Neural functional connections of pragmatics

A potential pragmatic network in development

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Abstract

Pragmatic ability is crucial in everyday interactions. In populations of neurotypical individuals, pragmatic skill varies greatly. The neural mechanisms behind the variety, and the neural development of pragmatics remain to be explained. The present study aims to deepen the understanding of pragmatics' neural basis, by investigating the functional connectivity (FC) between two pragmatically interesting brain clusters during a pragmatic task. The investigated clusters, located in the bilateral, dorsal precuneus and in the left superior inferior parietal cortex were found by Bendtz et al. (2022) to have higher activity for young adults with high pragmatic skill compared to young adults with low pragmatic skill. Mahal (2022) found that the clusters were more functionally connected for the high skilled group during rest. In this study, fMRI data acquired during a pragmatic task was used to analyze the FC between the beforementioned clusters and compare two groups of young adults, one with high pragmatic skill (n = 25) and one with low pragmatic skill (n = 24). The groups of young adults were also compared with a group of 16 - 18 year old adolescents (n = 12). The results revealed higher FC for the high skilled group in both analyses, where the difference between the high skilled group and the adolescents was significant (p=.02). FC-values did not correlate with age in neither age group. The results are suggested to reflect (1) a neural development of pragmatics in adolescence towards a potential pragmatic network that involve increased functional connections between two clusters previously identified as possible neural markers of pragmatic individual variation, and (2) a possible window of opportunity for pragmatic development during adolescence.

Keywords

Pragmatics, development, adolescence, networks, functional connectivity, theory of mind, executive functions

Pragmatikens neurala funktionella kopplingar

Ett potentiellt pragmatiskt nätverk i utveckling

Ronja Forsgren Roll

Sammanfattning

Den pragmatiska förmågan är avgörande i vardags-interaktioner. I neurotypiska populationer varierar pragmatisk förmåga mycket, och det är ännu inte klarlagt hur de precisa mekanismerna bakom variationen och utvecklingen av pragmatisk förmåga fungerar. Denna studies syfte är att fördjupa förståelsen för pragmatikens neurala grunder, genom att undersöka funktionell konnektivitet (FC) mellan två pragmatiskt intressanta hjärnkluster. De undersökta klustren, ett i bilaterala dorsala precuneus och ett i vänstra superiora inferiora parietala cortex, var mer aktiva för unga vuxna med hög pragmatisk förmåga jämfört med unga vuxna med låg pragmatisk förmåga (Bendtz et el. 2022). Mahal (2022) noterade att klustrena var mer funktionellt kopplade i vila för gruppen med hög pragmatisk förmåga. I denna studie användes fMRI-data från en pragmatisk uppgift för att analysera FC mellan de tidigare nämnda klustren, och jämföra två grupper med unga vuxna, en med hög pragmatisk förmåga (n = 25) och en med låg pragmatisk förmåga (n = 24). Grupperna med unga vuxna jämfördes också med en grupp 16 – 18 år gamla tonåringar (n = 12). Resultaten visade på en högre FC för gruppen med hög pragmatisk förmåga i båda analyser, där skillnaden mellan gruppen med hög pragmatisk förmåga och tonåringarna var signifikant (p = .02). Värdena av FC korrelerade inte med ålder i någon av åldersgrupperna. Resultaten föreslås återspegla (1) en neural utveckling av pragmatik under tonåren mot ett potentiellt pragmatiskt nätverk som involverar ökade funktionella kopplingar mellan två kluster som tidigare identifierats som potentiella neurala markörer för individuell variation av pragmatik och (2) en eventuell kritisk period för pragmatisk utveckling under tonåren.

Nyckelord

Pragmatik, utveckling, ungdomar, nätverk, funktionell konnektivitet, theory of mind, exekutiva funktioner

List of abbreviations in order of occurrence

fMRI – functional magnetic resonance imaging

EF – executive functions

ToM – theory of mind (network/cognitive function)

ASD – autism spectrum disorder

FTA – face threatening act

BOLD-signal – blood oxygen level dependent signal

FC – functional connectivity

ROI – region of interest

IFG – inferior frontal gyrus

MD – multiple demand network

FPN – fronto-parietal network

CCF – cognitive control functions

TPJ – tempero parietal junction

mPFC – medial prefrontal cortex

DMN – default mode network

ACC – anterior circulate cingulate

HS – high score (group of high pragmatic skill measured by two behavioral tests)

LS – low score (group of low pragmatic skill measured by two behavioral tests)

vmPFC – ventromedial prefrontal cortex

dmPFC – dorsomedial prefrontal cortex

PCC – posterior circulate cingulate

EOP – early onset psychosis

TD – typically developing

DC – degree of centrality

STG – superior temporal gyrus

CO/SN – cingulo-opercular/salience network

ISA – indirect speech acts

Contents

1 Introduction

In day-to-day interactions, communicative parties use linguistic abilities beyond morpho-syntax, phonology and semantics, referred to as pragmatic skills. Pragmatics is a cornerstone in social interactions, and therefore crucial in well-being. This is further emphasized by recent research showing associations between quality of life and pragmatic ability in healthy (Camia et al., 2021) and clinical populations (Bambini et al., 2016). In the Gricean framework and several subsequent theories, pragmatics constitutes of inferring the speaker's intended meaning rather than the literal semantics of an utterance (Grice, 1975; Sperber & Wilson, 1986). The pragmatic domain has historically not been easily distinguished from the semantic domain (Levinson, 1983: 10 – 38) and similarly, in neuroscience, pragmatics has been difficult to discern from other cognitive functions such as core language, executive functions (EF) and theory of mind (ToM). Being a key component in language acquisition (Clark, 2016: 139 - 169), pragmatics is well researched in childhood. It remains unclear how adult pragmatic competence is formed, since adolescence is understudied. The adolescent time period is interesting from a cognitive perspective since the brain is still maturing, and furthermore, the social environment for adolescents is drastically different from in childhood.

Historically, cognition has been explained from a modular point of view, which involved understanding specific areas of the brain as being responsible for specific cognitive functions. Over the years, neuroscience has steered towards a network approach. This encompasses the view on functional connections between large-scale networks as fundamental in supporting cognitive functions (Bressler & Menon, 2010). To understand human cognitive behaviors such as pragmatics, it is crucial to explain the underlying functional connections. This thesis studies neural substrates during a pragmatic task, aiming to understand more of individual variation in the pragmatic domain and the development of pragmatic competence. Recently, differences in pragmatic ability in groups of young adults were attributed to areas outside of the language and ToM network (Bendtz et al., 2022). The groups performed similarly on behavioral tests of EF and ToM. The same areas in the dorsal bilateral precuneus and superior inferior parietal cortex show indications of working as a pragmatic network during rest (Mahal, 2022). Building on the work by Bendtz et al. (2022) and Mahal (2022) the current study asks whether the dorsal bilateral precuneus and the superior inferior parietal cortex act as a pragmatic network during a task of processing indirect speech acts. This is investigated by making group-level comparisons of the functional connections between the areas. This thesis studies if (1) the functional interactions between pragmatically interesting clusters explain individual differences in pragmatic ability, and (2) can individual variation of pragmatic skill be understood in the light of developmental processes?

2 Background

This background chapter starts with defining the pragmatic domain of language. Pragmatic theories, in particular concerning indirect speech acts are introduced. Secondly, I briefly present brain mapping methods before describing the evidence of pragmatics' cognitive underpinnings, focusing on brain networks and the cognitive functions encompassed by them. The fourth section discusses development of pragmatic ability, and lastly, neural evidence on the mapping of indirect speech is described followed by a summary introducing the aim of the thesis.

2.1 The pragmatic domain of language

2.1.1 Defining pragmatics

Historically, the linguistic definition of pragmatics is not clear-cut and somewhat intertwined with the semantic language domain (Levinson, 1983: 10 - 38). On one hand, pragmatics is seen as a distinct domain of language. On the other hand, it is related to semantics, since both concern meaning. Pragmatics can be defined as language usage, making meaning in a pragmatic sense context-dependent, as opposed to pure semantic meaning (Levinson, 1983: 5-40).

As in distinguishing pragmatics from semantics in linguistics, the neurocognitive distinction of pragmatics from ToM, EF and core language is under discussion (see for example Cummings, 2017; Bendtz et al., 2022; Arvidsson et al. 2022 and a more detailed description in section 2.3). In everyday communication, pragmatic abilities involve adapting register to the interlocutor by taking social status into account, use context to infer intentions behind utterances, start conversations, respond contingent and relevant with new information, and understand non-literal language use. This set of communicative skills are defined as pragmatic skills (Matthews et al., 2018).

2.1.2 Indirect speech acts

The definition of a pragmatic skill set can be seen in relation to Grice (1975) cooperative principle. His principle includes maxim's where communicative parties are expected to provide true and relevant answer's that are not under- or over-informative. Consider the examples below:

(1) a: What happened to the wall?
b: Elsa's shirt is pretty muddy.

(2) a: What a terrible weather outside. Did anyone get mud on their clothes?
b: Elsa's shirt is pretty muddy.

In (1), an interpretation disregarding the context makes b's answer irrelevant to the question and not adequately informative. The expectation that interlocutors provide relevant answers will make a) infer that Elsa put mud on the wall, rather than believing that b) is stating an irrelevant fact. These types of context-specific interpretations of an utterance are called *particularised implicatures* (Grice, 1975). (1) and (2) are also examples of a *direct and indirect speech act* (Searle, 1975). As the answer b) is identical in syntactic and lexical terms but requires context to be adequately interpreted, the answers in (1) and (2) contrasts pragmatics from semantics.

2.1.3 Different indirect speech acts

Indirect speech acts come in different forms. Certain indirect speech acts: *conventionalized indirect speech acts,* such as (3) and (4) are easier to understand.

(3) Can you sit down?

(4) Could you pass me the salt?

Understanding of conventionalized indirect speech acts come early in development, for children younger than 3:8 years (Carrell, 1981; Reeder, 1980; Shatz, 1978). Adults and children with autism spectrum disorder (ASD, a neurodevelopmental disorder characterized by for instance impairments in social interactions) also understand conventionalized indirect speech acts (Deliens et al., 2018; Kissine et al., 2015).

Indirect speech acts are used for different reasons. For example: in (5), b) answers indirect to save the face of a). In politeness theory, *positive face value* is defined as a person’s wish to be wanted and included in the social group (Goffman, 1955). In conversation, communicators strive to protect each other’s face value by avoiding *face-threatening acts* (FTA's) (Brown & Levinson, 1987). Below is an example of an indirect speech act used to avoid an FTA (5) and its direct counterpart including an FTA (6).

(5) a: Do you like my new wallpaper?
b: I'm not used to such bright colors.

(6) a: Do you like my new wallpaper?
b: No, I don't.

2.2 Brain mapping

As means towards understanding human cognition, neuroscience readily use different methods of brain mapping. In this section, brain mapping methods used in this thesis are described. The brain mapping method *functional magnetic resonance imaging* (fMRI) has had a major impact on the field of cognitive neuroscience (Rosen & Savoy, 2012). Commonly in fMRI, the relative levels of oxygenated/deoxygenated blood: the *blood oxygen level dependent* (BOLD) signal is measured (Logothetis & Wandell, 2004). The BOLD response corresponds to the metabolic response to neural activity, thus indirectly measuring neural activity. A measure of fMRI is *functional connectivity* (FC), which measure the exchange of information by analyzing correlations of BOLD-signals between structurally distinct brain regions (Fox & Greicius, 2010). Brain areas investigated are commonly referred to as *regions of interests* (ROIs).

Traditionally, FC has been used to analyze *resting state data*, data which is obtained while participants are not performing a task. The recorded activity consists of the BOLD-signal's spontaneous fluctuations (Cole et al., 2010; Fox & Greicius, 2010). However, over the years, methods that allow *task data* to be analyzed in this manner have emerged (Fair et al., 2007). These methods include either (1) using interleaved rest sessions in block-designed experiments or (2) removing task effects from a dataset that lacks rest sessions, the second analysis method being used in this thesis. Fair et al. (2007) compared the two methods, concluding that connectivity profiles derived from analyzing task data with removed task effects were qualitatively similar although quantitatively different from continuous resting state data. There, correlation coefficients where higher for resting state data, something that may be attributed to dampening of the spontaneous BOLD-signal by task engagement (Fair et al., 2007; Fransson, 2006). On the other hand, a narrative review by Gonzalez-Castillo & Bandettini (2018) points to evidence of enhanced between network FC profiles during task, by the networks involved in the task performed (For example Cole et al., 2014).

2.3 Neurocognitive underpinnings of pragmatics

The precise building blocks of human cognition remains to be described. However, functional interactions between different areas of the brain are recently emphasized as underpinnings of cognition (Bressler & Menon, 2010). Brain networks consist of distinct brain regions that share input through functional connections (Bressler & Menon, 2010; Sporns et al., 2005). Complex cognitive behaviors are encompassed by the network activity. Uddin et al., (2019) emphasize Mesulam's (1990) description: a networks' functional interactions (within the network and between the network and other areas) may result in behaviors that are more complex than the sum of the same isolated regions' activity would add up to. When researching the cognitive underpinnings of pragmatic ability, it is still unclear to what degree pragmatics is related to other cognitive functions such as core language, EF and ToM. Limitations in pragmatic skill are documented in certain clinical populations, such as individuals with ASD and Aspberger's syndrome. Even among the neuro-typical population there is a great variety in pragmatic ability. Cognitive underpinnings explaining this variation is under debate, both in childhood (see Matthews et al., 2018) adolescence (see Arvidsson et al. 2022) young adulthood (see Bendtz et al., 2022) and among clinical populations (see Cummings, 2017). In this section, current evidence on pragmatic ability in relation to other cognitive functions and large-scale networks is presented.

2.3.1 Core language

A difficulty when studying pragmatics is to discern it from the performances in other linguistic domains. For example, meta-linguistic tests where participants are asked to explain intentions behind an indirect speech act also require proficiency in syntax and semantics. Understanding and producing language is a complex behavior derived from several cognitive processes related to language domain definitions. Syntax corresponds to combinatorial processes, phonology to acoustic analysis and unification of sounds, and semantics to lexical retrieval in relation to knowledge of the world and interlocutors (Hagoort, 2017). Brain areas involved in the linguistic processes of syntax, semantics and phonology are typically referred to as the *core language network*. Anatomically, language areas are found bilaterally but with a left-lateralization more or less dominant depending on language process. Semantic and syntactic processing are seen located to areas in the left tempero-frontal cortex according to a meta-analysis (Hagoort & Indefrey, 2014). Two important nodes are historically referred to as Broca's and Wernicke's areas (left inferior frontal gyrus, IFG and left superior temporal cortex) (Hagoort, 2017).

Reviewing studies on children's pragmatic development and associations with other cognitive abilities, Matthews et al., (2018) noted that core language skills were most consistently associated with pragmatic ability. Similarly, Wilson & Bishop, (2022) noted connections between pragmatics and core language skills in childhood. They constructed several tests aimed to target pragmatic skill vs. core language skills. Children aged 7 - 13 years completed the tests, and the analysis revealed that pragmatics and core language skills were highly correlated. Furthermore, performances on different pragmatic tests did not correlate to a high degree, indicating that pragmatics makes up a set of skills rather than a general ability. Pagmar et al. (in revision) observed that conversational ability in 5- to 7-year-old children (number of responses that acknowledged previous utterances by interlocutors) was not associated with their morphosyntactic accuracy. As suggested by Pagmar et al. (in revision), the ability to acknowledge previous utterances also require EF-abilities such as working memory and attention. In other age groups, some studies suggest a distinction between core language and pragmatics. Wilson & Bishop (2019) analyzed adult participant's performances on core language and pragmatic tests. A two-factor model including both social understanding and core language skill showed the best fit to the data, compared to a one factor model. Recent fMRI-studies on adults and adolescents contrasting indirect and direct speech acts observe significant differences in activation patterns, pointing to a neural distinction between core language and pragmatic processing (Asaridou et al., 2019; Bašnáková et al., 2014; Bendtz et al., 2022; van Ackeren et al., 2012, 2016).

2.3.2 Executive functions

The *multiple demand network* (MD) or termed differently, the *frontoparietal network* (FPN) supports a set of cognitive behaviors called *executive functions* (EF) or *cognitive control functions* (CCF). EF is a term for processes of cognitive control, including inhibition, working memory and task switching (Fairchild & Papafragou, 2021). Tasks involving for example working memory and attention elicit fMRI-detectable activity in areas located bilaterally in the fronto-parietal cortex and dorso-lateral prefrontal cortex, as well as anterior cingulate (Duncan, 2010). Due to the reasoning that pragmatic computation requires increased cognitive load, EF are discussed as being involved in the individual variation seen in pragmatic skill (Fairchild & Papafragou, 2021). Participant's performances on tasks of judging scalar implicatures (implicit descriptions of measures not corresponding to the literal translation of the utterance, e.g. *some cats are grey* being understood as *not all cats are grey*) have shown connections with their respective working memory (Antoniou et al., 2016). Bambini et al. (2021) found that executive functions, and in particular working memory, predicted pragmatic competence measured by understanding of figurative language, humor, implicatures and narratives in older adults. Fairchild & Papafragou (2021) investigated the role of EF in understanding of scalar implicatures and other pragmatic tasks such as indirect requests in healthy adults. They found that ToM ability rather than EF was important in both scalar implicature understanding and indirect requests. When controlling for ToM, EF was not associated, which made them suggest that EF only supports pragmatics mediated by ToM. Matthews et al. (2018) review on children's pragmatic development and other cognitive abilities showed mixed results between EF and pragmatic ability. Additional evidence suggesting a distinction between EF and pragmatics come from Bendtz et al. (2022) who found increased activation in a pair of brain clusters for individuals with high pragmatic skill, a difference that could not be explained by performance on a behavioral test for executive functions (OSpan). The clusters, which this thesis further investigates, are located in the bilateral dorsal precuneus and left superior parietal cortex (hereafter referred to as the *ParPrec-clusters*). The Bendtz et al. (2022) study which this thesis builds on is described in detail in section 2.5.

2.3.3 Theory of mind

Theory of Mind (ToM) or *mentalizing* encompasses the ability to imagine other people's mental state, and to attribute beliefs, intentions and desires upon others independent of our own dito (Gallagher & Frith, 2003). The ToM network and the cognitive function(s) the term encompasses is not consistently defined in the literature. In a meta-analysis, different types of ToM tasks activate different areas in the brain (Schurz et al., 2014). The areas consistently reported across tasks are the bilateral tempero-parietal junction (TPJ) and the medial prefrontal cortex (mPFC). In tasks where subjects processed mental perspectives, dorsal and posterior parts of TPJ were more active, and in comparison, tasks picturing rational behavior activated ventral/anterior parts of the TPJ (Schurz et al., 2014). In the mPFC, the ToM network shares an anatomical overlap with the default mode network (DMN). Gallagher & Frith (2003) attributes the mentalizing functions of the ToM network to the anterior circulate cingulate (ACC), an area that overlaps with the vmPFC.

ToM requires to take the perspective of another person, similarly to pragmatic interpretations, whereby a connection between ToM and pragmatic ability seem plausible. Neuroscientific evidence points to a connection: several fMRI-studies have found higher activation in ToM related areas when subjects processed indirect speech acts, compared to direct speech acts (such as mPFC and TPJ, see section 2.5 for a detailed description, Asaridou et al., 2019; Bašnáková et al., 2014; Bendtz et al., 2022; van Ackeren et al., 2012, 2016). This activity refer to the results comparing the indirect and direct speech acts condition for both groups in Bendtz et al., 2022, where the group-level interaction showed different patterns described in the next section. Matthews et al. (2018) (mentioned in section 2.3.1, 2.3.2) did a review on the literature regarding children's pragmatic development in relation to other cognitive abilities. Most studies found associations between core language skills and pragmatics, but when language ability was controlled for, results from several studies revealed associations between mentalizing skill and pragmatic skill.

There is evidence that suggests a more complex link between ToM and pragmatics than at first glance. Bosco & Gabbatore (2017) noted that understanding of sincere and deceitful speech acts by 3 - 8-year-old children could be explained by first order ToM. However, their regression analyses revealed no such connection between ironic speech acts and ToM. Similarly, Deliens et al. (2018) found that adults with ASD understood certain indirect speech acts, but had trouble understanding irony. The authors argue against the view that ToM limitations in ASD causes impairments in pragmatic abilities as a whole. Rather, they suggest that individuals with ASD have limitations in certain areas of pragmatics. A similar conclusion is drawn by Wilson & Bishop (2020), whose analysis of autistic and healthy adults' performances on core-language/pragmatic tests revealed a complex domain related difference between the groups, where language use and inferring was more difficult for individuals with ASD. Bendtz et al. (2022) compared two groups: high skill in pragmatic *(High score - HS)* and low skill in pragmatic *(Low score - LS)*. In addition to the fMRI experiment, the subjects did behavioral tests including a ToM test (Reading the Mind in the Eyes, RMET) and the results showed no group-level differences in ToM. Bendtz et al. (2022) (described briefly in section 2.3.2 and in detail in section 2.5) found clusters outside of the language and ToM network more activated by the high skill group during a pragmatic task, indicating a distinction between pragmatics, core language and ToM.

2.3.4 The default mode network

The Default Mode Network (DMN) is a network of brain areas that are active during rest (Raichle, 2015). The activation of the DMN is attributed to a default cognition, for example daydreaming and mind-wandering (Raichle, 2015). As described by Smallwood et al. (2021), DMN activity has been noted to increase during tasks of social cognition (Frith & Frith, 1999), self-reference (Kelley et al., 2002), and imagining events in the future or past (Addis et al., 2007). The DMN consists mainly of three regions, the ventromedial pre-frontal cortex (vmPFC), the dorsomedial pre-frontal cortex (dmPFC) and posterior cingulate cortex (PCC) as well as precuneus. Smallwood et al. (2021) describes the mPFC as an important node in the DMN, where deactivation during task is a prominent feature (Raichle et al. 2001). Functions of the PCC/precuneus are mainly recollection of prior experiences (Vincent et al., 2006). Other evidence suggests that precuneus is a key region in distinguishing between task and rest, since the ratio of functional connectivity between the precuneus – DMN and precuneus – MD was high during rest and during task the relationship was reversed (Li et al., 2019; Utevsky et al., 2014).

The ROIs investigated in this thesis (previous results on these clusters by Bendtz et al., (2022) and Mahal (2022) are described in detail in section 2.5) may be implicated in the DMN. The bilateral dorsal precuneus cluster is located more dorsally than the precuneus location typically allocated to the DMN. The cluster in the left superior parietal cortex is not one of the main DMN regions, but bilateral regions in the superior parietal cortex are at times suggested to be implicated in the DMN (Mars et al., 2012). Even though DMN is characterized by a deactivation during goal-directed tasks (Raichle et al. 2001; Raichle, 2015) it has a role in cognitive behaviors. A meta-analysis by Mak et al. (2017) indicated that performances on cognitive tasks and DMN connectivity are correlated. Potentially linked to pragmatic ability, a review by Nair et al. (2020) noted in several studies that adolescents with ASD had lower connectivity in the DMN compared to controls.

2.4 Pragmatic development

A key factor in mapping out the components of adult pragmatic skill is to understand the normal developmental trajectory for pragmatics. Development of pragmatic competence is well researched in children, but a rather uncharted territory in adolescence. In adolescence, pragmatic competence develops due to new social requirements in life. A change of communicative perspective from mostly family centered and caregiver dependent to peer centered and autonomous drives this development (Alduais et al., 2022). In this section a description of the current state of research regarding the pragmatic development during adolescence is presented.

2.4.1 Processes of brain maturation

Developmental changes of brain activity, cognitive functions, and structural changes related to brain maturation during adolescence may be important for forming an adult pragmatic competence. A brain maturation process involving a decrease of cortical thickness in the frontal and temporal lobe, with the parietal lobe showing the biggest decrease is active during adolescence (Tamnes et al., 2017). Cortex-thinning is suggested to improve the ability of distinguishing signals of input from each other (Seldon, 2005). Asaridou et al. (2019) note that activity-patterns are different for adolescents (ages 14 - 17) compared to young adults in a speech act recognition task. In comparison to adults, adolescents activated both the ventral and dorsal parts of mPFC (an area belonging to the ToM network) whereas adults only activated the dmPFC. The vmPFC is associated with arousal and heightened attention. The changed activity pattern from adolescence to adulthood can be attributed to lack of adult pragmatic competence and/or hormonal changes or brain maturation (Asaridou et al., 2019).

In clinical populations with pragmatic deficits there is evidence suggesting differences in functional connections compared to typically developing (TD) peers. Nair et al. (2020) (briefly mentioned in section 2.3.4) reviewed studies on FC patterns in the DMN for adolescents with ASD or early onset psychosis (EOP). ASD adolescents had lower connectivity of the DMN compared to controls in 15 of 29 studies, whereas results from studies on EOP adolescents were mixed in under and over connectivity. Similarly, individuals with Aspberger's syndrome did not develop a right lateralization of the posterior indirect pathway of the arcuate fasciculus, a development that took place over time in controls (Budisavljevic et al. 2010). This pathway connects areas related to language, social cognition and ToM, cognitive functions whose importance in relation to pragmatics is discussed in section 2.4.

2.4.2 Development of cognitive functions

A pattern in developmental studies is associations between different cognitive functions in childhood. For example, two earlier mentioned studies in childhood, one experimental (Wilson & Bishop, 2022) and one review (Matthews et al., 2018) observed correlations between pragmatic ability and other cognitive functions (core language ability/both mentalizing skill and core language ability respectively). A developmental trajectory of the ToM is described by Saxe (2009). The developing ToM is related to language acquisition, as exemplified by Schick et al. (2007) who tested deaf children's (3:11 - 8:3 years) ToM and language ability. Deaf children to hearing parents had delays in ToM and language abilities, regardless of the modality the test was performed in (verbal/sign language). In contrast, deaf children to deaf parents and hearing controls performed identical. The difference between the two groups being linguistic exposure points to the importance of language skills in forming a ToM. Interestingly, ToM abilities may be independent of language skills in adulthood. In adults, ToM tests activate ToM network regions even though they do not include any language use (Saxe, 2009). Furthermore, Varley & Siegal (2000) observed that a patient affected of severe agrammatic aphasia still had relatively intact ToM understanding. This indicates that as the ToM network matures, it becomes independent from language functions. Possibly, pragmatics follow a similar developmental trajectory, from being more reliant on other cognitive functions in childhood to becoming more independent in adulthood.

Other neuroscientific evidence highlights the importance of FC in brain networks during adolescence for later ToM ability. As described in section 2.3.3, ToM or mentalizing seem related although not identical with, pragmatic ability. Different types of mentalizing abilities are suggested to form before others: mentalizing of the beliefs and intentions of others precedes mentalizing about other people's emotional states (Keulers et al., 2010; Sebastian et al., 2012; Vetter et al., 2014). van Buuren et al. (2021) investigated adolescents' (11 - 14 years) connectivity within and between the DMN, FPN (or termed differently, the MD network), and Cingulo-Opercular/Salience Network (CO/SN), the latter two networks being implicated in processes of cognitive control. Their results showed that connectivity between the DMN - FPN, and FPN - CO/SN predicted the adolescent subjects' mentalizing ability measured with the Reading the Mind in the Eyes Test (RMET). The authors suggest that DMN and FPN connections aid mentalizing, by a contribution of socio-cognitive functions by the DMN and control processes by the FPN.

2.4.3 Neural mapping of pragmatic skill

The paradigm of contrasting indirect and direct speech acts have been used in several studies to map out neural activity related to pragmatics (Asaridou et al., 2019; Bašnáková et al., 2014; Bendtz et al., 2022; van Ackeren et al., 2012, 2016). Summarized, the studies' results show robust differences in activity patterns between direct and indirect speech acts. Qualitatively, activity patterns for the indirect compared to the direct condition differ somewhat, but is noted in areas of the core language network such as the IFG (Asaridou et al., 2019; Bendtz et al., 2022; van Ackeren et al., 2016), STG (Asaridou et al., 2019) and bilateral pFC/right temporal regions which are said to be involved in discourse-processing (Bašnáková et al., 2014). The other common denominator is higher activity in ToM areas for indirect speech acts, including mFC-regions (Asaridou et al., 2019; Bašnáková et al., 2014; Bendtz et al., 2022) and TPJ (Asaridou et al., 2019; Bašnáková et al., 2014; Bendtz et al., 2022).

Bendtz et al. (2022) used a paradigm contrasting affective indirect speech acts (indirect speech acts used to avoid an FTA) with direct speech acts. They compared activation patterns between two groups of young adults, one group with high pragmatic skill and one group with low pragmatic skill. They divided the groups based on performances on pragmatic behavioral tests and controlled for other cognitive functions not correlating with the pragmatic results (EF, ToM, core language). The results revealed a pair of clusters (the ParPrec-clusters) located outside the ToM and core language network, where the group with high pragmatic skill had higher activity during the pragmatic task. The distinction between pragmatic and core language processing supports the view that pragmatics and semantics are separate domains of language. Moreover, pragmatic skill seems to tap an ability that to a certain degree is distinct from ToM given the activation outside of the ToM network, and the differences in pragmatic skill not being attributed to ToM ability measured with RMET. In a master's thesis, Mahal (2022) compared the high skilled and low skilled group on functional connectivity during rest between the ParPrec-clusters. It turned out that the clusters were more functionally connected for the high skilled group, suggesting a potential pragmatic network between the clusters during rest.

2.5 The current study

In summary, there is an ongoing debate as to which extent other cognitive functions explain individual variation of pragmatics (Cummings, 2017; Bendtz et al., 2022; Matthews et al., 2018; Arvidsson et al. 2022). Associations between pragmatics and (1) core language in childhood (Matthews et al., 2018; Wilson & Bishop, 2022) (2) ToM in adulthood and childhood (Fairchild & Papafragou, 2021; Matthews et al., 2018) and (3) EF in adulthood and for older adults (Antoniou et al., 2016; Bambini et al., 2021) are documented. However, results on associations between EF and pragmatics are mixed between studies in childhood (Matthews et al., 2018), and certain conversational skills are not associated with morphosyntactic ability in 5 – 7 year old children (Pagmar et al., in revision). Furthermore, Fairchild & Papafragou (2021) suggests connections between EF and pragmatics to be mediated by ToM in healthy adults since they found no associations in their study. The view on ToM as being the key behind individual variation in pragmatics is also questioned lately, by for example more complex pictures of ASD individual's pragmatic impairments (Deliens et al., 2018; Wilson & Bishop, 2020). Recent evidence from Bendtz et al. (2022) and Mahal (2022) that compared two groups of high and low pragmatic skill suggests that pragmatics is a distinct cognitive function, characterized by increased activity in a pair of clusters possibly forming a pragmatic network. These differences could not be fully explained by ToM or core language skills, given that (1) the compared groups did not differ in ToM ability (measured by RMET), and (2) the clusters were located outside of the ToM and core language networks. Moreover, the compared groups were matched on OSpan (a test targeting EF), suggesting that this component of EF does not explain individual variation of processing indirect speech acts. A stronger indication of the clusters forming a pragmatic network would be if they are more connected during a pragmatic task for individuals with higher pragmatic skill, something that this thesis investigates.

A possibility given the location of the ParPrec-clusters is that other large-scale networks (specifically ToM and MD) aid pragmatic inferring in development. Results from Bendtz et al. (2022) and Mahal (2022) as described above, suggest pragmatics to be a distinct ability in young adulthood. In contrast, pragmatic ability in childhood seem to be associated with other cognitive functions (Matthews et al., 2018; Wilson & Bishop, 2022). There is thus a knowledge gap on the underpinnings of pragmatics in the adolescent age group. This thesis aims to understand more of the developmental trajectory in adolescence, by asking if clusters related to individual pragmatic variety in adulthood differ in their inter-functional connections in adolescence compared to young adulthood.

2.6 Aim and research questions

2.6.1 Aim

The aim of this work is to gain more understanding about the neural correlates that underlie individual pragmatic skill and development of pragmatic ability.

2.6.2 Research questions

(1) Is FC between ROIs anatomically resembling the ParPrec-clusters higher for a group of individuals with high pragmatic skill compared to low pragmatic skill? Higher FC for the high skilled group would suggest a pragmatic network formed by the ParPrec-clusters, as well as strengthen the conclusion by Bendtz et al. (2022) that pragmatic processing and other core language functions such as semantics are distinct from each other.

(2) a) Is FC between the ParPrec-clusters higher for young adults with high pragmatic skill compared to adolescents? A significant result to research question a), is followed by a follow up analysis: b) Is FC between the ParPrec-clusters higher/lower for young adults with low pragmatic skill compared to adolescents.

If yes on research question 2 a) this indicates a developmental trajectory to form pragmatic competence being active in adolescence. If 2 b) shows higher FC for the lower skilled young adults, this is an even stronger indication of a developmental trajectory in adolescence towards adult pragmatic ability. Higher or similar FC for the adolescents compared to the lower skilled young adults suggests that a developmental aspect connected to pragmatic competence is absent in certain individuals, resulting in lower pragmatic skill.

2.6.3 Hypotheses

Given previous results by Mahal (2022) and Bendtz et al. (2022), the hypothesis to research question 1) is:

(1) Higher FC for the group of high pragmatic skill compared to the group of low pragmatic skill between ROIs anatomically resembling the ParPrec-clusters.

Considering previous studies (see section 2.4) on adolescents (1) displaying different activity patterns from adults in speech act processing (Asaridou et al., 2019), (2) pointing to the development of cognitive functions (Saxe, 2009), and (3) processes of brain maturation possibly related to pragmatic functions (Budisavljevic et al. 2010), as well as (4) the relevance of FC in large-scale networks for neurotypical adolescents (van Buuren et al., 2021) and clinical populations (Nair et al., 2020) the hypothesis to research question 2) is:

(2) Higher FC for the group of high pragmatic skill compared to the adolescents between the ParPrec-clusters.

3 Method

The method of this thesis uses a resting-state analysis on data acquired during task, by removing the task-effect from the existing task-data. The analysis aims to compare three different groups, two groups of young adults with high vs. low pragmatic ability, and one group of adolescents. The data was acquired at two different time points. First, the young adult's data was acquired by Bendtz et al. (2022). Second, the adolescent's data was acquired during the spring of 2023.

3.1 Participants

3.1.1 Young adults

The adult participants come from Bendtz et al. (2022) study. Initially, 199 subjects (99 males, average age = 28.7 for males and 29.3 for females) were recruited to perform pragmatic behavioral tests. Out of the initial 199, 60 subjects were recorded in the fMRI-experiment. The 60 subjects were selected based on their behavioral test results; a process described in the section "group division". Inclusion criteria were native speakers of Swedish. Exclusion criteria were history of neurological impairments, brain surgery, ASD/Aspberger diagnosis, or language impairment. After fMRI acquisition, additionally 3 subjects were excluded due to technical malfunction, excessive movement (>4 mm in several volumes) and not enough correct answers on the compliance questions respectively. In this thesis, the pilot study used 8 subjects, leaving n=49 subjects for the full study (high skilled group, n = 25 and low skilled group, n = 24).

3.1.2 Adolescents

The adolescent participants (n = 15, ages 16 - 18) were recruited during this spring. In the recruitment process, schools, libraries, museums, scout organizations and youth recreation centers in the Stockholm area were contacted and provided information about the study. Posters where interested participants could sign up for more information were put up at the Stockholm University, around the area of central Stockholm, and online on LinkedIn. Inclusion criteria were that the participants had Swedish as their native language (multilinguals with Swedish as one of their languages were included). Exclusion criteria were history of addiction or ASD/Aspberger diagnosis, epilepsy, surgery to the throat or brain, known neurological/psychological impairment or claustrophobia. Out of the 15 recruited adolescents, one participant chose not to partake in the fMRI-experiment, and additionally 2 were excluded due to not enough correct answers on the compliance questions, leaving n = 12 participants (3 males, average age = 16.7 for males and 16.9 for females).

3.2 Ethical considerations

The Bendtz et al. (2022) study was approved by the Swedish Regional Ethical Review Authority in Stockholm. The data on the adolescent participants is part of a bigger study, which also was approved by the Swedish Regional Ethical Review Authority in Stockholm. This study has similar although not identical purposes as the ethic applications, performing a connectivity analysis on fMRI data from task rather than analyzing the functional activity during task, and therefore a new ethics approval was not applied for. The young adult participants in Bendtz et al. (2022) all signed for informed consent to participate in the study and received 350 SEK after the experiment. The adolescent participants also signed for informed consent and received 300 SEK after the experiment. All participants were informed that partaking in the study is voluntary and that they could discontinue their participation whenever they wanted to.

3.3 Group division

This section describes how the groups high pragmatic skill (HS) and low pragmatic skill (LS) were divided and matched based on behavioral tests in Bendtz et al. (2022).

3.3.1 Behavioural tests

Prosodic comprehension of request for response (PC-RR)

Bendtz et al. (2022) developed a test that asked the participants to judge an utterance as a statement or a request. The utterances where identical lexically and syntactically but differed in prosody.

Audience Design (AD)

The Audience Design test is an adaption of the Director's task. The Director's task is based on what is termed recipient design in conversation analysis (Sacks & Schegloff, 1979). Recipient design means that speakers adapt their utterances based on the needs of the interlocutor(s). Bendtz et al. (2022) introduces a new version of the director's task to address issues with validity in pragmatic studies. In their task, participants were asked to describe an object to an interlocutor. The object could be assumed to be either known or unknown to the addressee, based on their age, gender and/or cultural background.

Group characteristics

Group belongings for HS or LS was determined by the two pragmatic tests: prosodic comprehension of request for response (PC-RR) and Audience design (AD). LS group subjects scored lower than 50 percent on PC-RR and AD, and HS group subjects scored higher than 50 percent on those two tests. This is visualized in figure 1 below from Bendtz et al. (2022). The HS group and LS groups were also compared on the cognitive functions EF, ToM, and language ability. The two groups were matched on EF by similar performance on the OSpan test (Foster et al., 2015), age and ToM by the RMET (Baron-Cohen et al., 2001). When it comes to core language ability, the group's results differed in a test of vocabulary (Swedish Scholastic Aptitude test, vSweSAT) and the author recognition test.

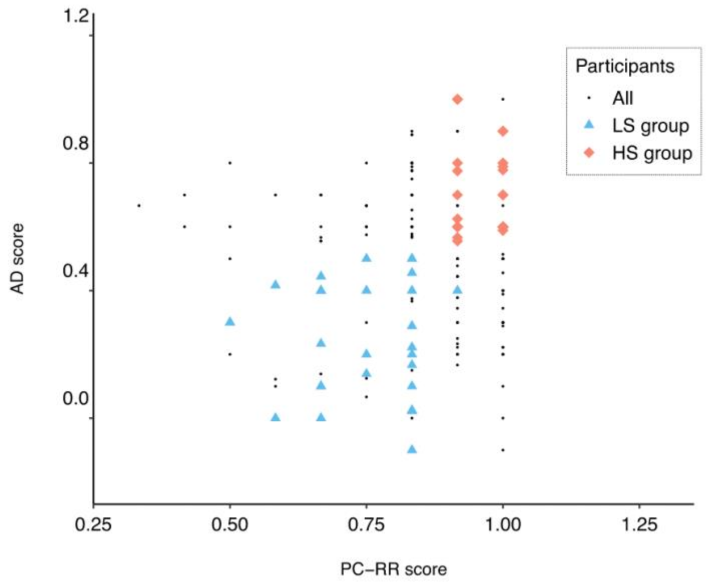

Figure 1: Illustration of group division. X-axis displays prosodic comprehension of request for response score (PC-RR) and y-axis audience design (AD) score. Low skilled group (Low score - LS), high skilled group (High score - HS). Adapted with permission from Bendtz et al. (2022).

3.4 Data collection

3.4.1 fMRI acquisiton

A MRI-scanner of the type Siemens 3T magneto prisma with a 20-channel surface coil located at Stockholm University Brain Imaging Center (SUBIC) was used to obtain the structural and functional data (Bendtz et al., 2022). Structural data to visualize each subject's brain anatomy was acquired with high-resolution, whole-brain T1-weighted Magnetization-Prepared Rapid Acquisition with Gradient Echo (MPRAGE) sequence (TR = 2,300 ms, TE = 2.85 ms, 192 slices with 1.3 mm isotropic resolution, and field of view = 256 mm) A GRAPPA (Generalized Auto Calibrating Partial Parallel Acquisitions) accelerated the process. The functional scan acquisition used a repetition time (TR) of 2.1 s and echo time (TE) of 30 ms. The functional scans consisted of 70 slices with 2.0 mm thickness, 1 mm slice gap per volume (flip angle 70° and voxel size 2.2 x 2.2 x 2.0 mm3).

3.4.2 Experimental paradigm

The paradigm used by Bendtz et al. (2022) (the ISA paradigm) contrasts indirect and direct speech acts. The paradigm is established, and similar versions have been used in several other studies, showing consistent results (Asaridou et al., 2019; Bašnáková et al., 2014; Bendtz et al., 2022; van Ackeren et al., 2012, 2016). Participants performed 78 trials that included listening to a dialogue consisting of an introductory context, a question and an answer. The dialogues were of two different conditions: indirect and direct. The conditions differed on two notes: the context and the question. The lexico-semantic content of the answer was identical in both conditions, as is illustrated in figure 2. Moreover, the answers in the indirect condition were indirect in order to avoid an FTA towards the addressee. In half of these, the speaker them self were avoiding to directly stating a critical opinion (*Criticism trials)* and in the other half, negative opinions from another person not present were paraphrased (*bad message trials)* (as in figure 2 below). Participants also listened to 14 filler trials, which were structured with a context, question and answer, identical to the proper trials. The purpose of these were to make the pattern of the dialogues less obvious. Moreover, participants answered 12 compliance questions. The questions asked about information in the previous dialogue, meaning that they did not require the participant to remember past dialogues.

Table 3. Example of an ISA test trial in the direct and indirect version and a following compliance question

Condition	Context	Question	Answer
Direct	Magnus and Emilia are old friends. They are discussing how hard it is to find restaurants which both you and your partner fancy. Emilia asks Magnus:	Why doesn't your girlfriend like Japanese food?	She is not so used to Asian seasoning.
Indirect	Magnus and Emilia are old friends. They are talking about the last time Magnus visited Emilia in her student dormitory. Emilia asks Magnus:	Did your girlfriend like my vegan noodles?	
Compliance question	Was there someone who was not so used to Asian seasoning?		
Filler trial	Benny and Ellinor are doing their laundry. Benny went out walking the dog but is now back. He asks Ellinor, who was the last to visit the laundry room.	Is the washing machine done?	Yes, just put everything in the dryer.

Figure 2: Example of ISA-trial. Adapted with permission from Bendtz et al. (2022).

3.4.3 fMRI-procedure

Young adults

The MRI-scanning procedure took approximately one hour per participant. Each participant performed 7 minutes of resting state acquisition, three task runs, and five minutes of anatomical capturing. In the resting state acquisition, participants were asked to lie still and relax. During the task session, participants were instructed to listen to conversations and think about the intention of the speaker. Each task session lasted around 12 minutes. The fMRI-experiment was double blinded (neither participant nor experimenters knew which group of pragmatic skill the participant belonged to).

Adolescents

Since the adolescents may have a lower tolerance for spending long time in the fMRI scanner, slight changes were made to the fMRI procedure. Adolescents did not perform a resting state scan before the task. The compliance questions were also adapted for the adolescent participants, to make sure that a correct answer required the attention of the participant. Moreover, the structural scan was two minutes 32 seconds compared to five minutes for the adult subjects. The paradigm was otherwise identical.

3.5 Pilot study

3.5.1 Aim

The pilot study aimed to adapt the analysis-pipeline used by Mahal (2022) for task-data, define ROI:s resembling the ParPrec-clusters, and to form hypotheses. Following the pilot results, the analysis, research questions and hypotheses where described and pre-registered to an Open Science Framework (OSF, Roll & Uddén, 2023). Pre-registrations are recommended by the Committee on Best Practice in Data Analysis and Sharing of the Organization for Human Brain Mapping (Nichols et al., 2017; COBIDAS).

3.5.2 Method

Mahal (2022) analysis pipeline in CONN toolbox (Nieto-Castañon & Whitfield-Gabrieli, 2021) was adapted to task-data by utilizing the CONN toolbox forum and manual, personal communication with experienced users of CONN toolbox and comparing the method against other studies utilizing the CONN toolbox to perform resting state analyses on task-data (For example Lynn et al., 2022). Furthermore, Mahal (2022) based and tested the robustness of his pipeline on a previous study by Paunov, Blank & Fedorenko (2019).

3.6 ROI-definition

In defining the ROI's measures were taken to avoid bias in the analysis pipeline. Therefore, the same ROI-definition as Bendtz et al. (2022) and Mahal (2022) was not used for the adult data (note that Mahal (2022) analyzed resting state data, independent from the task-data). The adolescent data is also independent from Bendtz et al. (2022) task data, and therefore the original ParPrec-clusters were used to analyze the adolescent data, with the adult data as a control condition. An analysis on the adult data using the original ParPrec-clusters was also performed in order to increase our understanding of the comparability of the two different methods. The anatomical ROI-definition on the adult data used the anatomical atlas Talairach (Lancaster et al. 2000; Lancaster et al. 1997). There, ROI's anatomically resembling the ParPrec-clusters were chosen. The Parietal ROI used the Talairach labels "left cerebrum parietal lobe inferior parieteal lobule gray matter" and "left cerebrum parietal lobe inferior parietal lobule white matter", with a cutoff at z = 39. The Precuneus ROI used the Talairach labels "right cerebrum parietal lobe precuneus" and "left cerebrum parietal lobe precuneus gray matter broadmann area 7", with a cutoff at y = -61 and x = 17. The ROIs are displayed below in picture 2 with the ParPrec-clusters in white and the anatomically defined ROIs in yellow. The anatomical definition of the precuneus ROI is less cohesive than the original ROI and stretches further lateral to the left and more anterior. The parietal ROI is larger than the original ROI in posterior, dorsal and left lateralized directions.

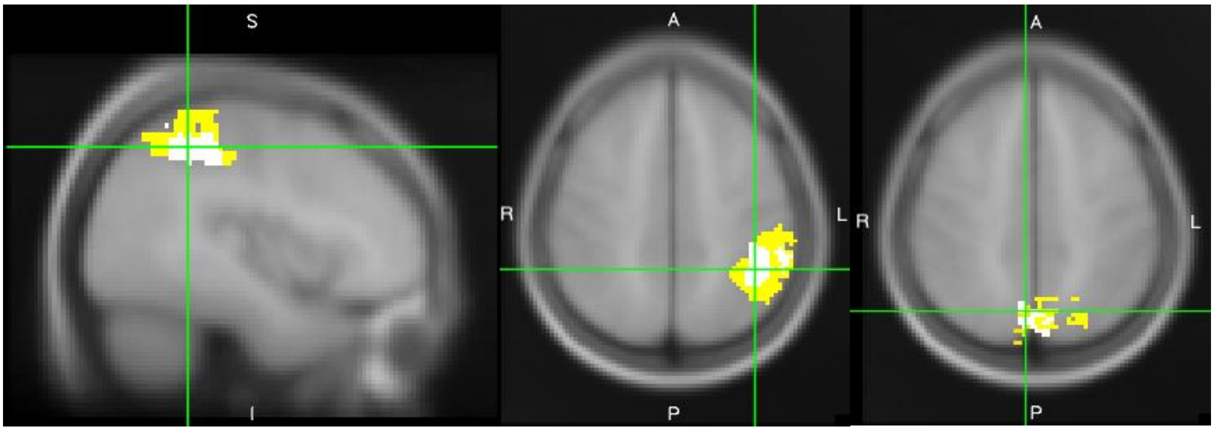

Figure 3: The superior inferior parietal cluster is displayed in the leftmost and middle pictures. Leftmost picture, sagittal slice. (x = -40,y = -46, z = 46). The middle picture is an axial slice (x = -40, y = -46, z = 48). The rightmost picture displays the dorsal bilateral precuneus cluster in an axial slice (x = 5, y = -68, z = 49). The white areas constitute the original cluster from Bendtz et al. (2022) and the yellow areas the anatomical definition. Note that left is displayed on right in these pictures. Pictures created in FSLeyes (McCarthy, 2023).

3.7 Data analysis

3.7.1 Preprocessing

Prior to preprocessing, a total of three runs for three different participants from the adolescent group was excluded and that data was not used further in the analysis. The reasons were one participant falling asleep (excluded run 2), another participant answered wrong on two compliance questions in the same run (excluded run 3), and a third participant cancelled the first run complaining that the audio settings were two low (excluded run 1). One adolescent participant moved >4 mm but <4,5 mm. The images with excessive movement were concentrated to only a few volumes of one run and were therefore not excluded. In the preprocessing stage, fMRI-pictures were realigned for motion correction, then functional images were co-registered to the anatomical image and normalized according to a standard Montreal Neurological Institute (MNI) space with affine regularization, resampling of voxels with a 4th degree B-spline interpolation to 2 x 2 x 2 mm. Segmentation of white and grey matter as well as bias correction was performed during the normalization process. This part of the preprocessing was performed in SPM 12 (The Wellcome Centre for Human Neuroimaging, 1991). Identical to Mahal (2022), the preprocessing did not include a smoothing of the images. Unsmoothed data is recommended in the ROI-to-ROI analyses in the CONN toolbox (Nieto-Castañon & Whitfield-Gabrieli, 2021). In the pilot stage, an analysis was performed with both unsmooth and smooth data, and it was noted that differences between the two groups were larger for the smoothed data. Therefore, unsmoothed data was used to perform the analysis by choosing the option of secondary: unsmoothed data in the ROI-setup in The CONN toolbox. Additional ART-based preprocessing with conservative settings (95th percentile) was executed in the CONN toolbox to detect functional outliers.

3.7.2 Analysis pipeline in CONN

The pipeline in the CONN toolbox (Nieto-Castañon & Whitfield-Gabrieli, 2021) measure functional connectivity across the entire session of data acquisition. All task effects of 2 dimensions each (indirect/direct question/answer/context, ITI, additional language stimuli and rest), scrubbing (from the outlier detection in the preprocessing step, 76 dimensions for the two groups of young adults and 121 dimensions for the group of adolescents), white matter (5 dimensions), CSF (5 dimensions) and realignment parameters from the SPM files (6 dimensions) were regressed out. Functional connectivity is measured by first calculating an average BOLD signal time course per ROI. Thereafter a fisher-transformed bivariate correlation is performed for each condition. The condition/task factor constitutes of the time-series defined for a specific condition. In this study, functional connectivity for the entire run was calculated in the time-window "rest" defined from start to end of the session. Thus, each subject received a value of functional connectivity corresponding to the fisher-transformed correlation between the averaged time-series per ROI. The analysis corresponds to the second method of performing resting state analyses on task data (removing task effects from a data set lacking rest sessions) described by Fair et al. (2007).

3.7.3 Statistical analysis

The two research questions (1) comparing HS and LS and (2) comparing HS and adolescents were conducted using two sample one sided t-tests. A one sided t-test was chosen since previous studies (Mahal, 2022; Bendtz et al., 2022) and the pilot study unambiguously showed higher values for the HS group. Based on previous literature described in section 2.4, the one-sided t-test was chosen for the second research question as well. Graphs and figures were created using R-studio (RStudio team, 2020) and the statistical analysis was performed in JASP (JASP team, 2021).

4 Results

4.1 Pilot study

The averaged correlation of activity between the anatomically defined ROI's located in the bilateral dorsal precuneus and the left superior parietal cortex was higher for the HS group (M = .21, SD = .24) compared to the LS group (M = .06, SD = .07), as is displayed in table 1 and 2. The results were in line with previous results by Mahal (2022) and Bendtz et al. (2022) indicating a robust analysis pipeline. One subject in the HS group with negative values overall was identified as a potential outlier. Drawing on these results, the hypothesis and research questions were formed (see section 2.7).

Group	Functional connectivity
LS	.02
LS	.08
LS	-.02
LS	.15
HS	.41
HS	.38
HS	.15
HS	-.11

Table 1: Averaged correlation between the anatomically defined dorsal bilateral precuneus ROI and superior inferior parietal cluster ROI per pilot subject.

4.2 Full study

All participants answered correct on 83% or more of the compliance questions. Furthermore, they did not have more than one incorrect answer per run. One adolescent participant answered incorrect on two questions in the third run, therefore the data for the third run was excluded (see 3.7.1).

4.2.1 Tests for normality and equal variances

The data for each group was tested for normality using Shapiro-Wilk's test. None of the tests turned out significant and data was assumed to be normally distributed.

Group	W-value	p-value
HS anatomical ROIs	.94	.19
LS anatomical ROIs	.96	.5
HS ParPrec-cluster	.96	.42
LS ParPrec-clusters	.99	.98
Adolescents	.98	.96

Table 2: W-values and p-values from Shapiro-Wilk's tests for normal distribution per group.

For each comparison, Levene's test of equal variances was conducted. For the comparison of the HS and LS group's FC between the anatomical ROIs (F(1) = .47, p = .5) and the comparison between the adolescents and HS/LS groups respectively (F(1) = 3.16, p = .08/ F(1) = .05, p = .82), variances where assumed to be equal and student's t-tests were conducted. The comparison of the HS and LS group's FC between the ParPrec-clusters was analyzed using a Welch's t-tests since Levene's test was significant suggesting unequal variances (F(1) = 4.19, p = .046).

4.2.2 Follow-up analyses

Non-significant results were followed up with Bayesian analyses investigating the evidence for no effect. These results are reported in conjunction to each research question. Adolescents' and adults' FC values were also plotted as a factor of age. The correlation between the adults' FC values and age was followed up with a Bayesian analysis, but no such analysis was performed for the adolescents since the group consisted of only 12 subjects.

4.2.3 Research question 1

The first research question investigated the FC in pragmatically interesting regions between the HS and LS groups. A two-sample one-sided student's t-test was conducted to compare the adult groups' average FC between the ROI's anatomically resembling the ParPrec-clusters. The mean of the HS group (M=.25, SD=.16) was higher than the mean of the LS group (M=.20, SD=.14). The difference was not significant (t (47) =-1.09, p=.14). A two-sample one-sided welch t-test was performed (assuming normal distribution but not equal variances) comparing the average FC between the original ParPrec-clusters. The analysis revealed slightly lower means for each group, but the results were otherwise similar with a higher mean for the HS group (M=.20, SD=.10) compared to the LS group (M=.15, SD=.15). A two-sample one sided t-test showed that the difference was not significant (t (47) =-1.14, p=.13). Following the t-tests, Bayesian analyses were carried out which provided anecdotal evidence for no differences between the two groups regarding the FC between the anatomically defined ROIs (BF_{10} = .77), and likewise for the original ParPrec-clusters (BF_{10} = .83).

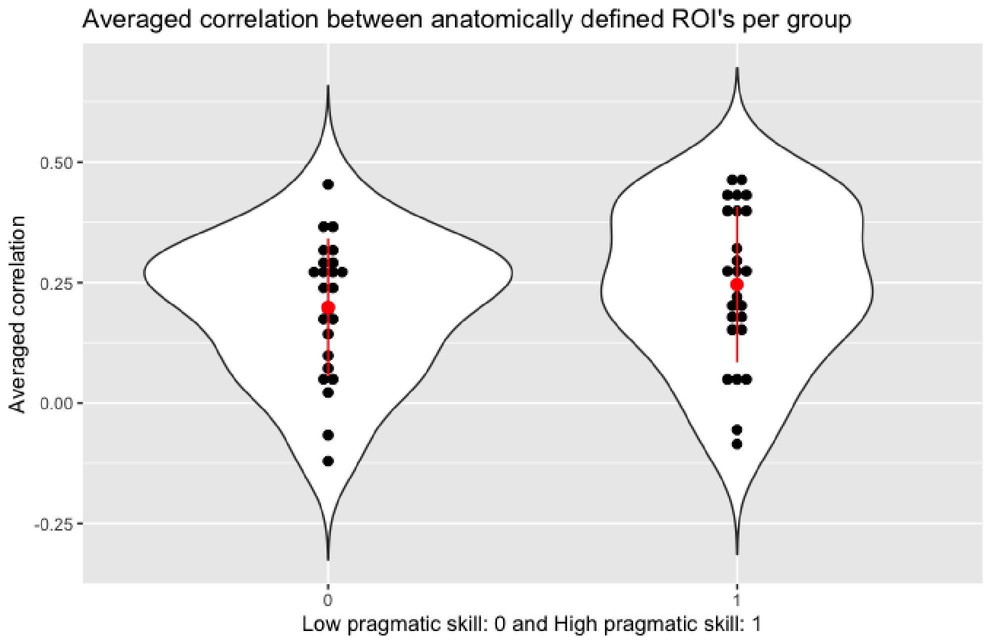

Figure 4: Averaged correlation between the anatomically defined ROI's. LS group (0) and HS group (1). Red dots represent mean values and red lines standard deviations.

Figure 4 and 5 illustrates the FC-value for each individual subject (black dots), between the anatomically defined ROI's (4) and the original ParPrec-clusters (5). As is visualized, the HS group had a larger spread across FC values with the anatomical definition compared to the analysis using the original ParPrec-clusters. The mean for each group was slightly larger in the analysis using the anatomical definition.

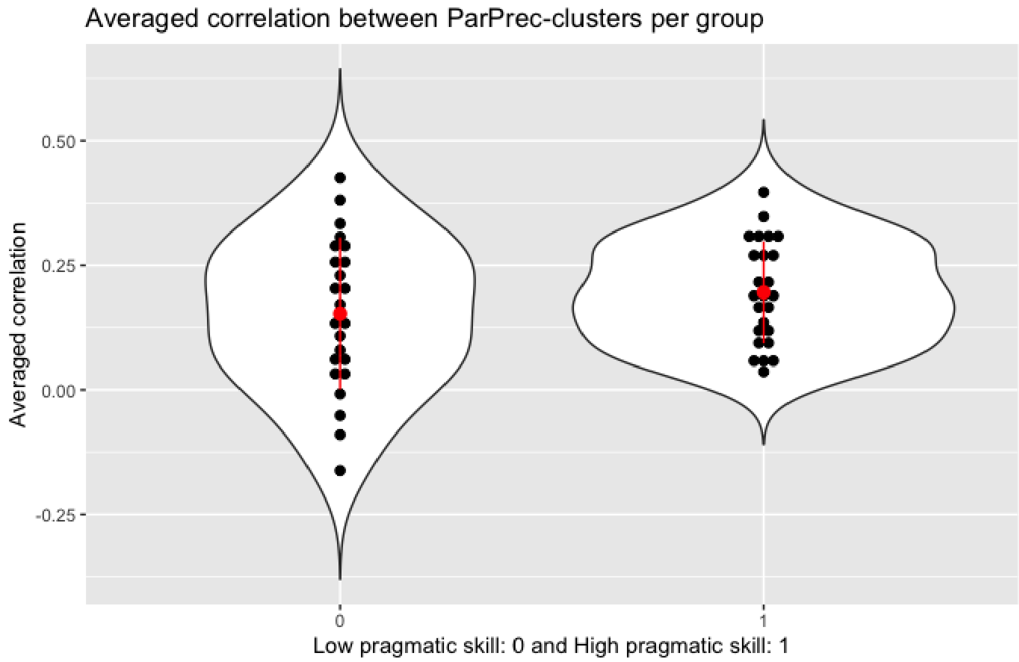

Figure 5: Averaged correlation between the original ParPrec-clusters. LS group (0) and HS group (1). Red dots represent mean values and red lines standard deviations.

4.2.4 Research Question 2

In the second research question the FC between the ParPrec-clusters was compared across two groups: adolescents and young adults. A two-sample one-sided student's t-test comparing the averaged correlation between the ParPrec-clusters for the adolescents and the HS group was conducted. The HS group had a higher mean (M=.20, SD=.10) compared to the adolescent group (M = .10, SD = .18). The difference was significant (t (35) = 2.08, p = .02).

Since the comparison between the HS group and the adolescents was significant, a two-sample two-sided student's t-test comparing the LS group and the adolescents was carried out. The difference was not significant (t (34) = 1.23, p = .23). The LS group (M=.15, SD=.15) had a higher mean than the adolescents (M=.08, SD=.18). As a follow-up, a one-sided student's t-test was conducted which did not turn out significant either (t (34) = .94, p = .18). A Bayesian analysis indicated that the evidence for no difference between the groups was anecdotal (BF_{10} = .74). Figure 6 illustrate the individual value of averaged correlation between the ParPrec-clusters for the adolescents, the low skilled group and the high skilled group.

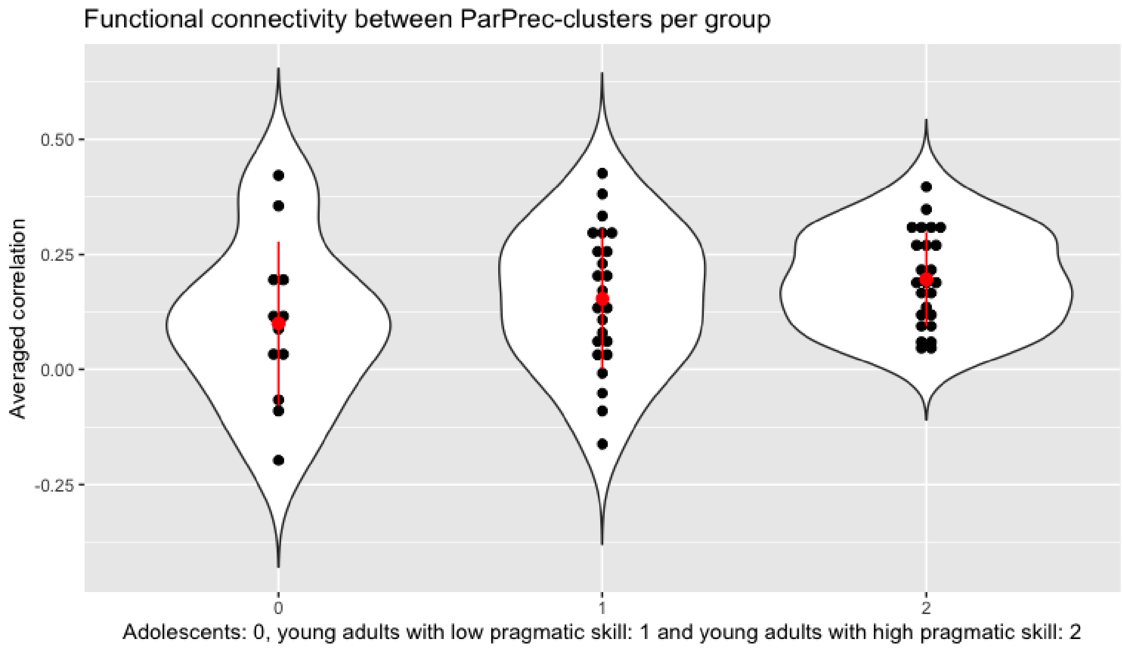

Figure 6: Averaged correlation between the ParPrec-clusters for the adolescents (0), the LS group (0) and the HS group (2). Red dots represent mean values and red lines standard deviations.

The FC between the ROIs was plotted as a function of age for the adolescents and young adults (figure 7 and 8). A one-sided Pearson's correlation test for the adolescent's FC and age revealed a low correlation that was not significant (r(10) = .16, p = .32). Likewise, a one-sided Pearson's correlation coefficient between the young adult's FC and age did not suggest a significant correlation (r(47) = -.03, p = .59). A following bayes analysis provided moderate evidence for no correlation between age and FC between the ParPrec-clusters for young adults (BF_{10} = .18).

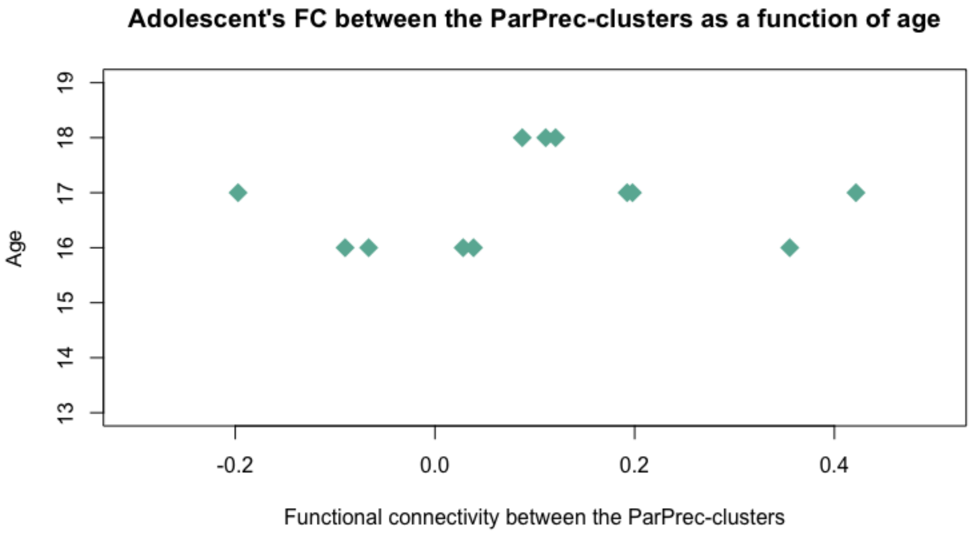

Figure 7: Functional connectivity between the ParPrec-clusters for individual adolescent subjects as a function of age.

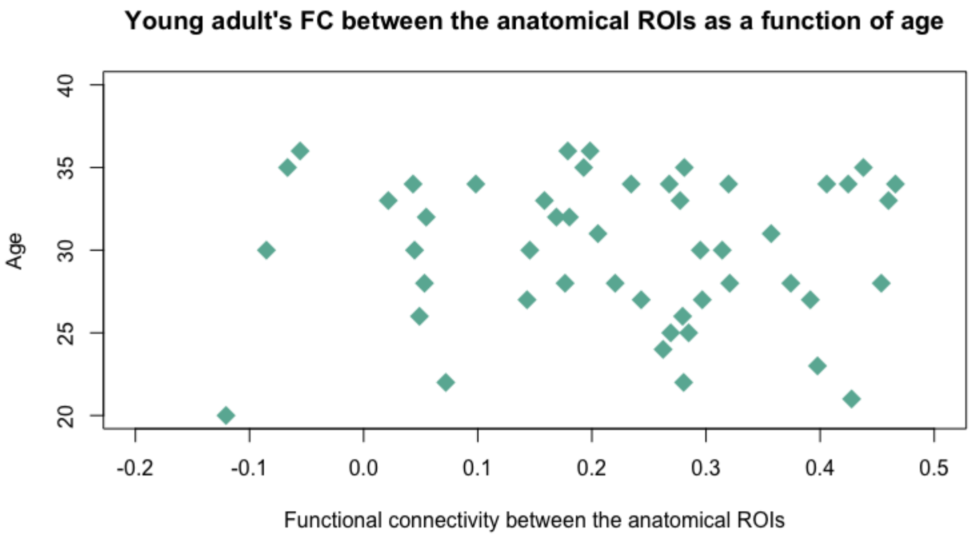

Figure 8: Functional connectivity between the anatomical ROIs for individual young adult subjects as a function of age.

5 Discussion

In this study, the aim was to investigate functional connections between two brain-clusters previously identified as key regions in pragmatic individual variation (Bendtz et al., 2022). Functional connections between the clusters during rest suggested a potential pragmatic network (Mahal, 2022). The question was if these results held up during the task - which in that case would be a stronger indication of a pragmatic network. There was no significant difference between the two groups of young adults (HS and LS). The comparison between the adolescent group and the HS group revealed a significant difference where the HS group had higher averaged connectivity between the ParPrec-clusters compared to the adolescents. As a follow up, the LS group and the adolescents were compared in a similar manner. The young adults again had a higher mean of averaged correlation between the clusters, the difference was however not significant. Taken together the results indicate a developmental trajectory during adolescence that involves forming functional connections between a dorsal bilateral cluster in the precuneus and a superior inferior parietal cluster.

The suggested developmental trajectory indicates that the functional connectivity between the ParPrec-nodes increases throughout adolescence. What this increase translates to in practice can be discussed from different perspectives, the results may for example (1) provide a neural marker of how pragmatic ability is shaped during development, or (2) reflect connectivity in other large-scale networks, as the functional connections between the dorsal bilateral cluster and the superior inferior parietal cluster may be attributed to DMN activity.

5.1 Specialization towards pragmatic competence

Several factors indicate that the results reflect neural underpinnings of pragmatics. These neural underpinnings involve specialization of two clusters (in the bilateral, dorsal precuneus and the superior, inferior parietal cortex) from functions of cognitive control, mentalizing, and/or social cognition towards pragmatic processing.

First, there are consistent differences in groups with different pragmatic ability related to the ParPrec-clusters. This suggests that the ParPrec-clusters to a certain extent explain individual variation of pragmatic skill. Even if the results of this thesis were not significant when comparing the HS and LS group, they can be seen in a bigger picture including Bendtz et al. (2022) and Mahal (2022). In this light, the differences between the HS and LS group related to the ParPrec-clusters are consistent. In the present study, the HS group had higher values of FC than the LS group in both the pilot and the full study. The differences were not statistically significant. A Bayesian analysis provided only anecdotal evidence for no effect between the groups. The behavioral results from the pragmatic tests AD and PC-RR (see 3.3.1 in method), differentiates the groups on a pragmatic basis, which suggest that neural differences during pragmatic processing may be clinically relevant even though they are minor.

Secondly, the results suggests that a distinct pragmatic ability is forming during adolescence, since the adolescents displayed significantly lower values of FC between the ParPrec-clusters compared to the HS group. In childhood, associations between pragmatics and other cognitive functions (Matthews et al., 2018; Wilson & Bishop, 2022) suggest that pragmatic skill rely on core language and ToM to function. This in opposition to adult pragmatic competence, that is suggested to be distinct (Bendtz et al., 2022; Mahal, 2022; Wilson & Bishop, 2019). There is a knowledge gap on the neural trajectory of pragmatic development during adolescence. The result of the current study suggests a specialization towards a distinct pragmatic ability taking place during adolescence. This specialization may be related to structural maturing processes of the brain. The brain cortex becomes thinner during adolescence, with the largest decrease being noted in the parietal lobe (Tamnes et al., 2017). A consequence of cortical thinning may be enhanced distinction of input (Seldon, 2005). In this thesis, one of the investigated clusters are located in the parietal lobe. A possible explanation for improved pragmatic ability from adolescence to adulthood is that adults have an improved capacity of distinguishing pragmatic input from other input, related to cortical thinning of the brain.

Third, individuals with high pragmatic skill seem to have a greater increase of functional connections between the ParPrec-clusters from adolescence to adulthood compared to low-skilled individuals. The results revealed higher FC between the ParPrec-clusters for the LS group compared to the adolescents, although a non-significant difference. This suggests that the increase in FC from adolescence to young adulthood is not as great in individuals with low pragmatic skill. With a Bayesian analysis only providing anecdotal evidence for no difference between the LS group and the adolescents, two possible explanations exist. 1) There is no difference between the groups, which in that case indicate that a developmental aspect that involves forming connections between the ParPrec-clusters have not happened yet for the LS group. Possibly resulting in lower pragmatic ability. Or 2) There is a difference between the groups. The direction indicated by the results is that FC between the ParPrec-clusters are higher for young adults with low pragmatic skill compared to adolescents. This would more strongly suggest that maturing processes important for adult pragmatic competence develops during adolescence, since the average adult probably lies somewhere in between the LS and HS group in terms of pragmatic skill. The functional connections overall strengthen from adolescence to young adulthood, but the strength of the connections may be stronger for high skilled individuals.

Fourth, the ParPrec-clusters are located in or in proximity to other large-scale networks that encompasses cognitive functions associated with pragmatic ability. The parietal cluster is located in an overlap of the MD/ToM networks (Vincent et al., 2008). The precuneus cluster is an important node in the DMN (Mak et al., 2017; Raichle, 2015). Precuneus is also implicated in the ToM network, however its function in the ToM network is not established (Schurz et al., 2014). The location of the ParPrec-clusters points to the cognitive functions encompassed by the MD, ToM and DMN (such as cognitive control, mentalizing and social cognition) being important for and/or closely related to pragmatic ability. Possibly, the connectivity in and/or between these networks during adolescent years impacts pragmatic skill by forming a later specialization where two nodes form a network with pragmatic function. A stronger indication of the ParPrec-clusters being a pragmatic network in adulthood rather than a reflection of connectivity in other large-scale networks, would be if the connectivity in the DMN, ToM and MD networks did not differ between the HS and the LS group. Mahal (2022) performed such an analysis on the pilot sample in his study. There were no significant differences between the HS and the LS group in within network connectivity for the DMN, ToM or MD. In order to draw any conclusions, this need to be tested with a larger sample.

Fifth, the results are in line with previous literature. In van Buuren et al's. (2021) result, adolescent's connectivity in MD, DMN and CO/SN network's predicted later mentalizing skill. In this thesis, connectivity between two nodes, both potentially implicated in the DMN, one in the overlap of MD/ToM and one in the ToM network are possibly connected to later pragmatic ability. Investigating potential relationships between the adolescents' current FC values and later pragmatic ability would give more insight on this matter. Bendtz et al., (2022) and Mahal's (2022) results were the ParPrec-clusters had higher activity during a pragmatic task and were more functionally connected during rest for pragmatically skilled individuals may point to these nodes being specialized for pragmatic processing in young adulthood. The results of this thesis suggest that such a specialization is possibly taking place in adolescence, which lines up with for example the maturing of ToM. Independence of ToM is suggested to be present in adulthood in comparison to in childhood (Saxe, 2009), indicating that adolescence is a crucial period for shaping the independence of ToM seen in adults. This process may be driven by network connectivity given van Buuren et al's. (2021) result. Considering the results of Asaridou et al. (2019) where adolescent's activity patterns when listening to indirect speech acts differed from the activity patterns of adults, the development towards adult pragmatic competence may involve both activation of relevant brain regions and establishing functional connections between them. In adolescence, pragmatic inferring may require recruiting and connecting areas of the brain that are generally geared towards similar cognitive functions (ToM, DMN and MD), before specialization is formed in young adulthood. To understand more about this, it would be interesting to perform seed-analyses (i.e. investigating which other brain regions a specific ROI is functionally connected to) on the areas that the adolescent's in Asariodu et al. (2019) activated.

Sixth, an alternative explanation presented (see section 5.3) involve the result reflecting DMN connectivity. It should be noted that the precuneus cluster in this study is located further dorsally than the classical areas noted for the DMN. Moreover, the superior inferior parietal cluster is bilateral in the DMN (Mars et al. 2012) but left-lateralized in the ParPrec-clusters. The left-lateralization of the parietal cluster is interesting as language regions generally are located in the left hemisphere. As suggested by Mahal (2022) an identical analysis using the bilateral superior inferior cluster would be informative regarding these questions.

Finally, the individual young adults averaged correlation between the dorsal bilateral precuneus and the superior inferior parietal cortex does not seem to be depending on age (see figure 7). A Bayesian analysis provided moderate evidence for no such effect. If seeing connectivity between the ParPrec-clusters as a factor of pragmatic skill, this suggests that increased exposure and practice with interpreting indirect speech acts in adulthood does not improve pragmatic ability. Rather, there may be a window of opportunity closing in adolescent years. This explanation would be strengthened by a relationship between adolescents' age and connectivity values, something that cannot be concluded in this thesis, with the adolescent group being too small to draw conclusions on such a correlation.

5.2 A reflection of DMN connectivity?

Due to their location in/in proximity to the DMN, the connections between the ParPrec-clusters can be viewed as an extension of the DMN (Mahal, 2022). As shown by Mak et al. (2017) meta-analysis, DMN connectivity correlates with performance on cognitive tasks. Moreover, adolescents with ASD who typically have limitations in pragmatic ability have displayed lower DMN connectivity compared to TD controls (Nair et al., 2020). The HS group having a higher averaged correlation between the ParPrec-clusters than the LS group (although not significant) may reflect that.

Stronger results reported by Mahal (2022) in comparison to the results of this thesis may be explained by DMN connectivity. The higher values of FC between the ParPrec-clusters during rest for the HS group may be explained by increased activity in the DMN (Mahal, 2022). The increased activity during indirect speech act processing noticed by Bendtz et al. (2022) does not necessarily mean that the clusters are functionally connected with each other. There may be other nodes that the ParPrec-clusters share information with during pragmatic inferring, possibly in the MD, ToM, DMN or the language network given the location of the clusters. In coming research, performing seed-analyses (which involve investigating the functional connections between one ROI and the rest of the brain) on each of the ParPrec-clusters would shed more light on these questions.

The adolescent's lower connectivity values compared to the HS adults could reflect a more general development trajectory of connectivity profiles in large scale networks. Such connectivity profiles may be related to cognitive functions but not to pragmatics specifically. The findings of van Buuren et al. (2021) indicate that connectivity in large scale networks during adolescence play an important role in forming mentalizing ability, something that may apply to pragmatics as well.

The results may also reflect a specialization of precuneus during adolescence. The precuneus is functionally connected with the left side of the MD network during task, and with the DMN during rest (Li et al., 2019; Utevsky et al., 2014). A study observed that the ratio of connectivity between precuneus and DMN during rest compared to precuneus and the DMN during task and conversely the precuneus and the lFPN during task/rest increased with age, indicating an improved ability of the precuneus to distinguish between task and rest (Li et al., 2019). Increased connectivity for the adult subjects compared to the adolescents in this thesis may be interpreted as an increase in precuneus and MD connectivity during task. On the other hand, the analysis in this study regresses out the effect of task, making it less likely that the results are reflected by that specific function of precuneus.

5.3 Limitations

Using the same data as Bendtz et al., (2022) to compare FC of pragmatically interesting regions between the HS and LS group, the measure of using anatomically similar regions rather than the same clusters were taken to avoid bias. The anatomical definition does not account for functional and anatomical individual variation between the subjects. However, the original ParPrec-clusters were used to perform an additional analysis, with similar results, suggesting that the method using the new ROI-definition did capture what the thesis intended to analyze.

For ethical reasons, the adolescents' time in the scanner was minimized, thus excluding a resting state session. With intriguing results from Mahal (2022) on the young adults' FC during rest, the prospect of performing a similar analysis comparing the adults and the adolescents was interesting. In this study a resting state analysis on task data that lacks rest sessions was performed by removing the task effect. When interpreting the results, it should be noted that Fair et al. (2007) found lower correlation coefficients compared to resting state data in task data with removed task. However, other studies performing connectivity analysis on task data by removing the effect of task have observed higher FC during task for areas involved in that specific task (Cole et al., 2014). In conclusion, this may mean different things when interpreting the result of this thesis. (1) dampened FC during task may result in lower correlation coefficients. Since this thesis studied the difference between the groups the result is probably not affected by this. However, (2) the groups of young adults are known to differ in their utilization of the ParPrec-clusters during task, and it is suggested that FC increases in areas employed in the task. As a consequence, the result may reflect that individuals with high pragmatic skill recruits the ParPrec-cluster to a greater degree during pragmatic processing than adolescents.

The ISA-paradigm investigates one aspect of pragmatic skill, the processing of indirect speech acts. Performing similar studies targeting other pragmatic abilities in the fMRI acquisition (for example production, scalar implicature understanding and repair processing) would clarify the neural connections between different pragmatic skills and their development.

6 Conclusions

The present study builds on intriguing findings by Bendtz et al. (2022) and Mahal (2022) on one dorsal, bilateral precuneus cluster and one superior inferior parietal cluster as potential neural markers connected to pragmatic ability. This study aimed to explain more of pragmatics neural underpinnings in development and individual variation. Performing a resting-state analysis with task fMRI-data, the functional connections between two pragmatically interesting regions were analyzed.

The comparison between the HS and LS group was not significant and could not confirm a pragmatic network between the two nodes, although the HS group had higher values of FC, in line with previous research. The difference between the adolescent group and the high skilled young adults was significant, and the young adults FC did not correlate with their age. This suggests that:

(1) There is a neural development during adolescence that involves forming functional connections between one node in the dorsal bilateral precuneus and one node in the superior inferior parietal cortex. This developmental trajectory is suggested to reflect neural aspects of pragmatic development, as steps towards a potential pragmatic network in adulthood.The location of the clusters indicate that EF and ToM skills may support pragmatic processing in adolescence, before specialization in two clusters are formed in young adulthood.

(2) Adolescence may be a critical period for shaping pragmatic ability, as the age factor does not seem to correlate with the functional connections in young adulthood.

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