she still has to do it"*
0	No answer, or incorrect facts, or no reference to Lila's feelings.	*"Jess thinks that Lila loves the rabbits and doesn't want to drown them"* *"Jess seems confused"*

Level 1 cognitive	***"What does Jess think about the bunnies?"***	
2	Reference to positive feelings.	*"Jess really likes the bunnies"*
1	Some confusion over feelings that Jess has, or confusion with Lila's feelings or previous answers.	*"Jess feels sorry for the bunnies"*
0	No answer, or incorrect facts.	*"That there is no need to drown them"*
Level 1 affective	***"How does Lila feel about the bunnies?"***	
2	Reference to positive feelings.	*"Leila also really likes the bunnies"*
1	Some confusion over feelings that Lila has, or confusion with Jess' feelings or previous answers	*"Lila likes the bunnies but knows that she can't keep them so she tries to get rid of them."*
0	No answer, incorrect facts.	*"She doesn't like the bunnies"*

	Burglar	
General	***"Why does the burglar give himself up?"***	
2	Reference to burglar's ignorance of policeman's true intention/knowledge state (Answer MUST have some reference to the thoughts of the policeman – i.e. the policeman had some knowledge/assumption/thought of the burglar's wrongdoing).	*"He didn't know the policeman just wanted to return his glove"* *"He thought the policeman had seen him rob the shop"* *"Because he thought the policeman had caught him stealing"*
1	More general reference to burglar's state of mind or outcome, or answer may reference thoughts of the policeman, but fails to link to policeman's knowledge/assumption/thought of the burglar's wrongdoing.	*"He thought he was being arrested"* *"He had a guilty conscience"* *"He thought the police might shoot otherwise"* *"He thought he had been caught"*
0	No answer, or incorrect facts, or reference to irrelevant facts/mental states.	*"He just wanted to come clean"* *"The burglar gives himself up because he thinks he's dropped something he's stolen"*
Level 2 cognitive	***"What does the burglar think the policeman thinks when he calls him?"***	
2	Reference to the policeman knowing about the robbery.	*"The burglar thinks the policeman knows he robbed the house"*
1	Reference to the policeman wanting to stop the burglar, but no reference to the robbery or the window.	*"The burglar thinks that the policeman thinks that he is the burglar, that he has done something wrong"* *"He thinks the policeman caught him"*
0	No answer, or incorrect facts.	*"He wants to give him his glove back"*.
Level 2 affective	***"What does the policeman think the burglar feels when he confesses?"***	
2	Reference to negative feelings (shocked, scared, guilty).	*"The policeman thinks the burglar feels shocked"*
1	Reference to positive feelings (relieved), or partial answers, or policeman's thoughts about the burglar, not the burglar's feelings, or confusion about the burglar's feelings.	*"He thought he was caught"*. *"The policeman thinks the burglar feels relieved or guilty which is why he confesses."*
0	No answer, or incorrect facts.	*"The policeman is confused"*
Level 1 cognitive	***"What does the policeman think when he calls the burglar?"***	
2	Reference to the glove and/or not knowing about the robbery.	*"He wants to give him back his glove"*
1	Partial answer without reference to the glove and/or not knowing about the robbery.	*"The policeman thinks that he is just someone in a hurry"*
0	No answer, incorrect facts, or reference to the policeman knowing about the robbery.	*"He wants to catch the burglar"*
Level 1 affective	***"What does the policeman feel when the burglar confesses?"***	
2	Reference to an emotion involving the policeman not knowing about the robbery (surprised, confused, shocked).	*"The policeman is surprised"*
1	Partial answer, or answer implying the policeman knew about the robbery (proud).	*"He feels…it's unexpected. He feels amazed probably."*
0	No answer, or incorrect facts	*"He feels he needs to arrest the burglar"*

	Crying man	
General	***"Why did Anna say "he is doing just fine"?"***	
2	Reference to the woman's use of sarcasm/irony/not being serious/being funny/ridicule/derision, the man is clearly not fine. (Answer MUST reference sarcasm/irony/not being serious/being funny/ridicule/derision). Simply 'sarcasm' is enough for 2 points.	*"Anna was kind of making fun of or questioning because it was clear that the other guy was not doing fine at all."*
1	Reference to the fact that the man is clearly not fine but without reference to sarcasm/irony/not being serious/being funny/ridicule/derision.	*"Because he is not fine"* *"He is obviously not ok"*
0	No answer, or incorrect facts.	*"She doesn't want to get involved"* *"Maybe she thinks he is actually ok"*
Level 2 cognitive	***"What does Bob think Anna thinks when she says "he is doing just fine"?"***	
2	Reference to understanding sarcasm, or reference to Anna thinking his question was inappropriate.	*"Bob knows she is being sarcastic and she doesn't think he is doing fine"*
1	Partial answer, or several steps needed to get to the sarcasm.	*"Maybe Bob thinks that Anna thinks that the guy is fine, but maybe Bob also understand that she was being sarcastic."* *"Bob thinks that Anna is making fun of him."*
0	No answer, or incorrect facts, or thoughts of Anna not Bob.	*"He thinks she is mean"*
Level 2 affective	***"How does Anna think the crying man feels when she says "he is doing just fine"?"***	
2	Reference to negative emotions.	*"She thinks he feels awful"*
1	Partial or confused answer.	*"She thinks that the crying man feels bad, but also that perhaps he's overdoing it"*
0	No answer, incorrect facts	*"She thinks he is fine"*.
Level 1 cognitive	***"What does Anna think when she says "he is doing just fine"?"***	
2	Reference to negative thoughts/feelings.	*"She thinks he feels bad"*
1	Partial or confused answer.	*"Anna thinks that Bob is asking silly questions."*
0	No answer, or incorrect facts.	*"She thinks he feels fine"*.
Level 1 affective	***"How does the crying man feel?"***	
2	Reference to negative feelings, or reference to the reason why he feels bad.	*"He feels awful"*
1	Partial or confused answer.	*"Frustrated"*
0	No answer, or incorrect facts.	*"He's a bit taken aback"*

Hat		
General	***"Why did Jess say she loves the hat?"***	
2	Reference to white lie or wanting to spare the aunt's feelings or cause offense/hurt aunt's feelings (Answer MUST include reference to the feelings of the aunt).	*"To please her aunt"* *"To make her aunt happy"* *"She didn't want to disappoint Auntie Jane"*
1	More general reference to trait (politeness), relationship, or social rules.	*"She's a nice person"* *"She likes her aunt"* *"It's the socially appropriate thing to do"*
0	No answer, or incorrect/irrelevant facts or feelings.	*"She likes the hat"* *"She wants to trick her"*
Level 2 cognitive	***"What does Auntie Jane think Jess thinks of her hat?"***	
2	Positive terms associated with the hat, or reference to Auntie Jane believing Jess.	*"Auntie Jane thinks Jess thinks the hat is really nice"*
1	Partial answer, or confusion with previous answers and own knowledge.	*"She should know that Aunty Jane came up a bit quickly after they were talking about the hat"*
0	No answer, or incorrect facts, or thinking that she heard the conversation between the girls.	*"She thinks it's ridiculous"*
Level 2 affective	***"How does Jess think Auntie Jane feels when she says she loves the hat?"***	
2	Positive feelings for Jane.	*"She is happy"*
1	Partial answer, or confusion with previous answers and own knowledge.	*"I am not sure if she really reckons that her Aunt believes she is loving that hat"*
0	No answer, or incorrect facts.	*"She knows Jess is lying"*.
Level 1 cognitive	***"What does Jess think of Auntie Jane's hat?"***	
2	Negative terms.	*"She thinks it's ridiculous"*
1	Partial or confused answer, or not clear that she doesn't like the hat.	*"I don't think Jess really likes that hat very much. She would have been wiser saying, 'oh Aunty Jane it's very colourful', a bit more neutral"*
0	No answer, or incorrect facts.	*"She thinks it's really nice"*
Level 1 affective	***"How does Auntie Jane feel when Jess says she loves her hat?"***	
2	Positive feelings for Jane.	*"She is happy"*
1	Positive feeling but not for the right reason (reassured).	*"Aunty Jane should feel reassured about her recent Australian fashion buy, even if it isn't true"*
0	No answer, or incorrect facts.	*"She knows Jess is lying"*.

	Party	
General	***"Was there anything awkward or uncomfortable in this interaction? If so, what was it?"***	
2	"Yes" + reference to the man making the situation awkward by assuming the man knew his son was gay and bringing it up in conversation. Some acknowledgment that one father was unaware and was now made aware.	*"Yes it was very awkward because Peter accidentally outed Finn to John"*
1	"Yes" + no further explanation, or "Yes" + reference to incorrect facts/intentions, or reference to attraction blooming/developing but no clear reference to the fact that the man let slip the young men were gay.	*"It was a bit uncomfortable for John, the father of Finn, because Peter kind of, was kind of saying that his son likes the other boy"*
0	"No", or no answer, incorrect facts	*"The thing that was awkward was the fact that the conversation got interrupted and he couldn't explain what he meant"*
Level 2 cognitive	***"At the beginning of the conversation between John and Peter, what does Peter think John believes about Finn?"***	
2	Reference to Peter thinking John knows his son is gay.	*"Peter thinks that John knows that Finn is gay"*
1	Partial or confused answer.	*"Peter probably knows that John is implying that Finn is gay"*
0	No answer, or incorrect facts	*"He thinks he is gay"*
Level 2 affective	***"At the end of the conversation between John and Peter, how does Peter think John feels?"***	
2	Reference to negative feelings (shocked, confused) implying John didn't know.	*"Peter thinks John is confused"*
1	Reference to mild feelings (surprised), or negative emotion not implying he didn't know.	*"Peter picked up that John clearly wasn't happy about the fact that his son was gay"*
0	No answer, or incorrect facts (positive feelings), or reference to Peter's feelings not John's.	*"I think Peter thinks he made a big mistake, and I think John feels surprised"*
Level 1 cognitive	***"At the beginning of the conversation between John and Peter, what does John believe about Finn?"***	
2	Reference to John not knowing about Finn's homosexuality and thinking he is straight.	*"John believes Finn is straight"*
1	Partial or confused answer, or not clear about the fact that John didn't know about Finn.	*"John believes that Finn is making friends"*
0	No answer, or incorrect facts.	*"He thinks he is gay"*.
Level 1 affective	***"At the end of the conversation between John and Peter, how does Peter feel?"***	
2	Reference to negative feeling (unease, awkward).	*"Peter feels embarrassed"*
1	Partial or confused answer, or factually correct but not actually feelings.	*"Peter feels that he might just have outed Finn accidentally"*
0	No answer, or incorrect facts.	*"I don't think Peter felt anything, he didn't pick up that John was upset"*

	Spaghetti	
General	***"When the mother said 'that meal must have filled you up' did she mean it? If not, why did she say it?"***	
2	"No" + reference to the mother's use of sarcasm/irony/humour/derision/ridicule (Answer MUST reference sarcasm/irony/not being serious/being funny/ridicule/derision). "No" + "sarcasm" is enough for 2 points.	*"She did not mean it, she was being sarcastic"*
1	"No" + no further explanation, or "No" + reference to incorrect/irrelevant facts.	*"She didn't mean it. It was a comment implying that he actually didn't eat everything"*
0	"Yes", or no answer, or incorrect facts.	*"Her facial expression was not happy when she picked up the full plate"*
Level 2 cognitive	***"What does Isaac think Anna thinks when she says 'that meal must have filled you up'?"***	
2	Reference to understanding of sarcasm, and/or the reason why she is using sarcasm (disappointment).	*"Isaac thinks that Anna is disappointed but does not necessarily care"*
1	Reference to Isaac not understanding sarcasm, believing Anna or thinking she is joking.	*"Isaac probably thinks Anna thinks he really is full or he's just not hungry"*
0	No answer, or incorrect facts, or answer about Anna, not Isaac.	*"She knows that it didn't fill him up because he didn't eat it"*
Level 2 affective	***"What does Anna think Isaac feels when she says 'that meal must have filled you up'?"***	
2	Reference to negative feelings.	*"She thinks that he probably feels a bit bad for not eating his dinner"*
1	Partial or confused answer.	*"Anna knows that Isaac is slightly irritated by what she said"*
0	No answer, or incorrect facts, or perspective-taking but no clear feelings, or what Anna hopes/wants to induce.	*"I think she's hoping that Isaac feels bad for not eating his food."* *"She tries to generate shame in Isaac"*
Level 1 cognitive	***"What does Anna think when she says 'that meal must have filled you up'?"***	
2	Reference to negative thoughts, acknowledging the sarcasm.	*"Anna thinks that the meal has not filled Isaac up. She may be a bit upset because she prepared the meal, so it's rude of Isaac not to eat it"*
1	Partial or confused answer, states facts, or understanding that she didn't mean it but not expressed clearly.	*"Anna thinks that he hasn't eaten much"* *"Anna thinks she is being ironic about it"*
0	No answer, or incorrect facts.	*"Anna thinks he is still hungry"* *"Anna is worried about him"*
Level 1 affective	***"What does Anna feel when Isaac says he is done eating?"***	
2	Reference to negative feelings (angry, irritated, not happy, unappreciated, sad).	*"She feels annoyed or disappointed that he didn't finish his meal"*
1	Partial or confused answer, no clear negative feeling (surprised, confused).	*"She feels sorry he didn't like the meal"*
0	No answer, incorrect facts. Anna's thoughts, not feelings.	*"She feels like she wasted a meal"*

	Car	
Control	***"Why does he accept the dealer's offer to pay in monthly instalments?"***	
2	Reference to relative gain from leaving money in the bank due to greater interest gained on savings than spent on monthly instalment payments (exact figures not necessary, but must suggest interest is better/different/more etc.). Must say *"better THAN the bank"*.	*"The interest rate is better than what it would be in the bank"*
1	General reference to saving money that way, or it being the sensible thing to do, or general reference to interest rates but without specific reference to saving money based on interest rates, *"better rate"* but no more details.	*"Because of the interest rates"* *"He thought it was the smart thing to do"* *"Because it's more convenient"*
0	No answer, or incorrect facts	*"He can't afford the whole thing"* *"He wants to keep some money in the bank to pay bills"*

	Leg injury	
Control	***"Why does she need an x-ray?"***	
2	Reference to the possibility that she has fractured/broken/cracked/split her leg, or seems to have understood that she may have caused further injury to her leg and there is a need to assess this damage.	*"They want to see if she has broken anything"* *"She may have fractured her hip"* *"The possibility of a fracture"* *"She may have damaged her bone""*
1	Reference to general aim, or not specific to checking the leg for further injury.	*"To check for bigger injuries"* *"To see what's wrong"* *"Because of her fall"*
0	No answer, or incorrect facts.	*"That's what doctors do"* *"It's standard procedure"*

	Librarian	
Control	***"Why did the librarian put the book in a special room?"***	
2	Reference to delicate condition of the book due to age/value, or reference to preservation/ protection/keeping it safe is suffice, may reference temperature control in the room.	*"It may be old and requires special handling"* *"To protect it"*
1	General reference to special status of the book, not further explanation.	*"The book is old"* *"It is special"*
0	No answer, or incorrect facts, or reference to other motivations not warranted by the story	*"The book is large"* *"So that she would know where to find it"* *"The book contains plant specimens"*

	Light bulbs	
Control	***"Why does the buyer buy the pack of 10?"***	
2	Reference to saving money (since multipacks are cheaper), may also, but needn't mention convenience of having more or future need for more than one bulb.	*"Better value"* *"Cheaper in bulk"* *"Saves money that way"*
1	Reference to convenience of having more, or future need for more than one bulb. No mention of saving money or better value, *"worth it"* but no reference to saving money.	*"So that he won't have to keep going out to the store"* *"In case one blows"* *"He will need more later"*
0	No answer, irrelevant or incorrect facts, or references to characteristics of salesman	*"He likes that brand the best"* *"It was a good sales pitch"*

Lost glasses		
Control	***"Why is the post office the most likely place to look?"***	
2	Reference to post office being the place she would most likely use her glasses (to read/write/fill out forms), or that she wouldn't need them at gym/flower shop.	*"It was the most likely place she would have left them/would need to use them"*
1	Partial or confused answer, or general reference to post office being where she left them.	*"Because she maybe has left there her glasses"*
0	No answer, or incorrect facts	*"That was the last or first place she went"* *"He decided to go there first as it was the closest"*
Swimming competition		
Control	***"Why did the boy win?"***	
2	Reference to the race being in the ocean/waves/surf/beach not a swimming pool, or that the boy is faster in the ocean/waves/surf/beach (Answer MUST reference ocean/waves/beach/surf).	*"He is better in the ocean"* *"He has more experience in the ocean"*
1	Partial or confused answer.	N/A

3. *Inter-rater agreement*

The full dataset combining neurotypical and autistic participants (prior to any exclusion due to age in the neurotypical group, or absence of clinical diagnosis of autism in the autistic group) included 139 participants, and was scored by two researchers. One neurotypical participant encountered technical issues and did not have any data for this task. The lead researcher scored the responses of 64 participants (46% of the data), the research assistant individually scored the responses of 38 participants (27%), and the responses of 37 participants (27%) were scored by both researchers. Inter-rater agreement was verified with these responses on each question (Table III.3). Across all outcome measures, the lowest mean agreement rate was 88%, which indicated high inter-rater agreement. For the double-scored responses, when there was disagreement between the researchers, the score given by the lead researcher was the one kept for the rest of the analysis.

Table III.3 - Inter-rater agreement rates

Score	**Mean agreement rate (range) (%)**	**Sub-scores**	**Mean agreement rate (range) (%)**	**Sub-scores**	**Mean agreement rate (range) (%)**
Physical					94 (84 – 100)
Social	91 (68 – 100)	General			93 (81 – 100)
		Cognitive	91 (68 – 100)	Level 1	94 (76 – 100)
				Level 2	88 (68 – 100)
		Affective	90 (78 – 100)	Level 1	91 (78 – 100)
				Level 2	89 (81 – 97)

Note. Inter-rater agreements calculated for each outcome measure, as a percentage of equal score between both researchers. The mean agreement was calculated across all the questions included in each score, and the range indicates the lowest and highest agreements rates.

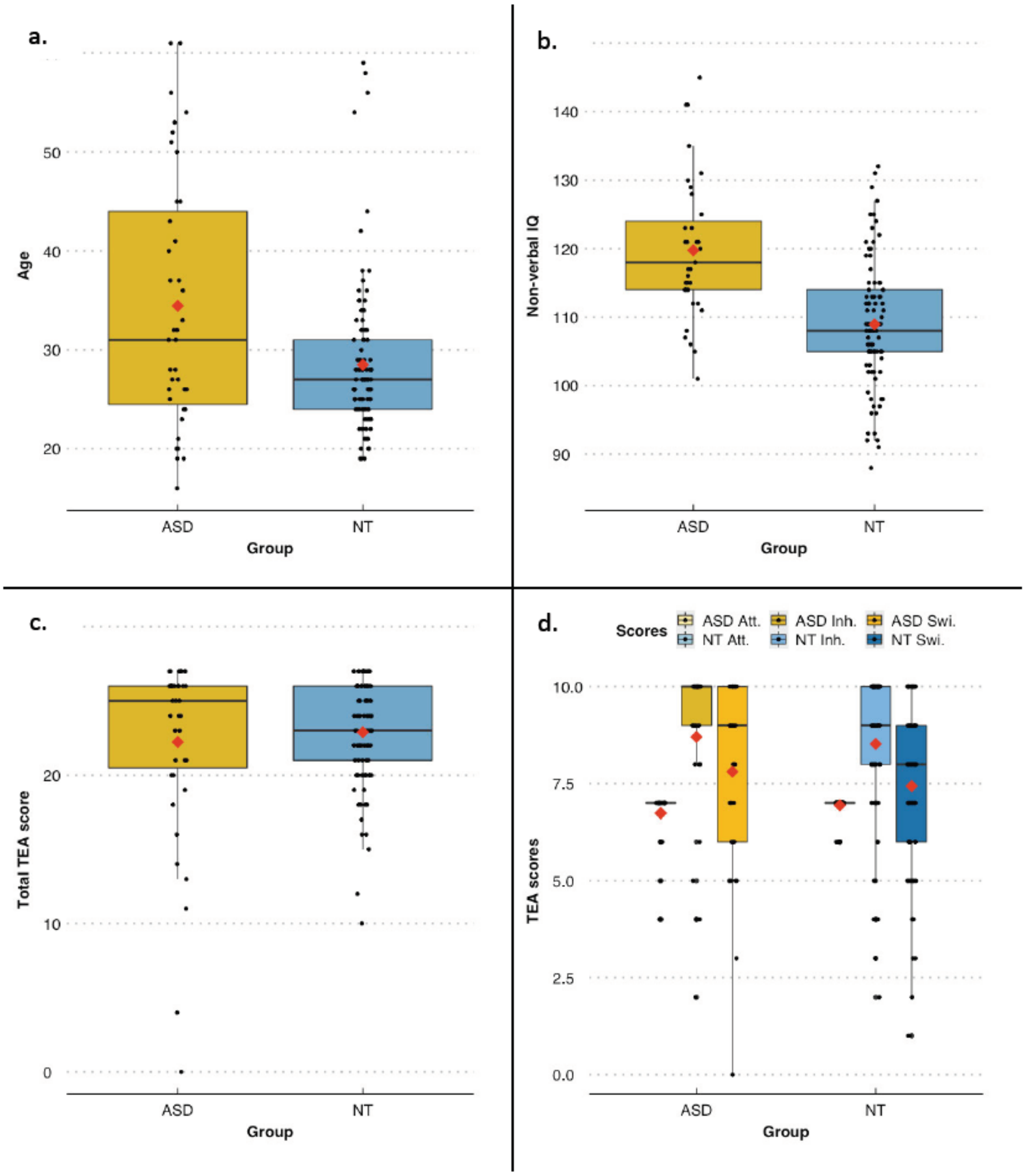
4. *Internal consistency*

Internal consistency was verified for each outcome measure across the videos using Cronbach's Alpha. While the overall social score had an acceptable internal consistency (α = 0.77), all other outcome measures had a low internal consistency (α < 0.6). This was interpreted as the wide range of difficulty in across the various types of social interaction presented (i.e. sarcasm, faux pas). As no single video was identified as consistently lowering in internal consistency scores, all the videos were kept in the analysis.

IV. Appendix IV. Predicting and outcome variables, neurotypical and autistic sample

1. *Control variables*

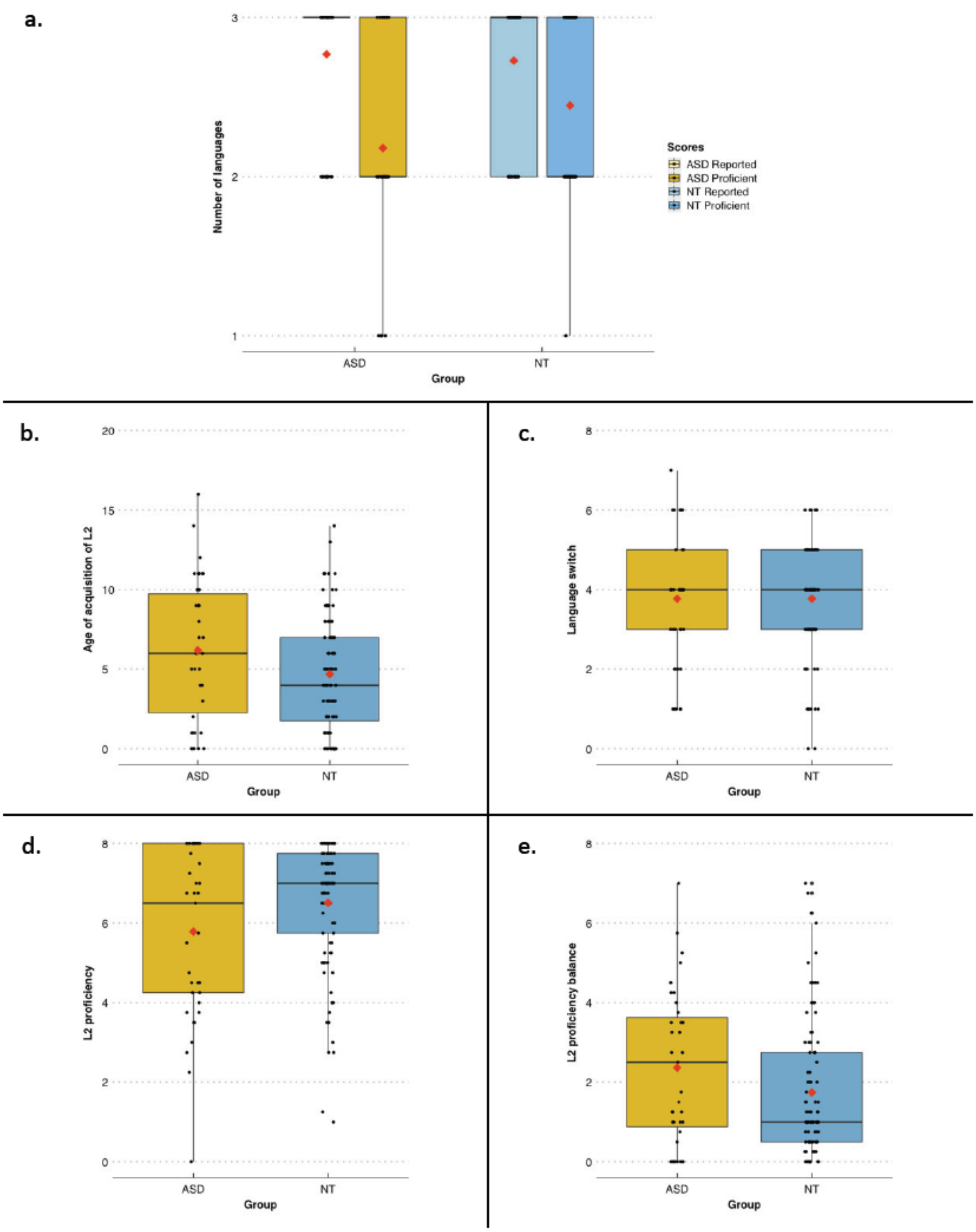
Figure VI.1 - Distribution of the control measures for the autistic and neurotypical participants



Note. Box-plot and scatter-plot diagrams showing for the autistic (yellow) and neurotypical (blue) groups: a. the chronological age in years, b. the non-verbal IQ, c. the total executive function score, d. the individual executive function scores. Each dot of the scatter-plots represents one participant, red lozenges represent the means of each condition. ASD = autistic participants, NT = neurotypical participants. In d.: Att. = sustained attention, Inh. = attention inhibition, Swi. = attention switching.

2. Bilingualism variables

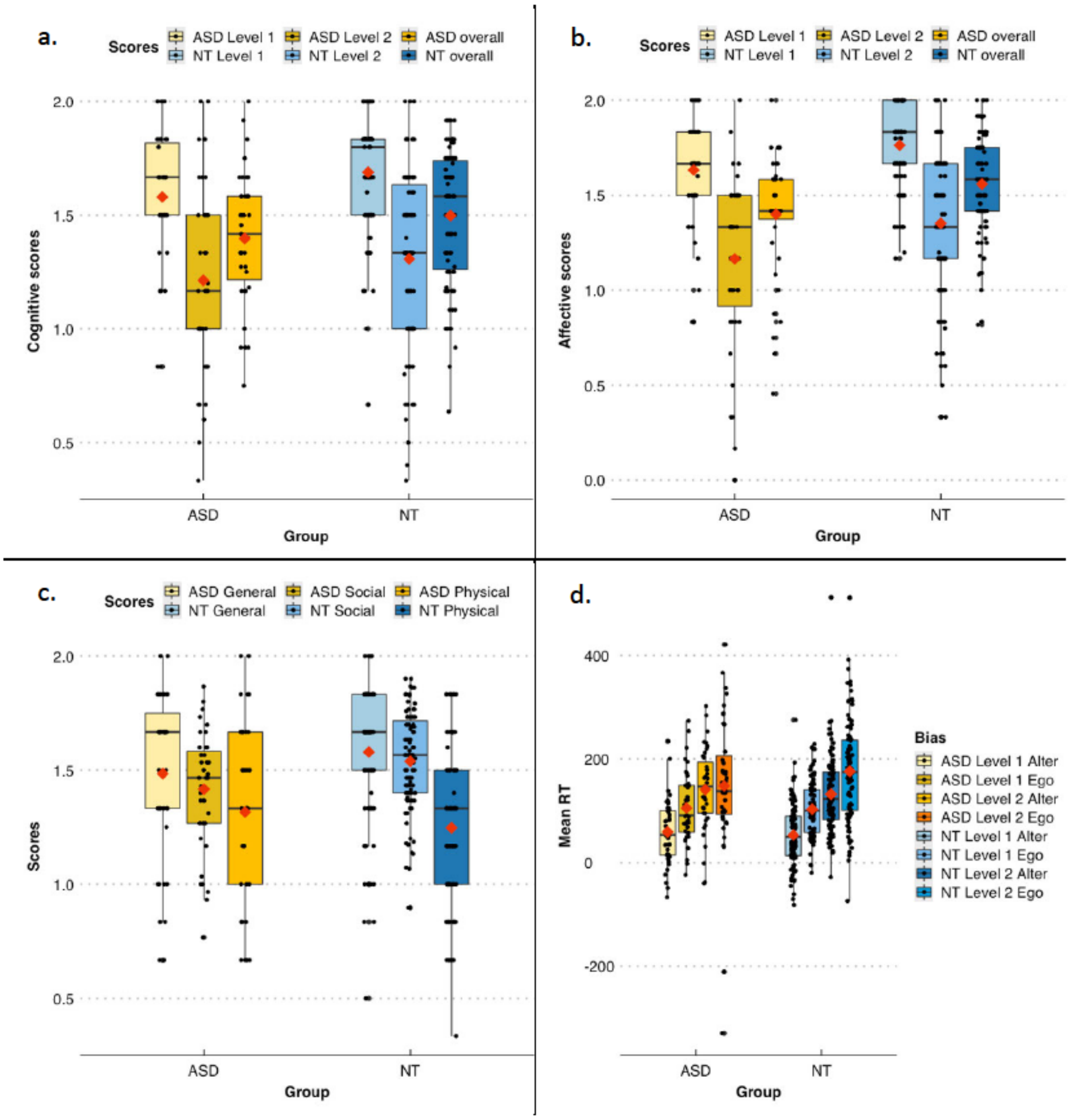
Figure VI.2 - Distribution of the bilingualism measures



Note. Box-plot and scatter-plot diagrams showing for the autistic (yellow) and neurotypical (blue) groups: a. the number of languages reported ("Reported") and known with an average to high proficiency ("Proficient"), b. the age of acquisition of the second language in years, c. the amount of language switching, d. the overall proficiency in the second language, e. the proficiency balance between the first and second language. Each dot of the scatter-plots represents one participant, red lozenges represent the means of each condition. In a. "3" corresponds to "3 or more languages". ASD = autistic participants, NT = neurotypical participants.

3. *Outcome variables*

Figure VI.3 - Distribution of the outcome measures



Note. Box-plot and scatter-plot diagrams showing for the autistic (yellow) and neurotypical (blue) groups: a. the cognitive modality scores, b. the affective modality scores, c. the general, overall social, and control physical scores, d. the visual modality mean response time (RT) in milliseconds. Each dot of the scatter-plots represents one participant, red lozenges represent the means of each condition. ASD = autistic participants, NT = neurotypical participants. In d.: Alter = altercentric, Ego = egocentric.

V. Appendix V. Perspective-taking in autism, overview of the literature

Table V.1 - Studies included in the literature review presented in Chapter 4 section I.A.2

Article	Group	Age	Task	Level	Mod.	Exp.	Results
Baron-Cohen et al, 1985	20 ASD 27 NT	11.0 4.4	- False-belief (Sally – Anne)	L1	C	E	ASD < NT
Mazza et al, 2017	52 ASD 55 NT	8.2 7.4	- Comic Strip Task	L1	C + A	E	ASD < NT
Pino et al, 2017	37 ASD 55 NT	8.0 7.1	- Comic Strip Task	L1	C + A	E	ASD < NT NT improved with age, not ASD
Peterson & Wellman, 2018	43 ASD 37 NT	T1 = 8.1, T2 = 9.5 T1 = 7.3, T2 = 8.5	- 6-step ToM Scale (diverse desires, diverse beliefs, knowledge access, false-belief, hidden emotions, sarcasm) - 3 standards False-belief tasks	unclear	C	E	ASD < NT ASD and NT improved with age
Scheeren et al, 2016	132 ASD 41 NT	10.2 and 15.2 9.8 and 14.0	- Strange stories (adapted)	L1	C	E	ASD = NT

Senju et al, 2009	19 ASD	36.8	- False-belief task with eye tracker	L1	C	E + I	Explicit: ASD = NT
	17 NT	39.6					Implicit: ASD < NT
Schneider et al, 2013	24 ASD	31.4	- Strange stories	unclear	C	E + I	Explicit: ASD = NT
	20 NTs	27.7	- ToM Scale (diverse desires, diverse beliefs, knowledge access, contents false-belief, explicit false-beliefs, belief emotion, real-apparent emotion) - False-belief task with eye tracker				Implicit: ASD < NT
Cole et al, 2017	17 ASD	23.7	- video-based task of intention inference	L1	C	E + I	Explicit: ASD < NT
	17 NT	23.7					Implicit: ASD = NT
Happé, 1994a	18 ASD	20.6	- Strange Stories	unclear	C	E	ASD < NT
	10 NT	20.5					
Jolliffe & Baron-Cohen, 1999	34 ASD	30.7 and 27.8	- Strange Stories	unclear	C	E	ASD < NT
Murray et al, 2017	20 ASD	30.6	- Strange Stories Film Task	unclear	C	E	Accuracy: ASD < NT
	20 NT	30.7					Mental state language: ASD = NT

Brewer et al, 2017	163 ASD	27	- Adult - Theory of Mind task	unclear	C	E	ASD < NT
	80 NT	26.1					
Heavey et al, 2000	16 ASD	34.7	- Awkward Moment Test	unclear	C	E	ASD < NT
	15 NT	30.7					
Booules-Katri et al, 2019	35 ASD	18.6	- Strange Stories	unclear	C + A	E	ASD < NT
	36 NT	19.4	- Faux Pas test				
			- RMET				
Pedreno et al, 2017	35 ASD	18.6	- Strange Stories	unclear	C + A	E	ASD < NT
	35 NT	19.4	- Faux Pas test				
			- RMET				
Rosenblau et al, 2015	28 ASD	33.1	- Arena of Emotions Task	unclear	C + A	E	ASD < NT
	23 NT	32.4					

Note. Summary table of the studies covered in the literature presented in Chapter 1.IV.F.2. Studies are listed in the same order as in the literature review. The first section of the table (7 articles) covers studies focusing on children, the second section (4 articles) covers studies focusing on adolescents, the third section (10 articles) covers studies focusing on adults. Age given in years. ASD: autism, NT: neurotypical. Mod.: modality. C: cognitive. A: affective. E: explicit. I: implicit. ASD < NT: autistic participants performed significantly lower than neurotypical participants. ASD = NT: no significant difference between autistic and neurotypical participants.

VI. Appendix VI. Neurotypical models applied to the autistic sample

Level 1 egocentric bias - Neurotypical model

Model 1ERT (level 1, egocentric, response time) included the following predictors: non-verbal IQ and L2 age of acquisition. It was applied to a subsample of 34 participants (four participants had missing non-verbal IQ scores, one had outlying L2 age of acquisition). Upon analysis of the regression assumptions, one data point was identified as highly influential values further than Cook's distance, and this point was excluded from the model, and the model then involved 33 participants. Following this, the data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Non-verbal IQ significantly predicted egocentric bias scores (β = -2.26, p = 0.041), but L2 age of acquisition did not (β = 3.24, p = 0.23). The results of the regression indicated that model 1ERT explained 12% of the variance, and was not a significant predictor of level 1 egocentric bias (R^2 = 0.17, R^2_{adj} = 0.12, F(2,30) = 3.11, p = 0.059).

Level 1 altercentric bias - Neurotypical model

Model 1ART (level 1, altercentric, response time) included the following predictors: non-verbal IQ; TEA inhibition; TEA switching. It was applied to a subsample of 32 participants (two participants had outlying or missing non-verbal IQ scores, one had outlying TEA inhibition, one had outlying TEA switching, three had outlying or missing scores in all three predictors). Upon analysis of the regression assumptions, one data point was identified as highly influential values further than Cook's distance, and this point was excluded from the model, and the model then involved 33 participants. Following this, the data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted altercentric bias (non-verbal IQ: β = -1.88, p = 0.11; TEA inhibition: β = -15.17, p = 0.074; TEA switching: β = 11.33, p = 0.11). The results of the regression indicated that model 1ART explained 1% of the variance, and was not a significant predictor of level 1 altercentric bias (R^2 = 0.15, R^2_{adj} = 0.06, F(3,27) = 1.59, p = 0.21).

Level 2 egocentric bias - Neurotypical model

Model 2ERT (level 2, egocentric, response time) included the following predictors: age; and TEA switching. It was applied to a subsample of 34 participants (three participants had missing TEA switching scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. Neither age (β = - 0.98, p = 0.44) nor TEA switching (β = 2.84, p = 0.71) significantly predicted level 2 egocentric bias scores. The results of the regression indicated that model 2ERT explained 0% of the variance, and was not a significant predictor of level 2 egocentric bias (R^2 = 0.023, R^2_{adj} = -0.040, F(2,31) = 0.37, p = 0.70).

Level 2 altercentric bias - Neurotypical model

Model 2ART (level 2, altercentric, response time) included the following predictors: N language R-group; N language P-group; TEA switching. It was applied to a subsample of 36 participants (three participants had missing TEA switching scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted altercentric bias (N language R-group: β = 17.65, p = 0.63; N language P-group: β = -10.61, p = 0.66; TEA switching: β = 4.05, p = 0.58). The results of the regression indicated that model 2ART explained 0% of the variance, and was not a significant predictor of level 2 altercentric bias (R^2 = 0.026, R^2_{adj} = -0.065, F(3,32) = 0.29, p = 0.83).

Level 1 cognitive - Neurotypical model

Model 1C (level 1, cognitive) included the following predictors: L2 age of acquisition; TEA inhibition; TEA switching. It was applied to a subsample of 33 participants (one participant had missing L2 age of acquisition, one participant had missing TEA switching scores, two participants had missing TEA inhibition and switching scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted L1C (L2 age of acquisition: β = -0.00093, p = 0.92; TEA inhibition: β = 0.0085, p = 0.79; TEA switching: β = 0.027, p = 0.31). The results of the regression indicated that model 1C explained 0% of the variance, and was not a significant predictor of L1C (R^2 = 0.078, R^2_{adj} = -0.018, F(3,29) = 0.82, p = 0.50).

Level 2 cognitive - Neurotypical model

Model 2C (level 2, cognitive) included only TEA inhibition as predictor. It was applied to a subsample of 37 participants (two participants had missing TEA inhibition scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA inhibition did not significantly predict L2C (β = 0.043, *p* = 0.20). The results of the regression indicated that model 2C explained 2% of the variance, and was not a significant predictor of L2C (R^2 = 0.046, R^2_{adj} = 0.018, F(1,35) = 1.68, *p* = 0.20).

Overall cognitive - Neurotypical model

Model C (cognitive) included the following predictors: L2 age of acquisition; TEA inhibition; TEA switching. It was applied to a subsample of 35 participants (one participant had missing L2 age of acquisition, one participant had missing TEA switching scores, two participants had missing TEA inhibition and switching scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted C scores (L2 age of acquisition: β = -0.020, *p* = 0.071; TEA inhibition: β = 0.052, *p* = 0.066; TEA switching: β = -0.013, *p* = 0.64). The results of the regression indicated that model C explained 15% of the variance, and was a significant predictor of C scores (R^2 = 0.22, R^2_{adj} = 0.15, F(3,31) = 2.99, *p* = 0.046), with a medium effect size (f2 = 0.18), and the post-hoc power was low, at 47%.

Level 1 affective - Neurotypical model

Model 1A (level 1, affective) included the following predictors: N language R-group; age; non-verbal IQ. It was applied to a subsample of 33 participants (four participants had missing or outlying non-verbal IQ). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted L1A (N language R-group: β = 0.090, *p* = 0.39; age: β = -0.0031, *p* = 0.36; non-verbal IQ: β = 0.0038, *p* = 0.35). The results of the regression indicated that model 1A explained 0% of the variance, and was not a significant predictor of L1A (R^2 = 0.079, R^2_{adj} = -0.017, F(3,29) = 0.83, *p* = 0.49).

Level 2 affective - Neurotypical model

Model 2A (level 2, affective) included the following predictors: age; TEA inhibition; L2 age of acquisition; N language P-group. It was applied to a subsample of 37 participants (two participants had missing TEA inhibition scores). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted L2A age: β = -0.0038, *p* = 0.51; TEA inhibition: β = 0.040, *p* = 0.23; L2 age of acquisition: β = 0.0055, *p* = 0.72; N language P-group: β = -0.19, *p* = 0.084). The results of the regression indicated that model 2A explained 15% of the variance with a medium effect size (f2 = 0.18) and a low post-hoc power (43%), and was not a significant predictor of L2A (R^2 = 0.25, R^2_{adj} = 0.15, F(4,30) = 2.53, *p* = 0.061).

Overall affective - Neurotypical model

Model A (affective) included the following predictors: age; non-verbal IQ. It was applied to a subsample of 34 participants (four participants had missing or outlying non-verbal IQ). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted A scores (age: β = - 0.0044, *p* = 0.20; non-verbal IQ: β = 0.0078, *p* = 0.070). The results of the regression indicated that model A explained 8% of the variance, and was not a significant predictor of A scores (R^2 = 0.14, R^2_{adj} = 0.083, F(2,31) = 2.49, *p* = 0.099).

General - Neurotypical model

Model G (general) included the following predictors: N language R-group; L2 age of acquisition; TEA total. It was applied to a subsample of 38 participants (one participant had outlying L2 age of acquisition). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted G scores (N language R-group: β = -0.11, *p* = 0.49; L2 age of acquisition: β = -0.018, *p* = 0.22; TEA total: β = 0.0042, *p* = 0.66). The results of the regression indicated that model G explained 0% of the variance, and was not a significant predictor of G scores (R^2 = 0.059, R^2_{adj} = -0.024, F(3,34) = 0.71, *p* = 0.56).

Overall social - Neurotypical model

Model S (social) included the following predictors: age; L2 age of acquisition; TEA inhibition. It was applied to a subsample of 35 participants (one participant had outlying L2 age of acquisition, two participants had outlying L2 age of acquisition). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. None of the predictors significantly predicted S scores (age: β = -0.0013, p = 0.72; L2 age of acquisition: β = -0.0085, p = 0.35; TEA inhibition: β = 0.029, p = 0.19). The results of the regression indicated that model S explained 2% of the variance, and was not a significant predictor of S scores (R^2 = 0.10, R^2_{adj} = 0.016, F(3,31) = 1.18, p = 0.33).

Control - Neurotypical model

Model P (physical) included only TEA attention as predictor. It was applied to a subsample of 38 participants (one participant had missing TEA attention score). The data met the assumptions of homogeneity and linearity and the residuals were appropriately distributed. TEA attention did not significantly predict P scores (β = 0.099, p = 0.27). The results of the regression indicated that model P explained 0% of the variance, and was not a significant predictor of P scores (R^2 = 0.034, R^2_{adj} = 0.0073, F(1,36) = 1.27, p = 0.27).